POLITECNICO DI MILANO

Scuola di Ingegneria Industriale e dell'Informazione

Master of Science in Management and Industrial Engineering

Developing an early-phase decision support tool for the client/owner in the engineering construction sector

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Academic year 2014/2015

Abstract

The identification of the factors that lead to the selection of the construction method is crucial to make a structured decision. There is currently a lack of a modern decision support tool for the engineering construction (EC) sector that is able to match the changing client needs, cope with the growing complexity of the contemporary market, and keep pace with recently developed innovations and technologies. This dissertation initially identifies the significant variables, drivers and constraints for the adoption of modularisation over traditional stick-build construction in the engineering construction sector. Previous research has briefly investigated this, but the uniqueness of this work is the development of an early-phase decision tool to support the client/owner during the selection of the construction method. The research methodology adopted a mixed approach, combining various quantitative and qualitative data collection methods, including interviews, questionnaires and focus groups. Drivers and constraints for the adoption of modularisation were identified. According to the factors influencing the decisional process gained from this data collection, a two level tool, strategic level and pre-feasibility level, was developed.

Key words:

modularisation, engineering construction sector, drivers, constraints, decision support tool

Table of contents

1 Executive Summary i

1.1 Introductive chapter i

1.2 Literature review chapter i

1.3 Research methodology chapter iii

1.4 Findings and discussion chapter v

1.5 Early decision support tool development chapter vii

1.6 Conclusions chapter ix

2 Introduction 1

2.1 Research Scope 1

2.2 Glossary 1

3 Literature Review 3

3.1 History and evolution 3

3.2 Introduction to modularisation 3

3.3 Definitions and Theory 5

3.4 Benefits and drawbacks of Modularisation 6

3.4.1 Benefits 7

3.4.2 Drawbacks 8

3.5 Engineering Construction Context 9

3.6 EC sector mutations 13

3.6.1 Building Information Modelling (BIM) 16

3.6.2 Virtual visualization 17

3.6.3 Sustainability ... 18

3.7 Decision Support Tool (DST) ... 19

3.7.1 Deciding to go modular ... 19

3.7.2 Existing DSTs ... 20

3.7.3 Client perspective ... 23

3.8 Summary of Literature Review ... 24

3.9 Gaps in the Literature and Scope of the Research ... 24

4 Research methodology ... 26

4.1 Research approaches review ... 26

4.2 Research methods ... 28

4.2.1 Qualitative research ... 28

4.2.2 Quantitative research ... 29

4.2.3 Mixed methods ... 30

4.3 Data collection research methods ... 32

4.3.1 Literature review ... 32

4.3.2 Questionnaire ... 33

4.3.3 Interviews ... 34

4.4 Consistency of the data ... 35

4.4.1 Sampling ... 35

4.4.2 Validity ... 35

4.4.3 Reliability ... 37

4.4.4 Triangulation ... 37

4.5 Adopted methodology ... 39

4.5.1 Research design and research methods ... 39

4.5.2 Literature review ... 42

4.5.3 Web-based questionnaire 44
4.5.4 Interviews 46
4.5.5 Conference data collection 47
4.5.6 Consistency of the data 50
5 Findings and discussion 53
5.1 Web-based questionnaire data analysis 53
5.1.1 Section one: general questions 53
5.1.2 Second section 54
5.1.3 Third section 57
5.2 Interviews data analysis 66
5.2.1 Plenary section questionnaire analysis 75
5.3 Workshop data analysis 79
5.3.1 Clickers results 79
5.3.2 Workshop focus groups 80
5.4 General findings 85
5.4.1 Characteristics findings 85
5.4.2 Inter-relationship table 94
5.4.3 Overall findings 96
6 Early decision support tool 108
6.1 MasterMOD conceptual design 108
6.2 MasterMOD first level design 109
6.2.1 Strategic level: algorithm 110
6.2.2 Strategic level: elements of the factors 110
6.2.3 Strategic level: calculation of the factors’ value 115
6.2.4 Strategic level: presentation of the result 117

6.3 MasterMOD pre-feasibility level design 119
6.3.1 Strategic level: logic 120
6.3.2 Strategic level: elements of the factors 120
6.3.3 Pre-feasibility level: calculation of the elements' value 122
6.3.4 Pre-feasibility level: presentation of the result 124
6.4 MasterMOD validation 128
6.4.1 MasterMOD example 1 128
6.4.2 MasterMOD example 2 141
7 Conclusions 153
7.1 Research impacts and limitations 153
7.2 Further research 154
8 References 156
9 Appendix 162
9.1 Appendix A – web-based questionnaire 162
9.2 Appendix B – Structured part of the interviews 169
9.3 Appendix C – Plenary section questionnaire 169
9.4 Appendix D – Plenary section questionnaire data analysis ... 171
9.5 Appendix E – ECI workshop 174

Tables

Table 1 - Benefits of modularisation 7
Table 2 - Drawbacks of modularisation 8
Table 3 - Truck able modules specifications 15
Table 4 – research design classification 28
Table 5 – advantages and disadvantages of a questionnaire 34
Table 6 – advantages and disadvantages of the interviews 35
Table 7 – characteristics ranking 49
Table 8 – benefits/drawbacks answer's text conversion 54
Table 9 – drivers/hindrances answer's text conversion 57
Table 10 – Interviews resume 67
Table 11 – client objectives 97
Table 12 –Site characteristics 102
Table 13 – project execution and management approach 104
Table 14 – EPC, contractor and industry players status 106
Table 15 – C first level factor 111
Table 16 – FE first level factor 112
Table 17 – T first level factor 113
Table 18 – Q first level factor 113
Table 19 – CP first level factor 113
Table 20 – RWE first level factor 114
Table 21 – S first level factor 114
Table 22 – D first level factor 114
Table 23 – M factor value explanation 118
Table 24 – site conditions second level factor 121
Table 25 – site location second level factor 121
Table 26 – transport infrastructure second level factor 121
Table 27 – EPC propensity to go modular second level factor 121
Table 28 – experience of the contractor second level factor 122
Table 29 – project management second level factor 122
Table 30 – elements group allocation 124
Table 31 – suggestions for strong constraints 125

Figures

Figure 1 – Research steps iv
Figure 2 – Research pyramid vi
Figure 3 - Pipe rack module 10
Figure 4 - Equipment or process module 10
Figure 5 - IPA Independent Project Assessment (Merrow, 2011) 12
Figure 6 – In situ facility plot size reduction (Fluor Corporation) 16
Figure 7 – Example of BIM operating structure 17
Figure 8 - representation of a typical quantitative research path 30
Figure 9 - Breath v. depth in “question-based” studies (Fellows and Liu 2003) 32
Figure 10 – roles of the literature review in the research 33
Figure 11 - Triangulation of evidence (Silverman 2010) 38
Figure 12 - research conceptual data gathering process 40
Figure 13 - research steps, narrowing process 41
Figure 14 – pointing index process 43
Figure 15 - population of the 35 sent questionnaire 46
Figure 16 - composition of the interview population 46
Figure 17 - Triangulation of the findings (web-based questionnaire, interviews and literature) 52
Figure 18 - Triangulation of the findings (plenary section questionnaire, focus groups and literature) 52
Figure 19 - general questions: organisation role 53
Figure 20 - general questions: years of industrial experience 53
Figure 21 – time line of the references 54
Figure 22 – questionnaire and literature, comparison on modularisation benefits 55
Figure 23 - questionnaire and literature, comparison on modularisation drawbacks 56
Figure 24 - Client requirements factors, respondents’ comparison 58
Figure 25 - Client requirements factors, years of experience comparison 59
Figure 26 - site requirement factors, respondents’ comparison 60
Figure 27 - site requirement factors, years of experience comparison 61
Figure 28 – project requirements factors, respondents’ comparison 62
Figure 29 - project requirements factors, years of experience comparison 63
Figure 30 – more significant drivers 64

Figure 31 – more significant hindrances....65
Figure 32 - Drivers ranking mean....76
Figure 33 - constraints ranking mean....77
Figure 34 – inter-relationship matrix....95
Figure 35 - sector drivers average comparison....171
Figure 36 - sector constraints average comparison....171
Figure 37 - years of experience drivers average....172
Figure 38 - years of experience constraints average....172
Figure 39 - familiarity with modularisation drivers average....173
Figure 40 - familiarity with modularisation constraints average....173
Figure 41 - voting section, general questions....174
Figure 42 - significance and novelty of the first characteristic....174
Figure 43 - significance and novelty of the second characteristic....175
Figure 44 - significance and novelty of the third characteristic....175
Figure 45 - significance and novelty of the fourth characteristic....176
Figure 46 - significance and novelty of the fifth characteristic....176
Figure 47 - significance and novelty of the sixth characteristic....177
Figure 48 – focus group, picture one....177
Figure 49 – focus group, picture two....178

1 Executive Summary

1.1 Introductive chapter

This study is part of a wider collaboration between ANIMP (Associazione Nazionale di Impiantistica Industriale) and the ECI (European Construction Institute) represented in Loughborough University (UK).
The aim of this dissertation is to provide to the client/owner of the project a modern early-phase decision making tool to evaluate the adoption of a modular approach in the engineering construction (EC) sector.

1.2 Literature review chapter

This study is set against a well-known background on modularisation. In this chapter a brief overview of the history and evolution of the method is outlined. Then an overall introduction of modularisation is provided, followed by a comparison of the benefits and drawbacks reviewing publications in most of the cases within last 20 years. After a broader view on the wider construction industry, including buildings and housing, we will focus on the treatment of the EC sector, analysing the drivers and barriers and existing decision support tools (DSTs) already developed. Moreover, the mutations of the EC sector and the client perspective in terms of decision framework are presented. Finally gaps in the literature will be investigated.

From the literature appears clearly that modularisation is not a new approach. The adoption of modular solutions started to gain momentum from the Second World War, but it is only in the last decades that the approach was fully understood and exploited in the construction industry. Moreover, thanks to the modern information technologies and design tools linked to the changing market needs the modular approach is more viable than ever.

A theoretical framework on the construction technique is provided, combined with the list of terms often used to express the same concept of pre-working offsite which is then assembled on site (e.g. preassembly, offsite production, prefabrication etc.). Since the target of this thesis is the EC sector we will use the term “modularisation” providing a recent definition of a plant module: *“A plant module is a transportable,* *prefabricated/preassembled steel structure containing static and rotating equipment. Piping, instrument, electrical hardware and associated cabling that can be constructed and pre-commissioned in areas with controlled conditions that differ from the final location. These areas are called yards. After the assembly in the yard, the modules are transported (by road or sea) at site for final installation and integration in the plant"* (Mancini 2014).

Then the main benefits and drawbacks treated by the literature are summarized in two different tables. All along the material reviewed, the list evolved during the years according to the changes that affected the industry. For this reason the investigation interested various points in time (see Figure 21 – time line of the references).The documents investigated denounce that in order to realize modularisation benefits it is necessary to evaluate it in the early phase of the project (Gibb & Isack, 2003), (Javanifard et al., 2013), in this respect see Figure 5 - IPA Independent Project Assessment (Merrow, 2011). From an overall comparison of the tables it is possible to evince that the papers analysed concentrate more on outlining opportunities of modularisation "forgetting" to describe the barriers and limitations that characterize the method.

This thesis aim attention at engineering construction industry, which is often concerned with the realization of large construction projects. Examples of EC plants are, oil and gas, chemical and metal processing plants, power plants, pharmaceutical plants and so forth (Gupta, Fisher, & Murtaza, 1996). From the existing literature a rough description of the principle elements of a process plant combined with a general categorisation of types of modules is outlined. In the last fifteen years EC projects have become more and more complex in terms of stakeholders/participants involved, completion uncertainty, technology adopted, management effort required and expectancy of the client. Moreover, the engineering product provided to the client is more complicated, in terms of design, technicalities, functioning and maintenance requirements along the life cycle. In this sense one critique moved to the engineering construction sector in the past, is the lack of capability to stay abreast of innovation and new technologies. In fact old systems and out dated management techniques are not optimal to cope with the growing amount of data, interdependencies and coordination need which characterize the modern mega projects. Therefore, innovations in the sector were introduced, increasing the integration of modern approaches and technologies (e.g. LEED, BIM, virtual visualizer etc.). According to changes affecting the sector an entire part dedicated to EC mutations is presented, encompassing the evolution of the market, new systems produced and new client awareness (e.g. sustainability concern). One of the evidence of advanced building techniques boosted by modern technologies employed in construction processes, is the ability of companies to produce and transport larger and heavier modules, see Table 3 - Truck able modules specifications for an overview of the advancement.

The literature reveals that often in the construction industry the selection of the construction method is based on decision makers' opinion and experience without adopting a structured approach (Salman Azhar, Lukkad, & Ahmad, 2013), (Pan et al., 2008). Moreover, in the industry still prevail a fragmented, cost- driven rather than value culture approach in the evaluation and selection of construction practice. This highlights the necessity of methodical decisional framework that diverges from a pure element-costing approach but encompasses an outright value-based benefits consideration. With this in mind a rough description of the decision support tools comparing the modular solution with conventional stick build construction developed in previous years is provided, see section Existing DSTs.

The documents investigated demonstrate that there is a limited number of early-phase decision support tools developed for the EC sector, and the existing tools was shaped many years ago. For this reason is reasonable to think that the existing tools are insufficient to exhaustively match the recent industry advancements. Therefore there is the necessity of a modern decision support tool that is able to match the changing client needs, cope with the growing complexity of the modern market and keep pace with innovations and the development of technologies.

1.3 Research methodology chapter

In this chapter an initial theoretical framework on the research approaches is presented. Definitions are provided combined with the choice of the appropriate methodology approach. The research method has to be selected keeping in mind the type of research question, time and resource availability. Moreover, the research has to be valid, reliable and inherently robust in each of the steps.

Then the thesis delves into the description of quantitative and qualitative research methods and their combination that gives life to the mixed approach. There is a wide spread consensus in the literature that the mixed approach encompasses the possibility to exploit the advantages of the quantitative and qualitative methods and compensate the weaknesses of the two (Kumar, 2005), (Creswell 2014), in this respect see Figure 9 - Breath v. depth in “question-based” studies (Fellows and Liu 2003). After the description of data collection methods (literature review, questionnaire and interviews) a characterisation of the elements that gives consistency to the methods, validity, reliability and triangulation of the findings is provided.

According to the theoretical framework presented, the research undertook can be considered close to a non-experimental retrospective-prospective cross-sectional study design (see 4.1 and 4.5.1). Furthermore, based on the research objective the various phases of the study can be classified as descriptive, correlational, explanatory and exploratory research (see 4.1). The adopted methodology describes the research conceptual data gathering process (see Figure 12) and the research steps, narrowing process (see Figure 13).

Below a resume of the steps of the research path is provided.

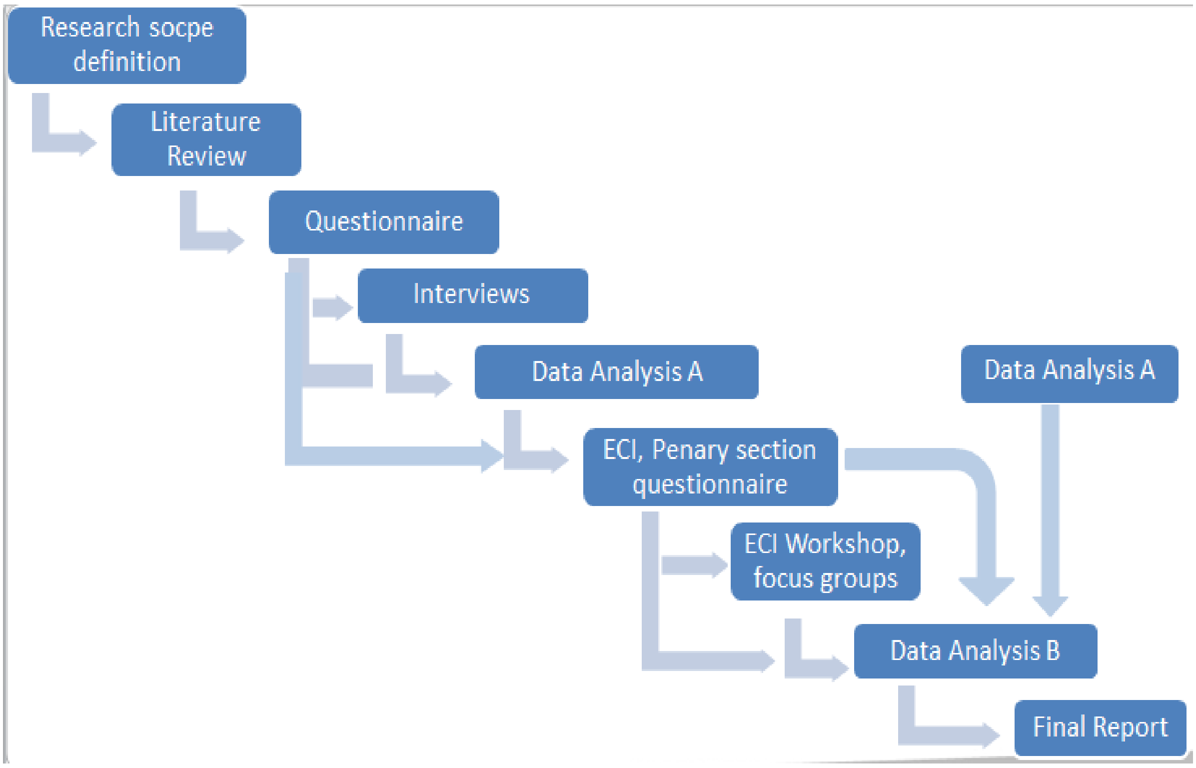


Figure 1 – Research steps

The research interested the collection of data in several period of time. The main phase of the literature review was realized throughout a pointing index (see Figure 14). A system that counts the citations pointed by the relevant predefined documents and investigates the most cited publications. The initial base of the relevant documents was represented by those electronically retrieved and the set of academic papers advised by the supervisor. Then a web-based questionnaire composed by closed-ended questions was designed and sent individually to the targeted sample; the response rate was 55%. Successively the questionnaire respondents were followed with semi-structured in-depth interviews, with an average duration of 45 minutes. After these first three steps of the data gathering process the results of the literature, questionnaires and interviews were triangulated (see Figure 17).

Completed the first analysis, a similar data gathering process interested the plenary section questionnaire and the focus group section. The former achieved a 65% response rate, the latter consisted of two sections of half an hour each, for a total of 60 minutes. Also here the quantitative and the qualitative method were triangulated with the existing body of knowledge. The triangulation process was fundamental to ensure consistency and validity to the findings, with this respect see 4.5.6. It is worth to point out the high response rate of the questionnaires is due to the membership of the experts to the ECI.

1.4 Findings and discussion chapter

This chapter presents the findings of all the data collection methods. Graphs of the web-based questionnaire are presented comparing the answers according to both the type of respondent and the years of experience. Then in a tabular form the resume of the in-depth interviews is presented. In total 13 experts were interviewed, 5 belonging to EPC companies, 3 contractors, 3 clients, 1 supplier and 1 consultant. Then results of the meeting, plenary section and focus groups were commented. Findings and the relative discussions are presented together, in fact due to the number of adopted methods and consequent collected data it was deemed to keep unite the two parts. The below picture represents the path followed in drawing findings and generating interpretations during the analysis.

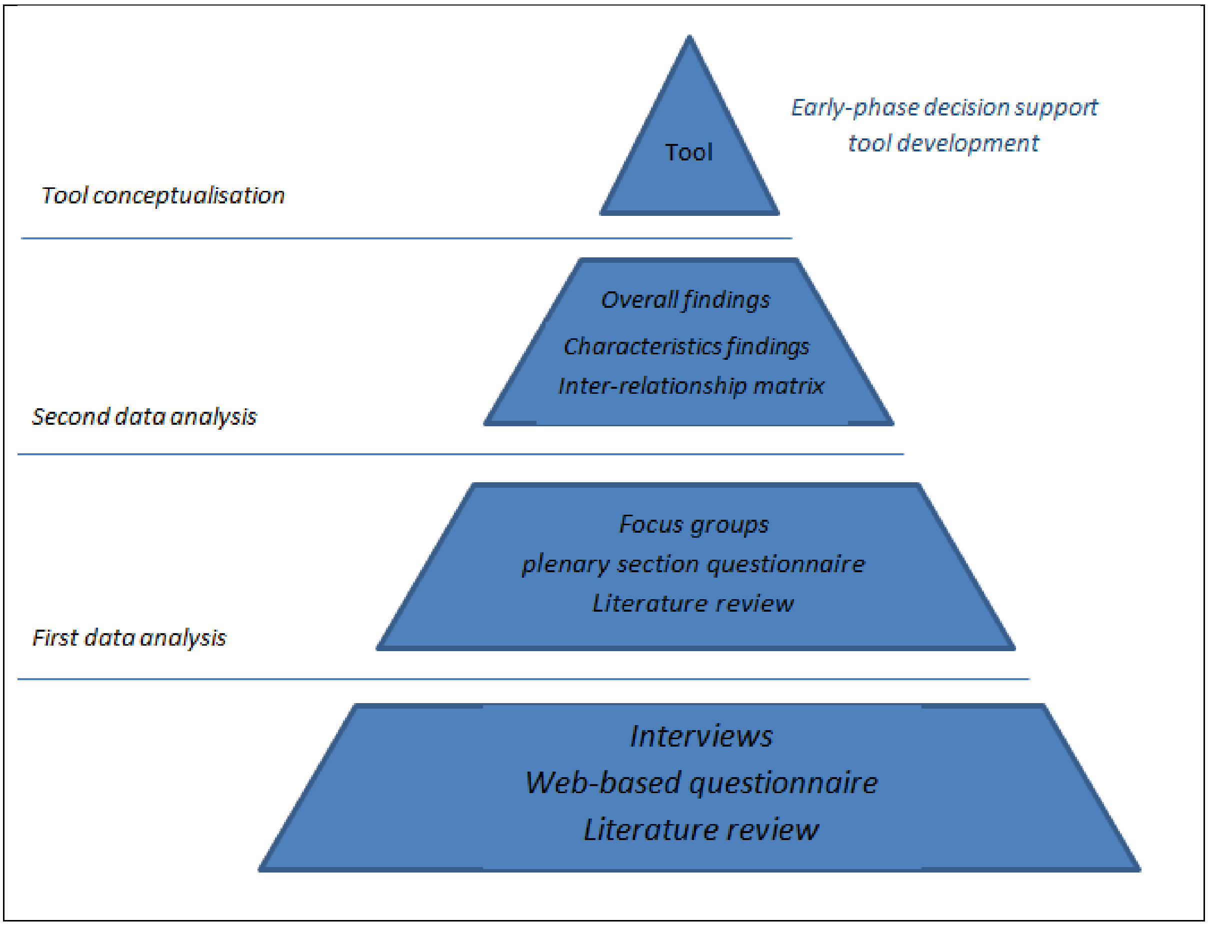


Figure 2 – Research pyramid

The highlighted point in this graph is the progressive logic leading to deduce and corroborate the overall findings. The initial basic conclusions were useful to narrow the research understanding to which topics dedicate higher resources. The analysis was executed both interpreting the single sources and comparing the results. Successively the second step corroborates the previous conclusions and investigated new topics disclosing information on the lacking areas. Both data analysis steps enforces the characteristics findings (see 5.4.1), contributed to the creation of the inter-relationship table (see Figure 34) and the generation of the overall findings (see 5.4.3). It turns out clearly that the conception of the tool is based entirely on the gathered data. Moreover the creation follows the client needs and sector specifications previously identified.

The following tables provide a resume of the overall findings presented integrally at the end of the chapter, including the specific element composing each of the identified factors.

Client objectives	
Cost of the project	Can be either a driver or a constraint
Running cost of the plant	Weak driver
Schedule time	Strong driver
Quality of the plant	Weak driver
Certainty and predictability	Strong driver
Health and safety	Strong driver
Sustainability	Weak driver
Develop local content	Strong constraint

Site characteristics	
Site conditions	Can be either a driver or a constraint
Site location	Can be either a driver or a constraint
Transport infrastructure	Can be a weak or a strong constraint

EPC, contractor and industry players	
EPC propensity to go modular	Can be either a driver or a constraint
Experience of the contractor	Strong constraint
Industry understanding of modularisation	Strong constraint

Project execution and management approach	
Engineering and design	Weak constraint
Complexity and risk	Weak constraint
Coordination and communication	Weak constraint

1.5 Early decision support tool development chapter

This chapter delves into the description of the early-phase decisions support tool, nominated MasterMOD.

Data collected and literature information led to the understanding that the client executes a set of strategic examinations prior to the feasibility study, selecting the construction method. Often clients ask a feasibility study to the EPC/contractor companies with a traditional-stick build construction method already in mind. At this stage it is difficult to propose a modular approach. Therefore, the first aim of the tool is to assist the client during the initial strategic evaluation of the construction method, avoiding entering in the process too late. The second purpose is to support the client at a pre-feasibility study phase highlighting the critical constraints and confirming the drivers of the execution of a modular approach.

MasterMOD was conceptualised in two levels:

1. Strategic level
2. Pre-feasibility level

In the first level the tool objectively assess the goodness of the selection of modularisation, providing the overall value “M” that synthetises the entire algorithm procedure, in this respect see 6.2.1. Moreover, the purpose is to promote a productive discussion between the operators involved in the selection phase, understanding benefits and drawbacks that lead to the method selection. Prior to the feasibility study, the second level aim is to assess the feasibility and main constraints of the modular approach in the specific project. This evaluation is useful for the client both to comprehend the main critical areas of the project execution and prepare questions for the EPC/contractor Corporation that will lately do the feasibility study. For example, asking which mechanisms and relative cost will be used to overcome the constraints.

A relative weighting system was used for the tool algorithm. The process is intuitive for the client, since it is based on the same decision-making criterion that governs the decisions of the industry experts, in fact often managers relies on different parameters weighted in terms of importance according to their experience. Moreover the client can understand the specific impact of each of the factors, realizing which of them is a driver and which a constraint. One of the hidden accomplishments of the utilization of the tool is the acknowledgment of the user on the modularisation practices; the lack of industry understanding of modularisation is one of the strongest constraints for the uptake of the method evinced by the data collected (see 5.2).

The entire logic and operation of the tool is described and two exhaustive reasonable cases testing the robustness of the tool are provided.

1.6 Conclusions chapter

In the last chapter the conclusions of the research are presented. Starting with a summary of research process, commenting issues rose during the study and pointing the results and discussion. Finally the achievements and limitations of the tool are addressed, providing in the last paragraph ideas for further research.

2 Introduction

2.1 Research Scope

Several previous researchers have identified significant variables, constraints and opportunities in selecting modular construction over stick-built techniques (Connor et al., 2015)(Pan, Dainty, & Gibb, 2012) (Salman Azhar et al., 2013),(V.K.Vernikos et al., 2013),(N. G. Blismas, Pendlebury, Gibb, & Pasquire, 2005) lots of them concerning the house building industry (Pan, Wei, Gibb, A.G.F. and Dainty, A.R.J., 2008) .However, there is little documentation about the engineering construction (EC) sector, and even less about an early decision making tool to support the client during the early stage of an EC project. Furthermore the tools proposed (Murtaza, 1994),((Song et al. 2005), were shaped and developed many years ago, with market conditions, project requirements as well as technologies and work practices dating back to the 1990s and before. In last few years the EC sector has begun to change, adopting advanced construction techniques and facing new technologies (Nepal & Staub-French, 2012). Technological progress, global factors and modern practices in construction projects have fostered the adoption of a more modular approach (Bowden, Dorr, Thorpe, & Anumba, 2006),(Vivian W Y Tam, Tam, Zeng, & Ng, 2007). Global changes, technological advancement and the recent economic downturn have shaped the EC sector in a way that was impossible to forecast by researchers (Haas & Fagerlund 2002),so it is possible to conclude that existing tools are likely to be inefficient in addressing the current dynamic situation of the market and modern needs of the clients. In order to fulfil the necessity of a contemporary decision support instrument, the aim of this dissertation is to provide to the client/owner of the project an early decision making tool to evaluate the adoption of a modular approach in engineering construction projects.

2.2 Glossary

Below the commonly accepted acronyms used in the dissertation are provided:

EC: Engineering Construction - also called Industrial construction, the sector comprehend oil and gas, power and energy, pharmaceutical, metal processing, chemical plants etc. (Gupta et al., 1996).

BIM: Building Information Modelling - **“***An IT package facilitating management of, and collaboration within, the construction process. The technology enables efficient* *coordination of the programming, designing, specifying and building processes"* (Ukces, 2013).

CAD: Computer Aided Design - ***"****A computer system to facilitate the creation and modification of a design"* (Ukces, 2013).

AEC: architecture, engineering, and construction

EPC: engineering, procurement, and construction

FEED: Pre-front end engineering design

DfMA: Design for Manufacturing and Assembly

LEED: Leadership in Energy and Environmental Design

ICT: Information and Communication Technology

IT: Information Technology

R&D: Research and Development

RFID: Radio Frequency Identification

DSS: Decision Support System

3 Literature Review

3.1 History and evolution

The concept of modularisation itself is not new, evidence of its use refers back to the Egyptian constructions, the Roman era and the industrial revolution, until the beginning of the 20th century (Salman Azhar et al., 2013) (Goulding, Pour Rahimian, Arif, & Sharp, 2014) (O'Connor, O'Brien, & Choi, 2014). Only since the latter part of the last century has the approach been fully understood and exploited by the civil engineering and building industry in undertaking and realizing advanced construction projects (Terry & Smith, 2011). Prefabrication techniques in the construction sector were adopted significantly after the Second World War to rebuilt destroyed cities, and respond to peaks in demand for housing in western and eastern Europe in the 1950s decade and early 1970s (Warszawski, 1999). Modularisation has been applied in construction for a long time, but in recent years, with the evolution of technology and the rise of modern construction processes, companies will be able to build higher quality and innovative edifices (McGraw Hill Construction, 2011). Moreover "recent advances in design and information technologies, combined with increasing emphases within the industry to address cost , schedule and labour issues have proven the use of prefabrication, preassembly and modularisation to be more viable than ever" (Haas & Fagerlund, 2002). Furthermore in the last few decades a substantial boost to the use and development of modularisation has been given to the growing demands and expectations of the clients. Lu & Liska (2008) state that in last years the client needs have become more rigid, from the 1980s for example, commercial clients started to expect better quality products, requiring shorter delivery time at a fairly price (Gibb, 1999).

3.2 Introduction to modularisation

The literature documents a growing trend of modularisation in the construction industry over the last 60 years (McGraw Hill Construction, 2011). After the Second World War there was a boom in modular building manufacture, triggered by the need for faster housing delivery (Terry & Smith, 2011). Moreover O'Connor et al (2014) found an accelerating progress of pre-assembly from 1970s until nowadays, and also Ukces (2013) confirms the idea that from 1960s the adoption of the approach was heightened by an advancement in construction procedure that led to increased cost efficiency techniques. This aided the opportunity for lighter and more resistant house building steel structures. A clearer picture of the growing trend of modularisation can be traced from Salman Azhar et al., (2013), from the paper transpires that modularisation in the construction sector has not risen constantly over years, but it has fluctuated depending on market trends (McGraw Hill Construction, 2011). For instance a positive impulse can be identified during the “economic boom” from 1980s to 1990s. Moreover, modern technology progress is significantly broadening the modularisation opportunities (Song et al., 2005).

A number of studies conducted at the turn of the 21st century foresee a larger adoption of modular techniques in the construction industry, for example in UK (Egan, 1998), (Gibb & Isack, 2003). Evans (1995) is quoted as highlighting the momentum that was gaining manufacturing industry, implementing more flexible techniques and technologies. He underlined the evidence of a technological shift in the sector that was pushing towards the enactment of economies of scope and a wider usage of pre-assembly. However more recent literature suggests that the real uptake of the approach is far from increasing (CIRIA, 1999), (Gibb & Isack, 2003), (Sacks et al. 2004), (N. G. Blismas, Pendlebury, et al., 2005), (Salman Azhar et al., 2013), (Goulding et al., 2014). Gibb & Isack (2003) highlighted the future intention of clients to rely on prefabrication, 52% of interviewed clients were keen to use again or even increase the use of prefabrication; however 20% communicated their unwillingness to continue to adopt prefabrication. The survey confirmed the eagerness of clients to increase the usage of modularisation. However, considering that the respondents are clients that intensively used the approach, a 20% of “no” is a quite high result that indicates dissatisfaction and corroborate the reason why off-site construction is not reaching the forecasted uptake. The constrained growth in the construction industry can be attributed to a loath adoption of new technology solutions (The Modular Building Institute, 2010). A different issue was identified by Blismas (2005), revealing that *“clients are the primary drivers for change in the way the construction views value”*: clients have to be more informed about the overall advantages that modular solutions can provide, not just form a superficial cost comparison (Goulding et al., 2014); Gibb & Isack (2003) share the same opinion, arguing that to support the development of modularization, industry players must focus on client needs. For Haas & Song (2002) the cause of a limited adoption of modularisation relies on a lack of knowledge and expertise of players in the industry. Particularly interesting is the point of view of Verinkos et al

(2012), who declare that the offsite evolution is inhibited by old style operational techniques and most of all by an averse mentality towards change of construction industry players (V. K. G. C. I. G. a. G. . Vernikos, 2013). For sure, in a similar way to most of the industries in recent years, construction has faced the economic downturn, that caused a deceleration on the forecasted expansion of modularisation (Ukces, 2013).

3.3 Definitions and Theory

A treatment of the theory on modularisation is out of the scope of this paper, an outright explanation of the theory can be found in (Tatum, Vanegas1986), (CIRIA 1999), (Gibb 1999), (Haas 2004), (Ukces, 2013), (Lawson, Ogden, Goodier, 2014).

There is not a universal definition of Offsite (Ukces, 2013), or rather, there is not a unified definition, but the terminology has evolved over the decades along with industry trends and geographical locations (V. K. G. C. I. G. a. G. . Vernikos, 2013).

The following list of terms was often used to express the same concept of pre-working offsite which is then assembled on site:

- Standardization, defined in CIRIA, (1999)
- Preassembly (S&P), defined in CIRIA, (1999)
- Modularisation (Modular), term often used in the EC sector (Ukces, 2013)
- Offsite production (OSP), offsite fabrication (OSF), offsite construction (OSC), offsite manufacture (OSM), for example OSF is utilized to describe activities of an offsite facility when both preassembly and fabrication are integrated (Gibb, 1999)
- Industrial buildings (IBS) more used in the Asian contexts (Gibb, 1999)
- Prefabrication (Prefab) often used in USA publications (CII publications), (Luo & University, 2008), instead in UE mostly used in the housing construction sector, dating from the post War World two when “prefabricated” houses was rapidly built to answer to the significant demand.
- Modern methods of construction (MMC) is “a term spanning a broad range of new construction technologies” (Ukces, 2013).

Since the target of this paper is to investigate the EC sector we will adopt the term “modularisation”. To define it we can refer to an exhaustive definition provide by an EC contractor: *“Modularisation is the pre-assembly of major portions of a plant into transportable units comprising process equipment, piping, instruments, cabling and other components assembled, painted, insulated, fireproofed, inspected and tested at manufacturing facilities away from the main construction site”* (Gibb, 1999).

One of the first researchers that gave a significant contribution to studies on modularisation in the EC sector was Tatum: ‘‘A module is a product resulting from a series of remote assembly operations. It is usually the largest trans- portable unit or component of a facility. A module consists of a volume fitted with all structural elements, finishes, and process components which, regardless of system, function or installing craft, are designed to occupy that space. Modules may contain prefabricated components or preassemblies and are frequently constructed away from the jobsite.’’ (Tatum et al., 1987). But for our study in the EC sector we are going to use a more recent definition of module: “A plant module is a transportable, prefabricated/preassembled steel structure containing static and rotating equipment. Piping, instrument, electrical hardware and associated cabling that can be constructed and pre-commissioned in areas with controlled conditions that differ from the final location. These area are called yards. After the assembly in the yard, the modules are transported (by road or sea) at site for final installation and integration in the plant” (Mancini 2014). The literature provides an interesting schema to catalogue types of module, albeit within the context of the commercial building sector rather than EC: (CIRIA, 1999), (Gibb & Isack, 2003).

Level 1: Components manufacture & sub-assembly

Level 2: Non-volumetric pre-Assembly

Level 3: Volumetric pre-assembly

Level 4: Modular Building

3.4 Benefits and drawbacks of Modularisation

Several previous research projects have tried to effectively point out the list of benefits and drawbacks deriving from the application of modularisation (references listed below). All along the material reviewed, the list evolved during the years according to the changes that affected the industry. As evidenced by previous studies the adoption of modularisation, must be evaluate as early as possible in the project (Emes, 1992),(CIRIA 1999),(Gupta et al., 1996),(Gibb & Isack, 2003), (Javanifard et al., 2013). Gibb 1999 explains that “in order to maximise the benefits from off-site fabrication it is essential that a project wide strategy is developed at an early stage in the project”. Emes (1992), states that the offsite strategy must be evaluated from an “overall project” view rather than an “element view”, for example, decisions like lifting and installations should not be considered at a late stage, but must be addressed as early as possible, for example during layout design. Moreover, benefits deriving from offsite fabrication depend on the project specifications, circumstances and combination of construction techniques employed, so we cannot simply list them and be sure of their realisation in every project (N. Blismas, Pasquire, & Gibb, 2006).

3.4.1 Benefits

Table 1 - Benefits of modularisation

	Shorter schedule (time)	Higher quality	Reduction of (overall project) cost	Enhanced sustainability	Improved Health and Safety	Improved predictability and reliability	Higher workers' productivity	Reuse, relocate the facility (decommissioning)	Easier testing and maintenance practices	Project risk reduction	Optimization of onsite preliminaries	Facilitating opportunities for innovation project options and customer choices	Waste reduction
Gibb, 1999	X	X	X		X	X	X	X					
CIRIA 1999	X		X	X	X	X	X		X			X	
Ryan E. Smith 2010	X	X			X		X			X			
N. Blismas et al., 2006	X	X	X		X		X						
Bowden et al., 2006	X	X			X	X	X		X				X
Gibb & Isack, 2003	X	X	X				X						
V.K. ... et al., 2013	X	X											
Mancini 2014	X	X			X		X						
McGraw Hill Construction, 2011	X		X		X		X						X
Haas & Fagerlund, 2002	X	X	X		X								
Javanifard et al., 2013	X		X	X	X	X	X						X
O'Connor 2013	X	X	X	X		X	X						
Ukces, 2013		X	X			X							
The Modular Building Institute, 2010	X					X					X		

3.4.2 Drawbacks

Most of the papers analysed concentrate more on outlining opportunities of modularisation "forgetting" to describe the barriers and limitations that characterize the method. The main drawbacks treated by the authors are summarized in the following table.

Table 2 - Drawbacks of modularisation

	Increased engineering/design effort	Decreased flexibility	Increased (overall project) cost	Lack of experience	Negative connotation of the method	More coordination required	Increased logistics difficulties	Operational issues	Transportation difficulties	Time lag of new technologies
Gibb, 1999	X						X		X	
CIRIA 1999	X								X	
Gibb & Isack, 2003	X	X	X					X		
V.K. ... et al., 2013				X		X	X			
Mancini 2014	X		X						X	
McGraw Hill Construction, 2011				X					X	
Haas & Fagerlund, 2002	X	X				X	X	X	X	
O'Connor 2013	X	X	X	X		X	X		X	
Ukces, 2013				X	X					X

3.5 Engineering Construction Context

This paper aims attention at the engineering construction industry, which is often concerned with the realization of large construction projects. Examples of EC plants are oil and gas, chemical and metal processing plants, power plants, pharmaceutical plants and so forth (Gupta et al., 1996). From the existing literature is possible to provide a rough description of the principle elements of a process plant (Gibb 1999):

- Substructure: Foundations and works below ground
- Frame and envelope: The structure of the facility, the walls and the roof that house the process plant. These two items are often considered together.
- Process equipment: The plant and machinery which form part of the end-user's business. For example, process plant, manufacturing machinery, along with all necessity supply and waste removal services and distribution. For process plant projects this is almost always the major element, and all other aspects are subservient.

Moreover, a general categorisation of the type of modules can be outlined, Hussein and Coordinator, (2014) illustrate six basic types of module: pipe rack module, equipment/process module, electrical module, stair module, building module, e-house module. Images of some of the basic types of modules listed are presented below:

Figure 3 - Pipe rack module

Figure 4 - Equipment or process module

In order to clearly point out the purpose of the dissertation, it is fundamental to consider that the EC sector includes a branch of offshore applications, which is historically the birthplace of modular components (Cigolini & Castellano, 2002). Since the remote location of the offshore platforms does not allow an onsite realisation, using as much modularisation as possible is almost the only viable option (Mancini 2014); therefore the focus of this dissertation is to study the adoption of modularisation in the onshore plant, where it is compared against conventional stick-build construction. The EC sector encompasses both the construction of the building itself and the construction of facilities, but it is the process plant that has value for the industry with the building structure seen solely as an envelope for machinery and equipment (Connor et al., 2015). Haas & Fagerlund (2002) state that in recent decades the pre-work practicability increased mainly due to advancement in IT and design support systems. They continue by declaring that drivers and factors influencing the usage of modularisation have changed in response to industry changes and global economic transformation (Song et al., 2005), forcing an acceleration in the embracement of modularisation in the EC sector. In fact Haas & Fagerlund (2002) state that its usage in the EC sector has doubled in the last 15 years of the 20th century. Even though late decisions in the industrial projects have hindered a wider adoption of the method in the industry (N. G. Blismas, Gibb, & Pasquire, 2005).

The EC projects are generally cost and schedule performance oriented, with the focus on cost rather than value (Merrow, 2012).

Merrow (2012) has roughly reported the list of factors that increases complexity in Mega projects:

- Technical and organizational complexity
- Stakeholder attention
- Experience is limited
- Cost and schedule targets are key success factors

In recent decades engineering construction projects have become more and more complex in terms of stakeholders/participants involved, completion uncertainty, technology adopted, management effort required and expectancy of the client (Fellows & Liu, 2012). Moreover, the engineering product provided to the client is more complicated, in terms of design, technicalities, functioning and maintenance requirements along the life cycle (Miller & Lessard, 2001).

Several efforts have been done along the years to study and clarify the complexity and uncertainty matter that grips the EC projects (Ruuska et al. 2011), (Fellows & Liu, 2012),(Lawrence & Scanlan, 2007). For example, reviewing performance of engineering projects, Lawrence & Scanlan (2007), have determined eight primary causes of poor project performance. Furthermore, (Ruuska et al. 2011) proposed seven practical essential features to deal with large and complex EC projects.

In the EC sector there is the need for a broad range of competences and specialisations, which range from design and construction ability, involving engineering competences, financial capabilities, management of the organization and legal visibility (Fellows & Liu, 2012). This fragmentation of knowledge (Bowden et al., 2006) and participants (Fellows & Liu, 2012) corroborates the necessity, in the organization, of a wide spread system over the organization that facilitate communication, manage information and develop knowledge among the human resources involved in the project (Lawrence & Scanlan, 2007).

One critique moved to the construction sector, so also to the EC one, is that it is not able to stay abreast of innovation and new technologies (Egan1998).This view is supported by Miller et al. (2002) underlining that old technologies and out dated management techniques are not optimal to cope with the growing amount of data, interdependencies and need of coordination which characterize the modern mega projects.
Another issue is represented by inadequate communication practices among players in the industry that lead to ineffective exchange of information during the execution of the project (Fellows & Liu, 2012). This problem is heightened contemporary by the numerous incompatible IT devices, and the increased number of employees involved in the project. Furthermore, spread of specialization, cultural differences and geographical distances make EC projects even more difficult to govern (Merrow 2011).

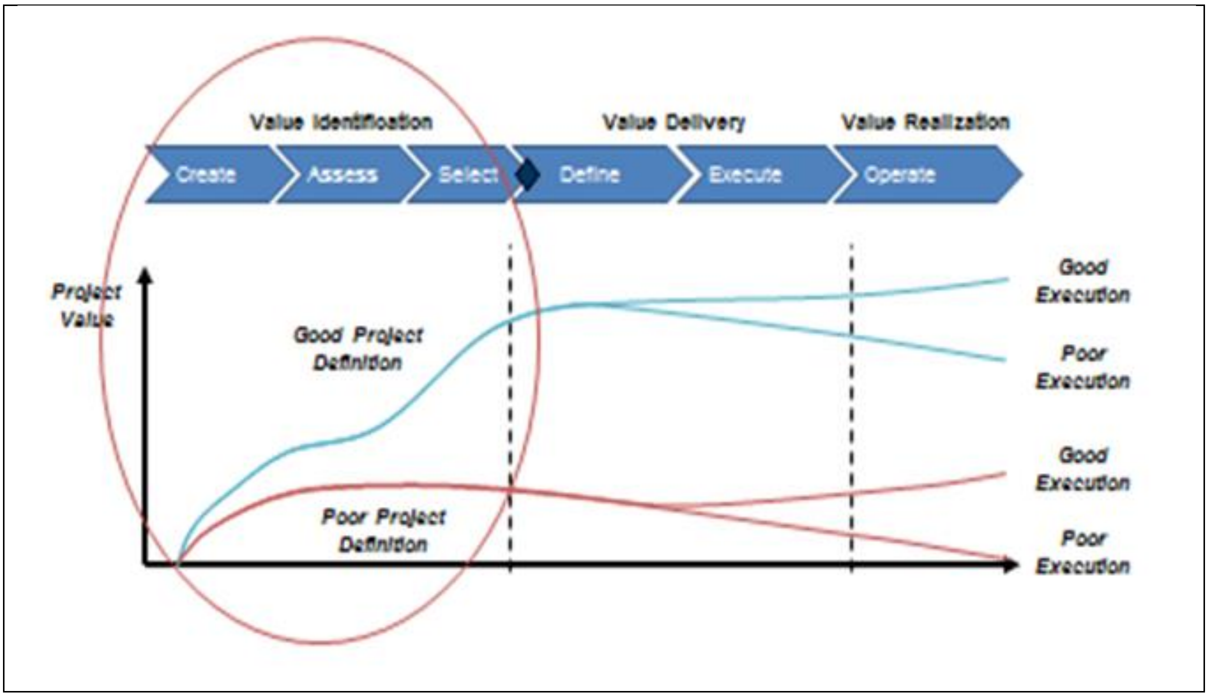


Figure 5 - IPA Independent Project Assessment (Merrow, 2011)

The Figure 3 outlines that in EC projects a considerable part of the goodness of the endeavour executions is represented by the initial project definition. In fact the location, capacity and nature of the land in which the plant will be located are highly influential in directing the project from the beginning in one of the two curves above represented. This graph underlines that the early phase of the projects, with the value identification is far more important than the project execution.

3.6 EC sector mutations

Analysing the EC sector inclination towards changings, some studies between the two centuries have evidenced a resistance to embrace new technologies and invest in innovation (Egan 1998), (Miller & Lessard, 2001). However, recent publications suggest an increasing integration of modern technologies (e.g. BIM, LEED) in the overall construction industry (Lawrence & Scanlan, 2007). (A detailed description of the recently introduced modern devices and advancements is provided in 3.6.1). The EC sector has been historically reluctant to innovation and investments in R&D (V. K. Vernikos, Goodier, Gibb, Robery, & Broyd, 2012), therefore offsite construction has been inhibited by an averse mentality towards changing (V.K. ... et al., 2013). A similar issue was identified by Ukces (2013) his research was focused on identifying opportunities and challenges of MMC. Basically interviewees reported a sort of “protectiveness” of stick-build methods over modularisation, and in some answers, it was evident a hostility towards recognizing benefits of the modular approach. Moreover, the research outlined that modern technologies are perceived economically risky. Goulding et al. (2014) suggest the use of technology as an enabler to promote the uptake of modularisation, but in order to pursue this objective Bowden et al. (2006) deem that implementing modern IT based systems requires a massive development of high-tech skills by all employees and players of the industry. Bowden et al. (2006) describe that adopting recent technologies in construction industry can bring advantages in terms of shortening construction time and capital cost associated, increment productivity, increase predictability, reduce operation and maintenance cost, lowering defects, diminishing wastes and increase health and safety by cutting down accidents. Conversely, the construction industry, in terms of technological innovations, claims about the discrepancy between the tools functionalities developed by researchers and the actual need of the industry (Song et al., 2005). Modern pc and tablet, mobile technology, bar-coding and RFID tag technologies; Global Positioning System (GPS), Building Information Model (BIM), these are only some of the devices and technologies that can be heavily implemented in the construction industry, but the technologies must fit the construction industry needs (Bowden et al., 2006). This view is supported by Lawrence & Scanlan (2007), that sustain that new functionalities of the devices should be developed according to expressed requirements of the industry. V. K.

Vernikos et al. (2012) deem that to establish a profitable growing strategy, construction company should firstly identify the optimal innovation direction and consequently invest on R&D. An example of a big investment in R&D is involving the Asian market: some Japanese companies are investing in robots for the prefabrication of components, modules and elements to be assembled on site (Bock & Georgoulas, 2012). This is perfectly aligned with the theoretical framework of referring to the manufacturing techniques to draw upon when solutions are to be found, in fact often in the literature the synergies between construction and manufacturing world are described (Goulding et al., 2014). Pan & Arif (2011) advocate a mutual interchange of information between the two industries. There is a great opportunity of improvement and innovation for modularisation by exploiting the relationships and the similarities between manufacturing practices and construction one (Ukces, 2013). Egan (1998) supports this statement, declaring that due to the high number of technological factors in common between the industries, modularisation can gain and make progress gleaning knowledge form the manufacturing industry. Even though an higher rate of innovation is advised by the literature (Pan & Arif, 2011), it is linked to a considerable risks for contractors (V.K. Venikos et al., 2013). This view is aided by Pan et al. (2008): they deem that investments in modernization can lead to unsustainable risks and losses for profit oriented companies. Moreover, testing new technologies can expose the corporation to unacceptable risk, since the introduction of innovation, inherently not understood, brings technical and business unpredictability (Pan et al., 2012). Modularisation is considered one of the modern methods of construction (Ukces, 2013), as well as lean approach and emerging construction technologies (Egan1998). V. K. Vernikos et al. (2012) state that recent practices such as the introduction of BIM and adoption of modularisation wants to achieve cost efficiency and this aim is endorsed by the cost based nature of the EC sector.

The construction industry has been slow in fitting recent technologies advancements, so the constrained growth in the construction industry can be attributed to a loath adoption of new technology solutions (The Modular Building Institute, 2010). Recent advanced in ICT allows an agile, faster and cheaper adoption of personal computer and mobile devices in construction industry (Bowden et al., 2006). This leads to benefits in terms of reduced time to retrieve data and schedule activities that turns out in an overall cost savings (Sloan, Paper, Miller, & Lessard, 2007). Moreover the fastness and easiness to manage a bigger amount of data gives the opportunity to facilitate the maintenance during the whole life of the plant (Bowden et al., 2006). Modern technologies, digitalisation of data, virtual modelling and simulation packages give the opportunity for a better design and a consequent coordination of FEED phase with the EPC activities (Preliminary research on Prefabrication). Moreover, the strength of adopting ICT solutions relies on the possibility to integrate different devices, for instance combining DfMA techniques with BIM and ERP system, in order to integrate the phases of the project both upstream and downstream (Goulding et al., 2014).

One of the evidence of advanced building techniques boosted by modern technologies, employed in construction processes, is the ability of companies to produce and transport larger and heavier modules (Smith, 2011). Comparing the document written by Gupta et al.(1996) with a recent presentation of a company leader in the sector (Fluor Corporation, 2014), is evident that standards of modules have changed.

Table 3 - Truck able modules specifications

Type of module	1996	2014
Small size module or Truck able module	Dimensions: 12 m to 15 m long, 3.5 m wide, 3.5 m to 4.5 m high weight: 50 to 100 tons	Dimensions: 18 m to 36.5 m long, 4 m to 7.5 m wide, 4 m to 7.5 m high weight: 60 to 160 tons

Recently, 3rd generation modules have been attracting increasing interest. Introduced by Flour Corporation (contractor company), 3rd generation modules have the potentiality, according to Honey (executive director of design engineering) to bring to the oil sands industry up to 60 % shrinkage of facility plot space requirements and 20 % in capital cost savings for all types of plant construction (Haney, 2012).

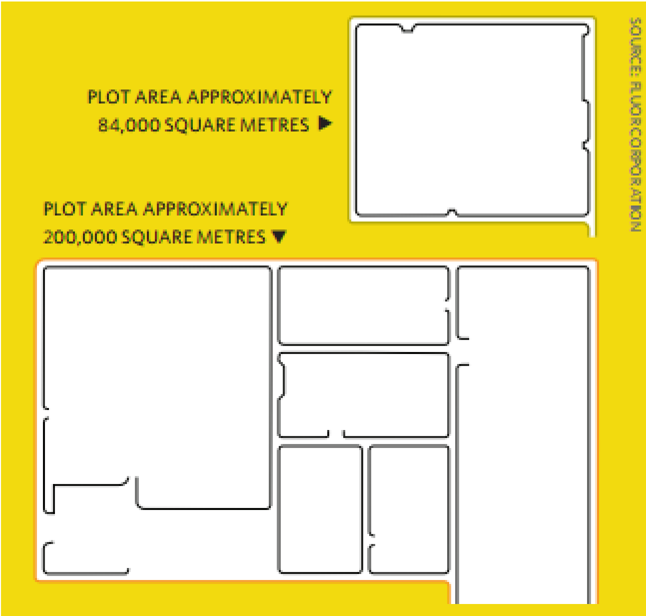
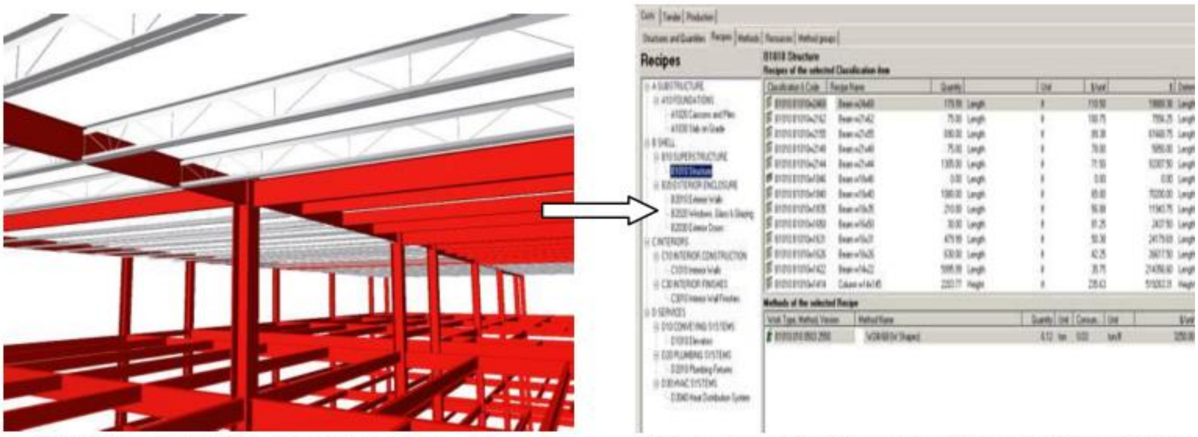


Figure 6 – In situ facility plot size reduction (Fluor Corporation)

3.6.1 Building Information Modelling (BIM)

In recent years the adoption of BIM as a method to improve efficiency and productivity in the construction industry has been emphasized (The Modular Building Institute, 2010). The UK government, for example, is pushing towards a wider usage of the method (Wolstenholme et al, 2009) and an extensive adoption of the method in the next years is predicted by Morrell, (2011). Lu & Korman (2009) is quoted as defining BIM as a process that creates smart and computable 3D data sets transferable among professionals involved in the realisation of the project. The re-emergence of modular construction as a ‘‘new’’ trend can be tied to the rise of Building Information Modelling (BIM) and green projects. Moreover, the usage of BIM is a driver for an increasing adoption of modularisation (McGraw-Hill Construction, 2011). The adoption of BIM in construction industry is gaining momentum, it's already widely adopted by designers, consultants and recently also contractors are becoming more and more used to the approach (Smith, 2011). The author argues about cooperation between modern devices and BIM undertaking project before unmanageable. Ukces (2013) highlights the great influence exercised by the BIM in all the critical phases (design, scheduling, procurement, fabrication) of a construction project. Its adoption can help managers to realize and coordinate the MEP (Mechanical, Electrical and Plumbing) system, which according to Lu & Liska (2008) represents one of the most challenging commissioned elements of the project. The Modular Building Institute (2010) refers to BIM as an “*interoperable* *technology application*” that embodies the ability to transfer data between designer and construction team; “Interoperability” is enabled by a wide range of IT devices and applications such as, computer-aided design and visual simulators (CADD), 3D and 4D visualization and modelling programs. Using BIM is possible to improve design activities and integrate the manufacture of construction units (Goulding et al., 2014). Vernikos et al. (2013) provide insights about the client perception of BIM technique, they found out that BIM is considered an innovative approach that embodies the potential to achieve an industry growth and realize monetary savings. Furthermore, the advantages that the adoption of BIM can bring to the whole life-cycle of the project are listed in the paper, for example the promotion of a better management of maintenance and repairing activities. The authors conclude stating that the actual reality is a confounding understanding and implementation of the BIM. In order to realize the complete advantages of the technique the main challenge is represented by the integration of BIM with other support systems, like GIS (Geographic Information System). For an exhaustive explanation of the implementation process of the BIM in the modular environment, it is possible to refer to Lu & Korman (2009), Jung & Joo (2011) and Dossick & Neff (2010).



(a) Structural Steel BIM Model (b) Automatic Quantity Takeoff from BIM

Figure 7 – Example of BIM operating structure

3.6.2 Virtual visualization

Virtual visualisation encompasses project virtual visualisation and simulation, enabling a graphic illustration of the building, plant, components, units and modules. 3D and 4D representations enable a dynamic view of the structure and permits feasibility simulation, such as pipe clashing (Nepal & Staub-French, 2012). Gibb (1999) argues that 3D CAD techniques were available even twenty years ago, but they were not intensively used. The technology employed nowadays permits a wider and powerful adoption, necessary to face the growing complexity in EC projects (Salman Azhar, Hein, & Sketo, 2007). Kamat and Martinez (2001) are quoted as promoting the adoption of dynamic construction visualizer in conjunction with 3D model creator and a wide variety of CAD modelling programs.

3.6.3 Sustainability

One common theme from the literature is that sustainability in the EC sector is getting more and more impetus (Egan, 1998), (Javanifard et al., 2013) (McGraw Hill Construction, 2011). McGraw-Hill Construction (2011) forecasts a growing percentage of non-residential sustainable building. The paper shows the trend from 2008 to 2010 revealing an increasing percentage from 28% to 35%. This suggests that the trend moves rapidly. It states that by the end of 2015 the percentage of non-residential green building is expected to be in the extent of 45% to 48%. Sustainability growth emphasis will heavily affect the realisation of future projects, the establishment of this kind of framework can help modular solutions and promote a favoured position of modularisation over conventional stick-build techniques (Vivian W Y Tam et al., 2007). The grown of sustainability awareness, in the global environment, is a good opportunity for offsite industry to carve out (for itself) a significant portion of the construction market (Goulding et al., 2014). Due to energy efficiency, limited material waste and inherently greener processes (The Modular Building Institute, 2010)m modular solutions embody the potential to realize environmental advantages and achieve general sustainability benefits (Lawson et al. 2014). However, these benefits are not always understood by the clients. In the research executed by V.K. Vernikos et al. (2013), only 4 out of 9 interviewees cited environmental sustainability as an effective benefit of modular techniques. Respondents even didn’t mention the economic and social aspect of sustainability. Javanifard et al. (2013) point out that modularisation method achieves a better level in all investigated parameters over stick-build construction. Some of the reasons are, less pollution generation that leads to better quality of air and so less energy used for air purification; moving operations offsite doesn’t cause congestion around the site that means less traffic and congestion. Moreover, it’s easier to organise recycling, design disassembly and disposal systems. In most of the client’s conception sustainability is seen solely as environment protection, but there are other aspects of sustainability that are exhaustively described in the Lawson et al. book.

This list comprises:

- Energy consumption and emission of CO_2
- Efficient usage of materials
- Reduction of wastes
- Water consumption
- Pollution
- Site management
- Performance improvement
- Adaptability and end of life and
- Social responsibility

Nowadays modules of process plants are equipped with green technologies that allow best performance in terms of energy efficiency, water consumption and recycling. Moreover, in assessing sustainability of modular plants particular attention must be paid to the whole life-cycle of the plant (Vivian W. Y. Tam, Tam, & Ng, 2007).

3.7 Decision Support Tool (DST)

3.7.1 Deciding to go modular

Often in the literature is reported that the selection of the construction method is based on decision makers' opinion and experience without adopting a structured approach (Salman Azhar et al., 2013), (Pan, Wei, Gibb, A.G.F. and Dainty, A.R.J., 2008), (Pasquire, C.L & Gibb, 2002). Particularly interesting in this direction is the research conducted by Pasquire et al.(2002), they noticed a scarcity of historic data, poverty of formal measures and absence of decision procedures, that ultimately results in hindering the selection of modularisation. Blismas et al.(2006) present further evidence demonstrating that decisions to compare traditional and off-site solutions were largely based on material, labour, and transportation costs, whereas other cost-related items such as site facilities, crane usage and rectifications or reworks were disregarded or buried within the nebulous preliminary cost items. Moreover, softer issues such as health and safety, effects on management, and process benefits were either implicit or disregarded. The industry, as a whole, still sees a fragmented, cost- driven rather than value culture prevailing in evaluation and selection of construction practice (N. G. Blismas, Gibb, et al., 2005). In order to overcome this impediment of the industry Pan et al. (2012) laid the foundation for the development of a decision support tool for the residential constructions, fitted with a value-base system to assess the modular feasibility. A rough description of the decision support tools comparing the modular solution with conventional stick build construction developed in previous years is provided in the next section.

3.7.2 Existing DSTs

One of the first efforts in the EC industry to develop a DST was undertaken by the Construction Industry Institute (CII). After 32 months of exertion, in 1992 a first version of the tool called MODEX (Modularization Expert) was launched, it was conceptualized as an early support decision tool for both process plants and power plants (Gupta et al., 1996).
The CII team grouped 43 variables into five influencing factors categories (plant location; labour-related factors; environmental and organizational factors), then variables was scored in terms of importance utilising a weighting system both during the preliminary screening and the subsequent detailed analysis (Murtaza, 1994). Basically the expert system is composed by three steps:

1. Pre-screening, this evaluates whether a modular approach is worth to consider for a given project.
2. Detailed feasibility study, gives insights about the design and construction phase as well as the degree of modularisation to adopt.
3. Economic study, this final phase reveals cost saving opportunities and possible reduction in the construction schedule.

One of the limits of the method is that the tool was designed for project executives, which means that it was not firstly intended for the client/owner of the project or his team. Secondly the way how the result is “spit” out prevents the client/owner to understand which are those project’s characteristics that most push towards the adoption of modularisation. Finally, the user can only see the final result without having the opportunity to interact with the tool going through his answers in order to get knowledge on modularisation drivers and hindrances.

Murtaza (1994) one year later validated the tool comparing suggestions provided by MODEX with industry experts’ judgement. The statistical comparison provided a 91% confidence of not misalignment of the two sources of data. In a sequent study Murtaza (1994) developed a more advanced tool called Neuro Modex. This tool is based on a neural network architecture, which allows dealing with unstructured decisions identifying interesting patterns through experience. They deemed to move towards a neural network approach, since in the industry decisions are often taken on the basis of experience without weighting each decision driver separately. The validation of the method highlighted that Neuro Modex is more accurate than the original MODEX (Murtaza, 1994).

In the early 2000s Cigolini & Castellano (2002) built a model to compare the overall project cost when a modular approach is selected over conventional stick build method. This model aimed at identifying cost related drivers of activities influencing modularisation and successively evaluate the impact of modularisation in these cost drivers. The model provides detailed calculations of six main areas (steel structures, work man-hours, construction equipment, site facilities, site consumption, harbor area) (Cigolini & Castellano, 2002). Nevertheless the detailed design, this model misses to consider the cost of increased man-hours work caused by an expansion of initial engineering and design effort, which is often reported in the literature (see Table 2).

Song et al. (2005) developed a decision support system to compare PPMOF (Prefabrication, Preassembly, Modularization, and Offsite Fabrication) with conventional stick build techniques. The purpose of this tool was to support decision makers at an early stage both in terms of strategic and tactical level, by helping them to recognise the critical factors to consider evaluating the adoption of PPMOF at an early stage of the project. The tool was shaped from the data gathered by Haas & Fagerlund (2002), they studied the adoption trend of prefabrication and preassembly in the proceeding fifteen years, finding a growing tendency, from 14% to 27%. The first step of the tool performs a rough strategic analysis, querying about six general categories with the purpose of identifying drivers and hindrances of the specific project. The sequent second strategic level exploits the logic of subjective judgements and requirements provided by the operator in ten different areas of interest. This second phase is intended to support the user during the realisation of the project planning. In the final step is performed a tactical level examination with the purpose to operate a cost comparison aiming at evaluating the feasibility of PPMOF and extent of its adoption (Song et al., 2005). The tool is based on relative weighting system, this means that the “relevance” of the factors is expressed by the users; according to this a partial and final score of the degree of PPMOF to adopt is calculated. The tool is very detailed and well-shaped; moreover the validation process confirms its good adaptability to real cases. However it is reasonable to think that since the tool was developed more than ten years ago (2002 data) it might be imperfect in properly addressing the growing complexity of the recent market and industry advancements, for example the higher actual or upcoming concern in green projects (see EC sector mutations). For example, after the first rapid screening of the environmental regulations and requirements, the sustainability topic was set aside and it was not mentioned both in ten factors of second section and in the final tactical step. This is probably due to the fact that in the early 2000s the sustainability interest was at its conception. Moreover the feasibility solutions proposed by the system might not be consistent with the modern evolution of technology applications for construction industry. For example the resent adoption of BIM, LEED and virtual visualizer provides the possibility to reduce the hindrances of the method, in fact through advanced design options a better involvement of the client is possible, with 3D-4D models and BIM systems, some impediments and infeasibilities can be overcome increasing the range of applicability of modularisation(Lu & Korman, 2009).

Diez et al.(2007) developed AUTMOD3 "an automatic modular construction software environment that combines architectural design, planning and simulations tools in a well-known CAD program commonly used by designers". The system encompasses two methods of modular design: the first one is used as a traditional architectural design, while the second is executed by means of a library of 3D parametric modules. The tool is mostly delimited in the house building sector, and has been profitably applied in various projects in Spain and Netherlands.

Pan et al. (2008) developed a value based decision criteria, to evaluate the feasibility of modular approach over conventional stick build techniques, in the house building sector. The author individuated more than fifty criteria that later was grouped in eight main sections (cost, time, quality, health and safety, sustainability, process, procurement, and regulatory and statutory acceptance). They graded cost the most important driver, since in the industry is mostly cost-driven, the following time, quality, process and procurement were expressed in financial terms, either explicitly or implicitly. Other sections were considered compulsory (Pan et al., 2012).

One of the most important toolkits developed is IMMPREST (Interactive Method for Measuring PRE-assembly and STandardisation benefits in construction). The tool also called VALUE OFFSITE was developed at Loughborough University by Christine Pasquire, Alistair Gibb and Nick Blismas with further input from Ian graham. It makes effort to understand the costs and benefits of offsite solution. One relevant characteristic of IMMPREST is the introduction of features like health and safety and sustainability in the decision making process. A measuring framework for these not easily monetaryconvertible variables is providing, in fact Blismas et al. (2006) states that *"monetary measures are inadequate for items that cannot be directly attributable to an element"*.

Another significant tool developed by the Loughborough University is the Consider Offsite. It evaluates the opportunity for using offsite techniques in construction projects. The tool has been designed in seven driver dimensions including: cost, time, quality, design, sustainability, H&S and process and two constraints dimensions including: procurement and site. The tool does not utilize a quantitative algorithm and provides qualitative suggestions on the utilisation of offsite solutions.

3.7.3 Client perspective

The interest in DSS in construction is increasing, boosted form the advancement of technology and the need of making more knowledgeable decisions that enables a better problem comprehensions (Pan et al., 2008). Especially valid in EC sector where often managers have to deal with huge amounts of data, economic, cultural, social, and environmental constraints in the realisation of a project (N. G. Blismas, Pendlebury, et al., 2005). A direct cost based comparison between onsite and offsite construction seems pointless due to a high number of complex interactions between factors. An holistic cost comparison represents both an arduous path to follow and it is hindered by the existence of some not costly commuting benefits (N. Blismas et al., 2006). Conversely a value based approach has the disadvantage of being more context specifications and objectives related (Pan et al., 2012). Surely, Clients have to be more informed about advantages of modular solutions, not just form a superficial cost comparison, but from an overall point of view (Goulding et al., 2014). V. K. Vernikos et al., (2012) suggest that a "client driven" approach fostering the adoption of modularisation should be used; because the embracement of modular solutions must be triggered by the client. Moreover, the engagement and contribution of the client during the development of the project is fundamental, because clients are more responsible than how it's commonly thought about the successful implementation of modularisation in projects (N. G. Blismas, Gibb, et al., 2005). Therefore this dissertation's aim is to promote more involvement of the client in understanding modularisation in order to promote the uptake of the method. What emerges from Egan (1998) is that the industry should focus more on developing higher valuable products to the client targeting his need and requirements. In this dissertation a value based approach focused on supporting the client will be used, providing insights and advices for the decision process to foster knowledgeable choices to the greatest extent possible (see Early decision support tool).

3.8 Summary of Literature Review

The literature provides an exhaustive description of the modularisation method (the structural and technical mechanical part was not covered in this dissertation), important contribution comes from the CII with the early nineties publications and the ECI between the two centuries. From the literature emerges clearly that the method is not new, but only since the latter part of the last century it has been fully understood and exploited by the civil engineering and building industry. Moreover, starting from the Second World War a growing adoption of the method is documented. However, more recent literature suggests that the real uptake of the approach is far from increasing. Reviewing the publications, it is possible to notice that there are different terms that relate to the same concept of modularisation. These terms are listed in the section Definitions and Theory. The papers reviewed display a broad range of advantages and disadvantages (see Benefits and drawbacks of Modularisation) of the method and produce in depth studies on the drivers and barriers of this construction approach. Regarding the EC sector, the modularisation body of knowledge on the topic is more limited, however a description of the sector and its recent mutations is provided. The last part of the analysis involved the early decision support tool developed by the industry in the EC sector and not only. In almost all the tool developed the designer focused on the identification of factors and drivers affecting the selection of the construction method. Furthermore, a client perspective view is provided, showing that the interest in early decision support tools is increasing, but the production should match the clients' needs.

3.9 Gaps in the Literature and Scope of the Research

The scope of this dissertation is to establish the client/owner needs and project requirements that lead to the use of modularisation in engineering construction and to establish the evidence base for and develop an early-phase decision support tool for modularisation in the EC sector. The purpose of the first part of this dissertation is not new, many research studies have identified drivers and hindrances of modularisation (Haas & Fagerlund, 2002),(N. Blismas et al., 2006),(S Azhar, Lukkad, & Ahmad, 2012),(Connor et al., 2015), and few of them concentrated on the EC sector (Mancini, 2014). However there is a limited number of early-phase decision support tools developed for the EC sector and the existing tools was shaped more than 20 years ago or at the beginning of the century (see Existing DST). For this reason is reasonable to think that the existing tools are insufficient to exhaustively match the recent industry advancements.

There is the necessity of a modern decision support tool that is able to match the changing client needs, cope with the growing complexity of the modern market and keep pace with innovations and the development of technologies.

4 Research methodology

4.1 Research approaches review

Research methodology: *"refers to the principles and procedures of a logical thought process which are applied to a scientific investigation"* (Fellows and Liu 2003). The selection of the right methodology in a research study is crucial. The research method has to be selected keeping in mind the type of research question, time and resource availability. Moreover, the research has to be valid, reliable and inherently robust in each of the steps (Kumar 2005). In the following parts we describe some of the methods and based on the characteristics of our research the selection process of the appropriate methods.

Kerlinger (1986) defines a scientific research as *"a systematic, controlled empirical and critical investigation of propositions about the presumed relationships about various phenomena*". In this definition the emphasis lies on finding correlations between observable variables and the author stresses the systematic and critical nature of the investigation. A business related description of what a research is can be provided: Kumar (2005) describes research as an endeavour, based on "clinical impressions" and/or "scientific procedures" started in most of the professional works, in order to examine in a critical way those aspects affecting the daily working activities. Also in this explanation we recognize the "how" dimension (scientific procedures, critical way) and "what" dimension (findings, examining aspects).

In general terms, Fellows and Liu (2003) state that research is learning process, a "voyage of discovery" even if nothing is discovered. Findings depend on the techniques adopted and the research design. Conversely, the abilities of the researcher should not influence the results, but his skills can be significant whilst shaping the research structure, interpreting results and outlining conclusions. This definition concerns the finding of new conclusions and knowledge.

Criteria to consider for the selection of the approach include (Creswell 2014):

- The research problem
- Personal experiences of the researcher
- Audience for whom the report will be written

After deciding the topic of the research, the next step is to define how the research will be conducted and the plan and strategy to adopt in order to obtain the right information and answers to the research question.

Kumar (2005) refers to the research approach listing eight types of research approaches: positivist, Interpretive, phenomenolist, action or participatory, feminist, qualitative and quantitative. He does not include the mixed approach, probably considering that can be implemented just combining the other methods. Furthermore, also Creswell (1994) describes only qualitative and quantitative methods, but as he asserts in Creswell (2003) the development in research led to the introduction of mixed research methods integrally described in his further editions (e.g. Creswell 2014). We will deal with the description of some of the listed methods in the next sections. Concerning the validity and reliability of the research, many books (Kumar 2005), (Fellows and Liu 2003), (Silverman 2010), (Densocombe 2014) stress the fact that these are key and fundamental characteristics to ensure consistency of the research. Some of the methods will be discussed in the following sections.

Kumar (2005) differentiates between bias and subjectivity, clarifying that subjectivity involves the way of thinking influenced by knowledge background, education, experiences and competencies; instead bias is a voluntary action of hiding or highlighting an "object".
Kumar (2005) introduces four research classifications based on the objectives that it tries to accomplish:

- Descriptive research – It tries to describe systematically a specific situation or a phenomenon providing information about it.
- Correlational research – the objective is to find correlations between factors.
- Explanatory research – gives reasoning of the correlations, providing an explanation of why and how that relationship exists.
- Exploratory research – it attempts to reveal unknown topics or explore new research possibilities, it is usually undertaken to develop tools and procedures.

The author encourages integrating all the aspects in a research study and declares that most of the studies include all the first three aspects.
Fellow and Liu (2003) also include a fifth dimension:

- Interpretative research – its objective is to compare conclusions with a theoretical framework.

There are different research approaches and a broad range of research design process that can be adopted in a research study. Kumar (2005) classifies and discusses different study design based on circumstances of the study. The three perspectives analysed and the respective groups of study design are represented in the following table.

Table 4 – research design classification

Study design based on the number of contacts	Study design based on the reference period	Study design based on the nature of the investigation
Cross-sectional studies Before-and-after studies Longitudinal studies	Retrospective Prospective Retrospective-prospective	Experimental Non-experimental Quasi or semi-experimental

Moreover the author describes some other commonly used study design, e.g. action research, feminist research, case studies etc. A description of each of the design processes is out of the scope of this presentation, but in the next paragraph "Adopted methodology" we will describe and provide the reasoning of the adopted design approach. The next section focuses on describing the macro distinction between research methods concerning qualitative and quantitative approach and the combination of the two that gives life to the mixed research approach.

4.2 Research methods

Different methods can be used to gather the right data for the research, several authors (Creswell 2014), (Kumar 2005), (Harwell, 2011) provide insights and suggestions about the proper characteristics of each of them, but the biggest distinction concerns quantitative, qualitative and mixed methods. It is important to understand the benefits and drawbacks of each of the methods and select the proper one based on resource available.

4.2.1 Qualitative research

In the last decades there has been a growing interest in the qualitative research methods. This method explores the set of believing, thoughts, perceptions and experiences of the studied population, moreover it tries to delve into the world's mechanisms and understand in an inductive manner the meaning and functioning of the reality (Fellows and Liu 2003). With inductive it is meant that based on the respondents answers, the research has the possibility to formulate hypothesis, interpretations, inferences and outline theories

(Harwell, 2011). The data gathering process of this approach results more problematic due to the higher number of exogenous factors to consider, e.g. while conducting an interview the researcher investigates the opinions of the respondent, but in the same time has to check how the language is used, what does it really mean, gestures, interview circumstances etc. (Creswell 2014). During this process the researcher cannot set aside his background, believing and experience, hence the research results are biased and the results are bounded by the knowledge and abilities of the researcher to interpret and codify the interviewer testimony (Kumar 2005). According to (Lincoln and Guba 1985) qualitative methods lead to multiple “truths”. This is reasonable due to the fact that the outcome of the research is heavily influenced by more uncontrollable variables, such as researcher knowledge and study circumstances. With this in mind it is evident that replicability and generalizability are not objectives of this approach (Harwell, 2011).

4.2.2 Quantitative research

According to Creswell (2014) and Fellows and Liu (2003) quantitative approaches are related to the positivist philosophy. This way of doing research goes under the definition of “scientific method” or empirical science, due to the fact that a scientific approach is adopted in conducting the research, making analysis and revealing measurements. Both the papers agree on the fact that quantitative methods are inherently linked with a deterministic philosophy; this implies finding quantifiable correlations between variables. All the findings, rigorously quantitative and measurable are set against the theory and existing literature. Quantitative methods focus on finding deterministic cause to observed outcomes. In finding these relationships the researcher should put aside his perceptions, experience and bias in order to ensure objectivity of the evaluations. The study has to be structured and replicable in order to guarantee generalizability of the findings (Harwell, 2011). Usually quantitative data gathering techniques includes surveys and experiments, but quantitative sources of data can be also collected form interviews and observations (Denscombe 2014). Quantitative methods are usually characterized by a deductive logic; this allows researchers to perform tests of statistical hypothesis and generalise inferences. According to (Lincoln and Guba 1985) quantitative methods identify a unique truth that exists independently from the human interpretation.

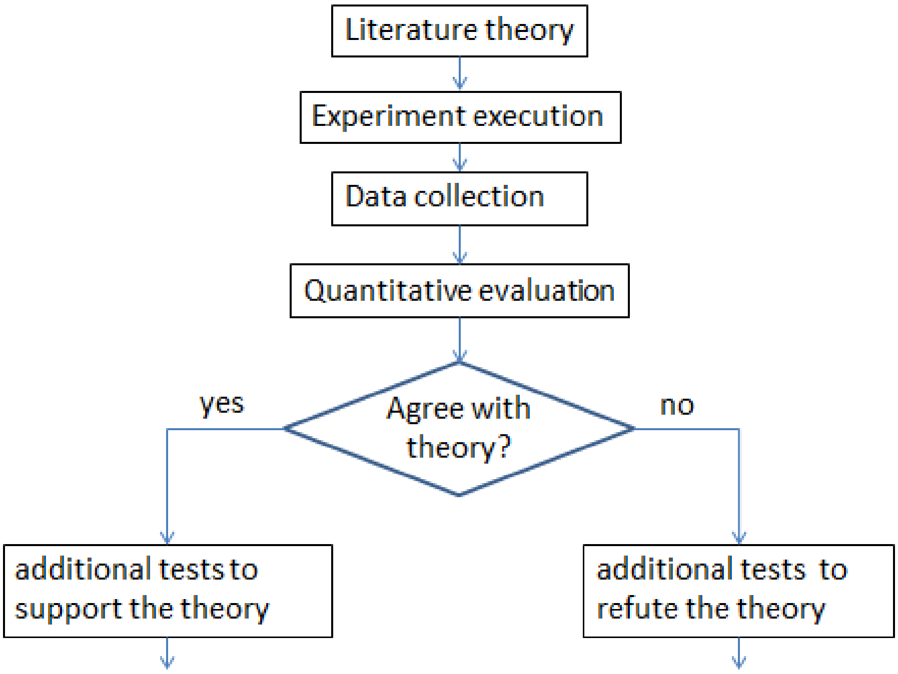


Figure 8 - representation of a typical quantitative research path

4.2.3 Mixed methods

Mixed method research is the combination of quantitative and qualitative approaches to find a solution to the research question/objective (Creswell 2014). There is a wide spread consensus in asserting that mixed method approach encompasses the possibility to exploit the advantages of the quantitative and qualitative methods and compensate the weaknesses of the two (Fellow and Liu 2003) (Harwell, 2011) (Creswell 2013). This view underlines the potential as well as the complexity of the method. The principle of this method is to gather data from the two methods, this collection of different data allows reaching results, making interpretations and formulating analysis otherwise not possible with the adoption of a single research technique. Moreover, the mixed method is deemed to require more effort and involvement of the researcher in conducting the study (Fellows and Liu 2003). Greene et al. (1989) recognize five primary goals to adopt a mixed method approach:

- Triangulation, measures the coherency of the results obtained with different methods
- Complementarity, analyses the quantitative and qualitative overlapping outcomes
- Development, results of one method affects the development of the other method (e.g. in shaping the data gathering process)
- Initiation, outcomes of one method inspire new research paths

- Expansion, enhance the clarification and comprehension of the results

According to (Harwell, 2011) there is disagreement in the literature about the following aspects of the mixed methods.

- What constitutes a mixed method study
- Necessity of a mixed method question
- Mandatory presence of quantitative and qualitative analysis
- Presence of integrated interferences
- When mixing should occur

1.3 Data collection research methods

"Research methods concern the technique available and those which are actually employed in a research project" (Fellows and Liu 2003). Kumar (2005) states that data can be collected either from primary or secondary sources, the first source concerns data gathered directly by the researcher, while the second refers to the adoption of already gathered data, for example by government of private institution. Kumar (2005) continues stating that the data collection has to be carried out for the specific objective of the research and the choice of the method depends on three factors:

- Purpose of the study
- Resources availability
- Skills of the researcher

Fellows and Liu (2003) shows an interesting model that illustrates the breath and the depth of the study:

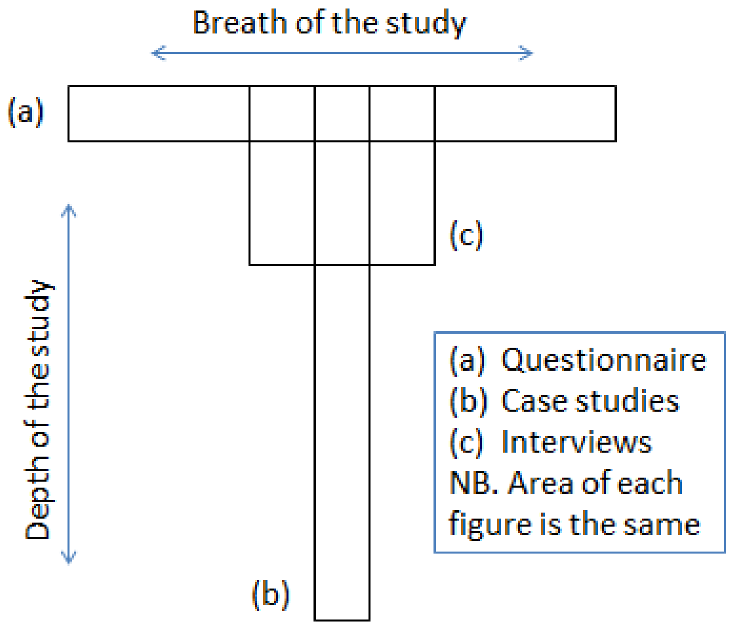


Figure 9 - Breath v. depth in "question-based" studies (Fellows and Liu 2003)

There is different data collection methods listed in the literature; some of them include observations, experiments, case studies etc. We will describe some of the most treated and adopted one: literature review, questionnaires and interviews.

4.3 Data collection research methods

4.3.1 Literature review

In order to examine the existing body of knowledge either a literature review or a systemic review can be used. The former focuses only on a specific set of the relevant documents, while in the latter the researcher has to study all the documents produced for the particular topic identifying and summarizing findings, to do so explicit and transparent methods has to be adopted (Denscombe 2014). In the research only a limited but relevant part of the existing literature was examined. The review of the literature fulfils a fundamental role in conducting the research, it is the first step of conceivably all research studies, it basically concerns the screening of all the significant literature in the topic of interest (Fellows and Liu 2003). Kumar (2005) deems that the literature review has a crucial role in all the research phases; even before the research question/objective is defined it helps to select the study focus and clarify ideas on the path to follow. Then it helps to consolidate and improve the knowledge of the researcher on the studied area. From Kumar (2005), even if not explicitly outlined, it is possible to evince the dual role of

the literature review; from one side it informs about the relevant theory and significant body of knowledge developed in the researched area; from the other, it helps to improve the methodology and contextualise the findings.
A scheme can be drawn to represent this dichotomy:

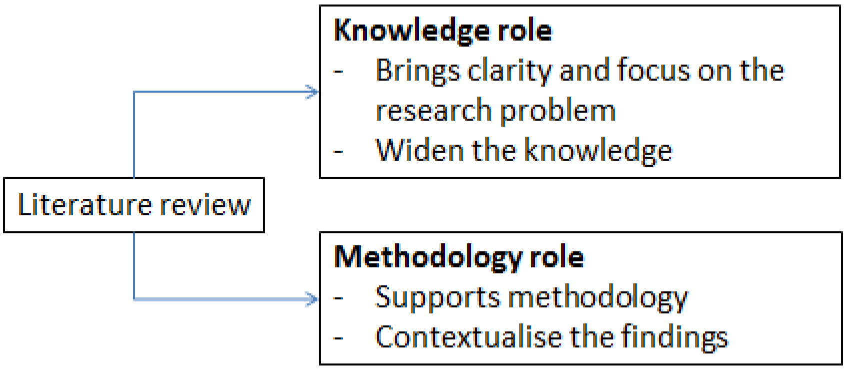


Figure 10 – roles of the literature review in the research

Fellows and Liu (2003) suggests a critical review of the literature. This means that a mere list and summary of articles red is not sufficient, but is necessary to deeply understand issues and arguments of the topics presenting alternative and controversial views, justifying inclusions etc. Kumar (2005) speaks about initially reviewing the literature in the broad area of interest, then narrowing the review around your research objective. Conversely Fellows and Liu (2003), reputes it is better to search from the beginning only for the significant papers.

4.3.2 Questionnaire

A questionnaire is a research tool composed by a written list of questions. The respondents read the questions, interpret and answer them. The answers are recorded by the researcher (Kumar 2005). Creswell (2014) distinguishes between open-ended and closed-ended questions. The former indicate that the list of responses is not provided, while the latter indicate that the list of responses is provided and the responded can pick one of the answers that best indicates his opinion. Fellows and Liu (2003) reputes useful to have a prior pilot phase of the questionnaire, where it is sent to a small number of respondents in order to a avoid imperfections and guarantee clarity to the questions. Denscombe (2014) listed advantages and disadvantages of the method:

Table 5 – advantages and disadvantages of a questionnaire

Advantages	Disadvantages
• Questionnaires are economical • Relatively easy to arrange • Delivery of questions is standardized • Data accuracy • Facilitate accessibility (mainly for online questionnaires)	• Pre-coded questions can be frustrating • Fixed structure of the answers • No possibility to check the truthfulness • No possibility to explain questions

It is worth to point out that Kumar (2005) identified a more exhaustive list of disadvantages. Those that do not compare in the table are: limited application, generally low response rate, possibility to consult others, no spontaneous responses and no further information obtained.

4.3.3 Interviews

It is an old and common method of collecting information from people. The only difference between questionnaires and interviews, according to Kumar (2005), is that the interviewer directly asks questions during the interviews. The author explains that any interaction between two individuals can be considered an interview if made with a purpose in mind. Fellows and Liu (2003) and Creswell (2014) classify three types of interviews according to the degree of flexibility: Structured interviews, semi-structured interviews and unstructured interviews. Conversely, Kumar 2005 does not explicitly speak about semi-structured interviews but simply identifies a middle area between the structured and unstructured one in which lies a set of "*interviews at different levels of flexibility and specificity*". Structured interviews are characterised by a fixed prearranged set of questions, also the questioning words are always the same. The main advantage is the uniformity of results and the easiness to compare them (Fellows and Liu 2003). Unstructured interviews are characterised by flexible structures, content and questions. The interviewer has freedom in selecting the wording of the interview, ask clarifications, and raise doubts depending on the discussion context. The common types of unstructured interviews described in the literature are: In-depth interviews, Focus group interviews, Narratives, Oral histories (Kumar 2005).

Semi-structured interviews incorporate both aspects of the previous types, integrating a part of structured questions and leaving the interviewer to formulate inquiry based on the flow of the conversation. The advantage of this method is that it assures a better management of the interview, since it helps to deal with every type of situation (Fellows and Liu 2003). Denscombe (2014) listed advantages and disadvantages of the method:

Table 6 – advantages and disadvantages of the interviews

Advantages	Disadvantages
• Depth insights and information • Simple equipment required • Higher response rate • Higher flexibility (less in structured one) • Usually higher validity of the data • Therapeutic	• Validity reliability verification • Interviewer effect ("please" the researcher) • Interviewee behaviour (few time) • Time consuming • Inhibitions • Invasion of privacy

4.4 Consistency of the data

4.4.1 Sampling

Fellows and Liu (2003) state that the sampling process is necessary to provide a good representation of the studied population. It is not easy to judge the representativeness of any sample, moreover it leads to bias in the research, in order to reduce it non-random samples can be obtain with:

- Systemic sampling
- Stratified sampling
- Cluster sampling

4.4.2 Validity

Research concerns often in finding relationship between variables, if this relationship exists, inferences can be made. The "truth" of the findings is not took for granted, this is where the validity comes in, the research has to be solid in proving that consistency of the procedures adopted to draw conclusions.

Inaccuracies can affect the research at any phase; Kumar (2005) argues that validity should be considered at the research design phase, sampling strategy, outcomes evaluation, statistical analysis employed and during the measurement procedures. Kumar

(2005) treats validity of the measurement procedures, instead Fellows and Liu (2003) provides an accurate description of various validities:

- Construct validity: concerns, if variables effectively measure what they are designed to measure.
- Internal validity: it represents if the observed effect is truly linked to the causal relationship recognized.
- Statistical inference validity: it represents how close results of the sample and the entire population are. If it is high performances of the population can be deducted from the sample.
- External validity: it represents if the study can be generalised to conditions different from the investigation.

Fellows and Liu (2003) highlights the inverse relationship between internal and external validity, where the focus on the single research increases the generalizability decreases. Moreover it is argued that the internal validity tends to be privileged by researchers since it is crucial in drawing outcomes instead the external one is usually less important since findings depends heavily on the research circumstances.

Validity in qualitative research

Creswell (2014) deems that validity is one of strength of the qualitative research and suggests eight strategies to check the accuracy of the findings in a qualitative research study, among which the first in the list is the triangulation of the data. The author states that a proper instrument to ensure validity is the *intercoder agreement* (*or cross-checking*) which consist in relying on another person judgment to control the results (e.g. he can be the supervisor or a an industry expert)

Validity in quantitative research

Creswell (2003) reputes it is crucial to identify threats of the internal validity of the experiments. Threats may hide in the execution of the procedure, instruments or even experience of the researcher and lead to incomplete or incorrect inferences on the observed data. Additionally, recognising the threats can help to better shape the inferences avoiding generalisation of the outcomes beyond the observed experiment or studied group, increasing in this way the external validity.

4.4.3 Reliability

Reliability is linked to the repeatability of the results (Silverman 2010). As the word suggests a research has reliability if it is reliable, for example considering a research instrument, if data gathered with this tool are consistent, stable and predictable it means that the research from this aspect is reliable (Kumar 2005). The author states that it is not possible to have a research instrument which is 100% reliable, because the accuracy depends on a high number of uncontrollable variables that affects the collection of the data. Moreover, he speaks about external and internal consistency procedure to measure the reliability of an instrument. The former includes the split-half technique and the latter comprehends test/re-test and parallel forms of the same test.

<u>Reliability in qualitative research</u>

In order to guarantee external validity the most effective strategy is to provide thick and rich detailed description of the data gathering process and analysis executed in order to facilitate the comparison of the results (Creswell 2014). Moreover, Creswell (2014) states that reliability and generalizability plays a minor role in qualitative researches, because usually the aim is not the generalisation of the findings.

<u>Reliability in quantitative research</u>

Fellow and Liu (2003) argue that a theory can get generalizability if the experiments give similar results changing the context, subjects, techniques or procedures. Moreover, reliability in a quantitative context is more important than in a qualitative one since generalisation and enlargement of findings are more likely objectives of the study.

4.4.4 Triangulation

Triangulation encompasses the adoption of different research methods to conduct the same investigation (Fellows and Liu 2003). It consists in a comparison of different data sources in order to support evidences and draw coherent research findings (Creswell 2014).Triangulation procedures are naturally adopted in the mixed methods, since it helps to compensate weakness of a single research method, providing reliability to the whole data set and strengthen the validity of conclusion drawn (Silverman 2010). An example of triangulation can be the adoption of interviews and experiments on a cases study. This enables a quantitative and qualitative data gathering process for the same topic.

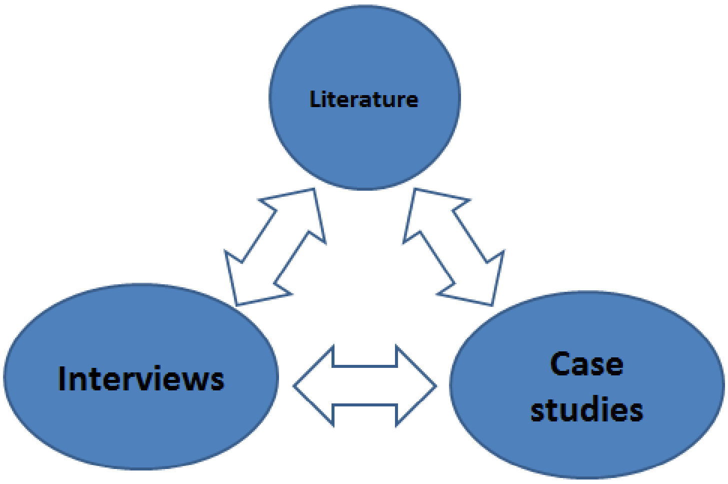


Figure 11 - Triangulation of evidence (Silverman 2010)

4.5 Adopted methodology

4.5.1 Research design and research methods

According to Kumar's (2005) classification of the research design approaches (see 4.1), the research undertook can be considered close to a non-experimental retrospective-prospective cross-sectional study design. The word "close" represents that our research cannot be integrally identified with the research design proposed, but has characteristics in common with the designs described by the author. The cross-sectional study design indicates that the study is taken in a certain period studying a certain phenomenon/situations. This represents our on-shot study designed to find the current prevalent factors affecting modularisation. It cannot be a before-and-after or longitudinal study because those concern in finding differences of a situation in two different points in time. According to the reference period this study is retrospective-prospective, since it studies the past trends of modularisation phenomenon, the evolution, the past drivers and constraints and studies the future adoption of the method. As regards the nature of the investigation our research is classified as non-experimental study since the difference between an experimental studies and a non-experimental one is that in the former the relationship between variables is studied starting from the cause to establish the consequences. In this case independent variables can be observed and controlled to influence the result. Instead in the latter the effects manifests themselves and causes already happened, so the only viable path is to start from the effects to trace the causes. This is what we did when conducting the research we asked the experts to provide reasons for the adoption of modularisation and reasons against it. Furthermore, based on the research objective the study can be classified as a mix of the four paths explained by Kumar 2005, (see 4.1). In the beginning of the endeavour we tried to systemically describe the modularisation construction method in the EC sector investigating advantages and disadvantages, as well as drivers and constraints of the practice. This was done prevalently with the study of the relevant existing body of knowledge on the topic and through the questionnaire sent to the industry experts. During the execution, the study took the form of a "correlational research" and "explanatory research", we figured out the factors affecting modularisation and we built reasonable correlations between these factors based on the information gathered interrogating industry experts. Associations between elements were investigated (see 5.4.2). The last part of the research can be considered "exploratory", since we tried to provide an as much as possible reasonable and reliable early decision support tool.

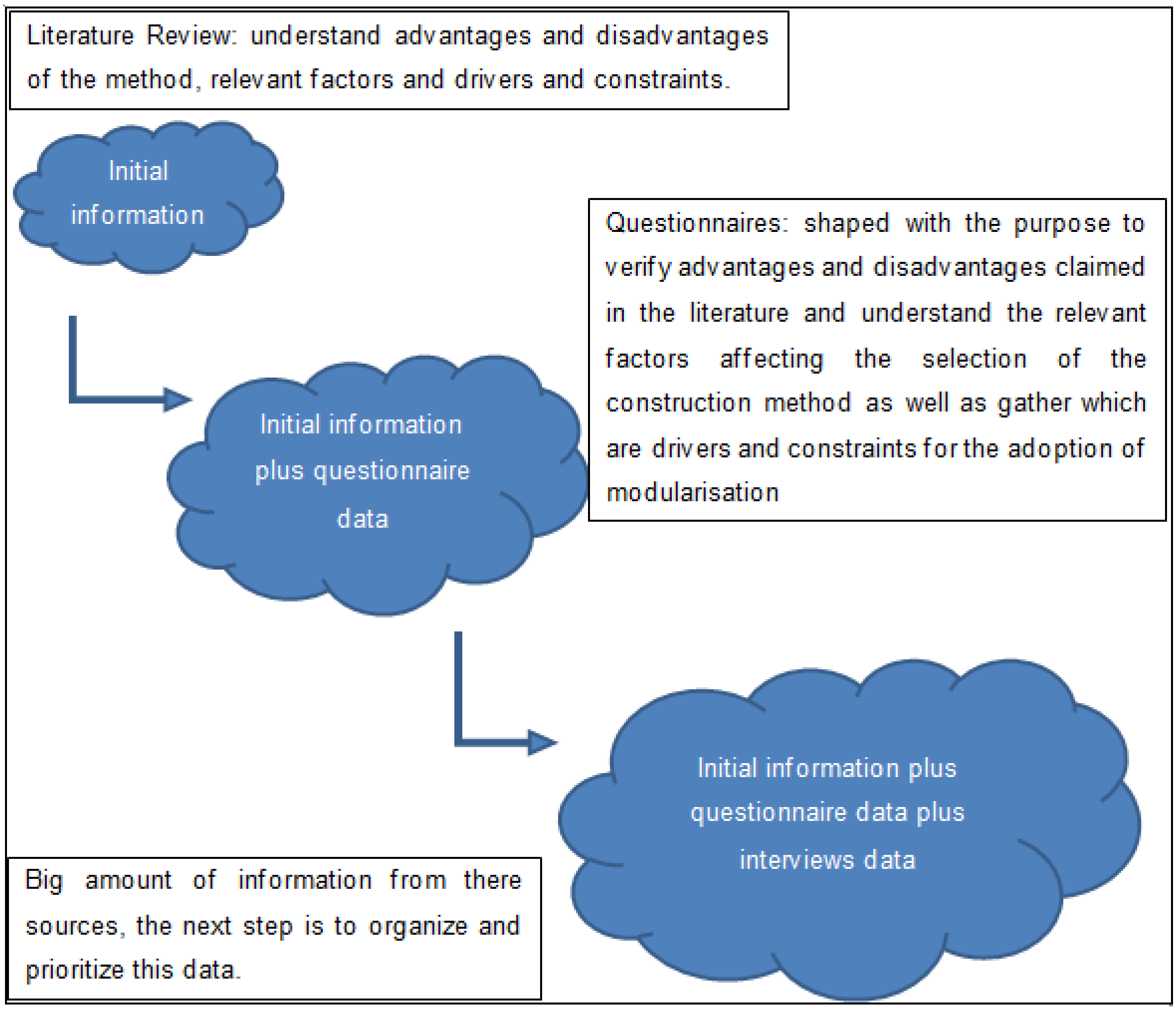


Figure 12 - research conceptual data gathering process

Having acquired a global view of the factors affecting the selection of the construction method and drivers and constraints of the adoption of modularisation, the research was narrowed selecting the group of relevant topics for further and deeper investigation.

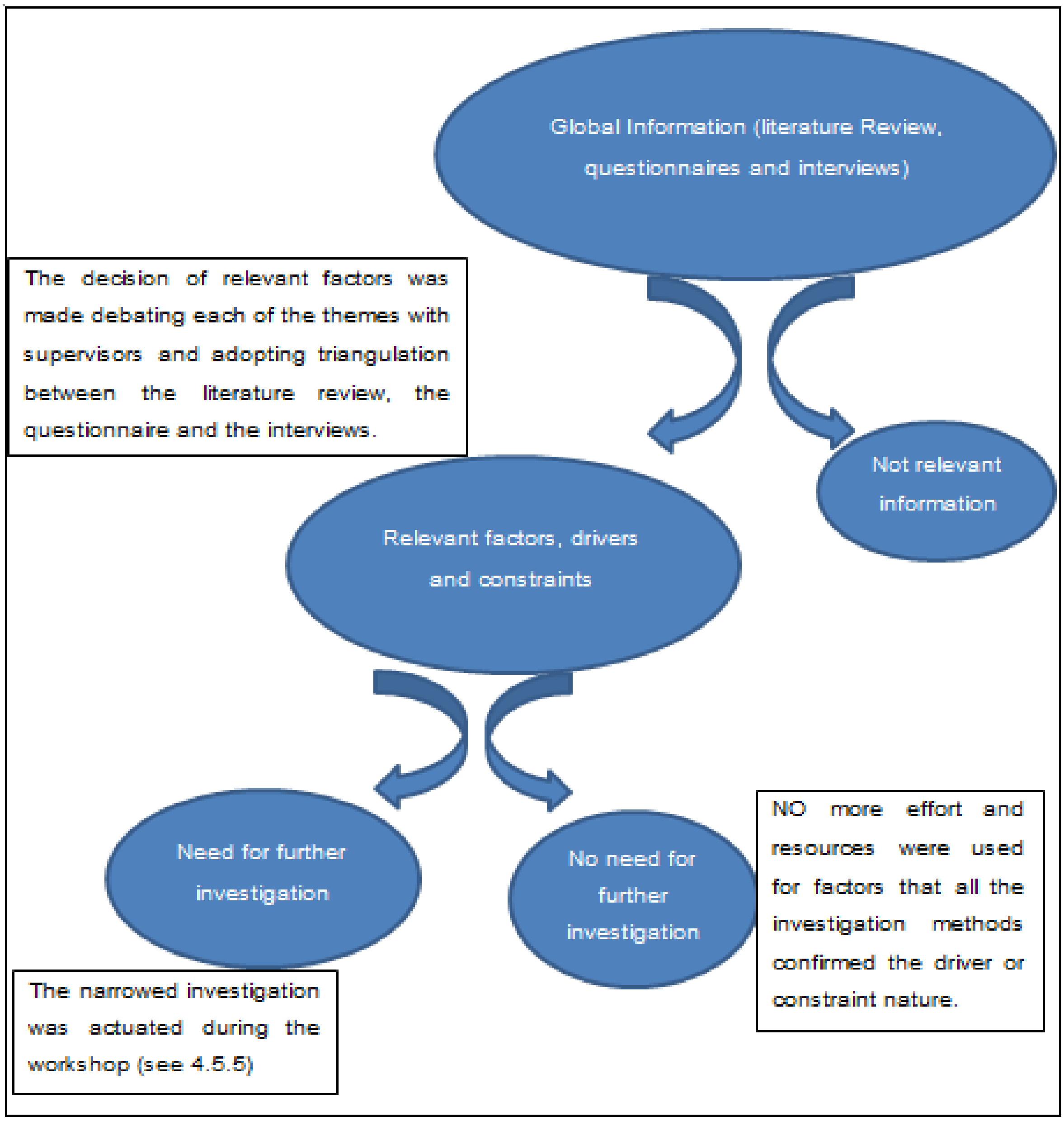


Figure 13 - research steps, narrowing process

In order to capture the best of both quantitative and qualitative approach a mixed method design was selected. Adopting only one of the two methods would have present constraint in giving constancy to the findings and worsen the robustness of the final tool. Moreover, it seemed the optimal choices due to the challenging research objective and high resources availability.

4.5.2 Literature review

In the first steps of the research we went throughout the existing body of knowledge, identifying the relevant publications and getting acquainted with the most relevant research. Considering that the research problem was clear since the beginning, the research was focused around the pertinent area of study. Initially a broadly research around the research question was executed, subsequently the investigation interested specific papers. The sources used to prepare the literature were journal articles and books, the former were accessible on the web databases and a considerable amount of the latter, were available on the University library. The initial investigation was realized searching in Google scholar and Loughborough University set of data bases. Since the purpose was to acquire general knowledge we used the following words or a combination of them:

- Modularisation
- Drivers and Constraints or hindrances/barriers
- Modular solutions
- Prefabrication
- Offsite construction or Offsite fabrication or Offsite production
- Preassembly
- Decision support tool
- Factors affecting modularisation
- Construction management
- Project management

During this first phase manly abstracts were analysed, this process aimed at reviewing in an efficient manner the publications, balancing time and number of paper reviewed. After the initial investigation the search was focused on specific papers: during this phase we progressively moved towards Loughborough University set of databases and internal catalogue gradually abandoning Google scholar since it seemed too wide and not as specific as the single databases. The list of the data bases mostly used is:

- Civil Engineering Abstracts
- ARCOM (Association of Researchers in Construction Management)
- Construction Management abstracts
- Loughborough university catalogue plus
- Scopus
- Web of Science

In order to manage and organize the documents retrieved, Mendeley software was used. Mendeley is an application that supports the investigation of references, facilitates the annotation on pdf files and helps to automatically format the citations. The specific investigation of the literature review was realized evaluating the pointing index. After having a considerable amount of pertinent papers an assessment and classification of articles highly cited by the documents already available was performed. Then the research was actuated on those articles that had a higher pointing index. The starting point was represented to the combination of words above described. It was thought to assign a relative weight even to the “pointing” document, attributing more value to the most relevant documents, but the decision to keep it standard prevailed, because of both increasing complexity and lack of exhaustive evaluation of all the existing literature on the research area. It is worth to mention that some of the relevant papers were advised by the supervisors. The pointing index process and a practical example are represented below:

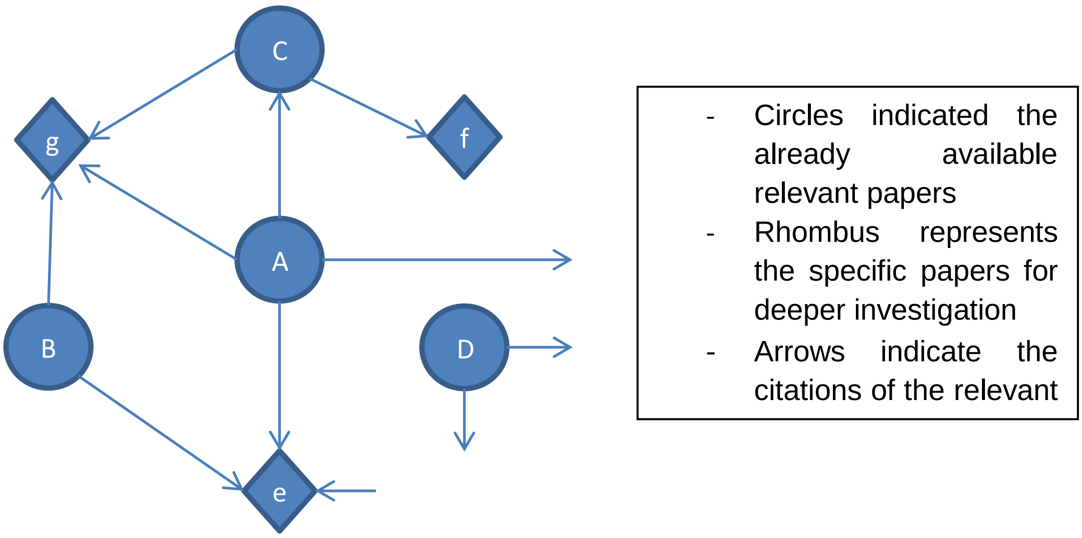


Figure 14 – pointing index process

This example explains the logic used to further investigate papers pointed (cited) by the relevant publication. The paper “g” and “e” are pointed three times which in this system is a high number, instead “f” is only pointed one time. For example, only the two more cited documents can be investigated omitting the third. With this in mind, the logic followed in the research was to investigate only the publications with the higher pointing index. This process continued until interviews started to be conducted. It is worth to point out that due to the high number of papers analysed in the initial investigation only the publications receiving more than two or three paintings was took in consideration, and most of the paper cited only ones was not studied. An explicative example of a paper exanimated due to the high number of pointing index is the Egan's pamphlet: *"Rethinking construction"* published in 1998.

4.5.3 Web-based questionnaire

The questionnaire was designed using the application provided by BOS (Bristol Online Survey). This led to an easier creation of the questionnaire since standard formats of questions were available. Moreover it was easier to send the questionnaire to respondents, organize, collect answers and process data after the completion. The questionnaire was sent to 33 individuals, of which 12 was part of the Modularisation Task Force, more generally all of them had prior contacts with ECI (Loughborough university organisation). Out of the 33 questionnaires 18 was completed with a response rate of 55%. Fellows and Liu (2003) state that the average response rate in case of random questionnaire is around 20%. The research questionnaire was not sent randomly but directly to specific person, in fact the percentage of returned questionnaires is quite high. All 12 Task Force members completed it and they were lately contacted for the interviews (see 4.5.4). Out of the 18 questionnaires returned three was partially completed. We considered valid all the returned questionnaires since the investigation was designed in separated macro blocks of queries: the lack of completion of one part did not affect the responses of the others (e.g. one of the respondents not having the managerial visibility on client needs did not answer the questions related to the client drivers, but his technical judgments and project characteristics evaluation was valuable). According to Kumar (2005) a questionnaire can be administrated in different ways: the mailed questionnaire was selected. Having access to respondents emails a personal message was sent, inviting the experts to complete the questionnaire following the link of Task Force Modularisation Survey on BOS (see Appendix A – web-based questionnaire) .

4.5.3.1 Questionnaire design

Being a researcher for Loughborough University empowered to adopt all the features of the online software (licence acquired). This results in a cleaner and simpler questionnaire creation with a lean graphic structure due to the matrixes and answer tables.

The questionnaire design benefitted from all the advantages of a web-based questionnaire claimed by Denscombe (2014):

- Templates: utilisation of a range of available design
- Appearance: customisation of the font, background and layout

- Logos: introduction of the University logo and evaluation of the possibility to insert the ECI one.
- Response option: introduction of a limited number of initial mandatory demographic questions.
- Progress bar: useful to show to the respondents the state of progress of the questionnaire
- Identifier: possibility to trace uniquely the address of the respondent, this was particularly useful to follow up respondents having their questionnaire answers during the interview phase.

The questionnaire was designed in five parts, of which three main sections (1, 2, and 3):

- Aim of the survey
- First section: general questions
- Second section: benefits and drawbacks
- Third section : factors affecting modularisation
- Final section: contact details, anonymity and thanksgiving

The aim was a rational and lean progress of the questionnaire, avoiding open questions (only closed-ended questions). This was done to reduce the fatigue of completion and increase the response rate. For example factors affecting the adoption of modularisation (35), they were divided in three groups: client requirements, project characteristics, project management factors.

4.5.3.2 Research sampling

The sampling process of the research was influenced by the ECI availability of experts. There were a range of heterogeneous group of people covering a broad range of managerial role and competences in the EC sector. These individuals were selected for the questionnaire submission and interviews conduction.

The graph below represents the organization roles covered in the questionnaire (a more detailed presentation of the configuration of respondents is available in 5.1.1):

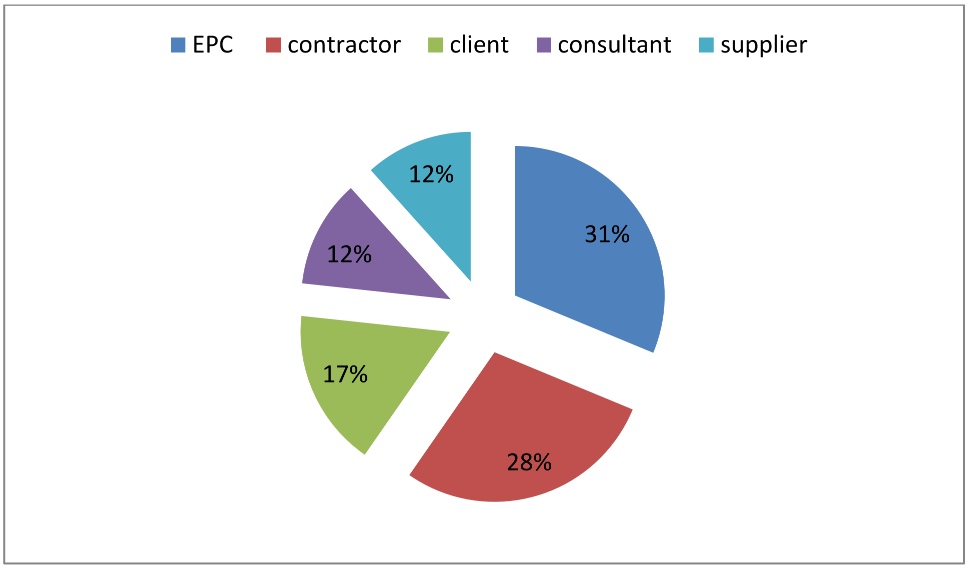


Figure 15 - population of the 35 sent questionnaire

4.5.4 Interviews

The invitation for an in-depth interview was sent to all of the 18 participants that returned the questionnaire, and 13 of them accepted to participate to it. All of them except one gave the permission to be recorded. The interviews were conducted by telephone since the studied population was scattered over different countries. In this way we also retained time and resources for the data collection process. The duration of the interviews ranged from 30 minutes to one hour and 15 minutes, with an average duration of 45 minutes.

The experts that accepted to participate to interviews were represented as follow:

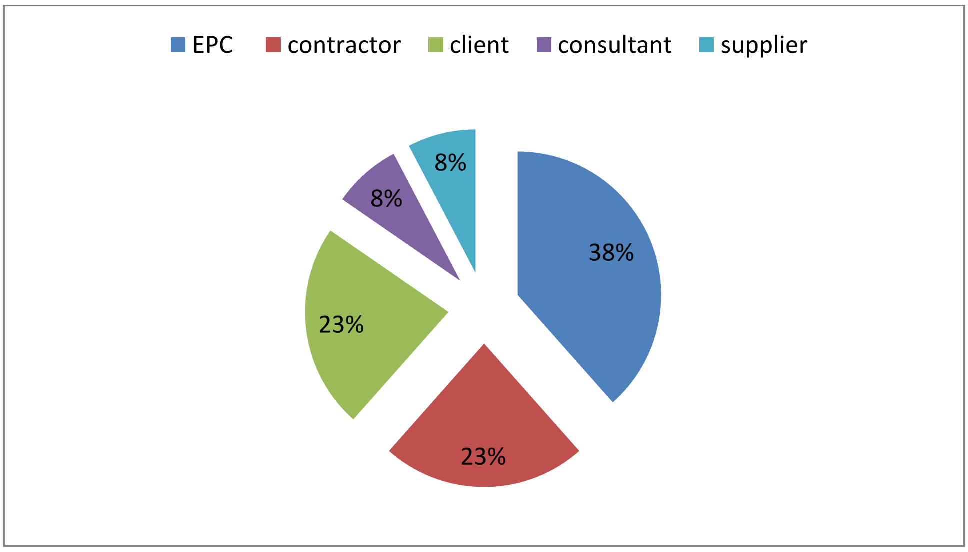


Figure 16 - composition of the interview population

4.5.4.1 Interview design

A semi-structured structure was adopted (see Appendix B). The structured part was organized in three parts, the first one concerning discussion of the overall results (a first analysis was sent to all participants) and clarifications or further explanations of the questionnaire responses; this section was useful to resolve some ambiguous views. In case of contrasting testimony between questionnaires and interviews, the interview judgment had priority.

The first part was customized for each of the interviewee. The second part concerned the definition of the three most important drivers and constraints for the adoption of modularization. The last part concerned personal evaluation on the sustainable trend, the state of the art in innovation and hi-tech solution and a final forecast of the future adoption of modularisation. All of the questions were asked in an open-ended format in order to boost personal comments and promote real working experiences.

For a good outcome, the establishment of a confidential interaction between the researcher and the interviewee was crucial. The process was boosted by the fact that the members had prior contacts with ECI or even was member of the Modularisation Task Force. This turned out in informal conversation and wider personal judgment: for example, one of the interviewee provided some information on the mechanisms of interaction between EPC and small contractors, another one described in detail a wrong risk allocation practice frequently adopted by the companies.

The unstructured part changed every time, it was the result of the interaction between the parties involved in the interview; Kumar (2005) states that the quality of the interview depends on the quality of the interaction. Surely the ability of the researcher increased over the interviews becoming more effective to drive the conversation in hidden areas and disclose a higher quantity of interesting data.

The quality of the interviews was affected by the following factors.

- It was worsen by the fact that the researcher was not English mother tongue
- It was improved by the prior data analysis (and presentation of them to the interview) of the prior questionnaire
- It was facilitate by the semi-structured structure.

4.5.5 Conference data collection

This data gathering process was divided in three parts:

1. EC Task Force Meeting
2. Plenary section questionnaire
3. Modularisation Workshop

Through three iterations of a similar Delphi method the research was narrowed on the topics of interest. Initially the questionnaire was sent to ECI Task Force members and other industry experts in modularisation (see 4.5.3). Analysing the results, out of the 33 characteristics treated in the questionnaire, the ten most critical characteristics to consider when evaluating the adoption of modularisation were identified. In the ECI Modularisation Task force meeting, we asked to Task Force members (experts of modularisation) to indicate the six most important factors out of the ten proposed. Successively in the workshop participants were asked to judge and discuss the significance and novelty of each of the most important factors previously chosen. According to Hanafin (2004) the typical Delphi method is characterised by the following features:

- Anonymity
- Iteration
- Controlled feedback
- Statically control
- Participants are experts and gives pinions to arrive to a stable response

The author states that over the years the method has been modified and adapted on the needs, and in the paper different types are proposed (e.g. Classical Delphi, Policy Delphi and Decision Delphi)

In our version almost every one of the five main characteristics are respected; the only difference with the traditional Delphi is in the iteration procedure and the concept of anonymity, from the meeting to the plenary section the number and the type of participants changed. Moreover during the workshop the data collection has been implemented through a focus group, which might have led to bias and influence in comments and opinions.

4.5.5.1 ECI Task Force Meeting

In the first part of the meeting experts had the opportunity to critically comment on results of the research presented and give their opinions. Below the quantitative analysis of the selection of the six topics out of the ten proposed is presented.

Table 7 – characteristics ranking

CLIENT AND PROJECT CHARACTERISTICS	resp A	resp B	resp C	resp D	resp E	tot. score
Reduction of workers' exposure to onsite conditions	4	3	2	6	2	17
Maximise sustainability (during construction and the whole life cycle of the plant)	1	2		4		7
Level of predictability and certainty achievable (schedule, cost, risk reduction...)	6	6	6	1	6	25
Location/Position of the site (weather conditions, distance from sea/rivers, closness to big cities)	5	5	5	3	4	22
Condition of the site (type of ground, closness to living environment, space availability)		1		5	5	11
Political and socio-economic situation in the site area		4	4		3	11
Experience of the industry players (Clients, EPC, Contractors, Suppliers) to deal with modularisation	3		3		1	7
Geographical distribution of suppliers and reliability			1	2		3
Particular testing and/or maintenace practices and waste material managment required						0
Type of coordination/communication and IT systems to adopt in the realisation of a modular project	2					2

The total score was simply obtained summing all significance scores provided by the respondents for each of the ranked characteristics. Since the questions asked to rank the factors, the first factor indicated received 6 point, the second received 5 and so on, for example the number 4 next to the first characteristic indicate that the respondent A, ranked third this characteristic in term of significance in considering the adoption of modularisation. When the total score was the same we selected the characteristic that we needed to understand more.

4.5.5.2 Plenary section questionnaire

The questionnaire was ideated to be completed in few minutes. It was divided in two parts: the first one characterised by the demographic questions, (the same general questions appearing in the web-based questionnaire). The second part included two questions: the first one asked to rank the drivers affecting the selection of modularisation and the second one the hindrances. Both questions had few options to choose from, these options were the most significant one individuated during the previous parts of the research. The integral version of the plenary section questionnaire is available on the Appendix B. The total number of the participants to the conference was around 70, we collected 46 questionnaires with a response rate of 65%. This percentage is quite high; part of the merit relies on the speed of completion. The experience maturated with the first questionnaire was useful to shape the plenary section one avoiding imprecisions and possible ambiguities.

4.5.5.3 Modularisation Workshop

28 industry experts attended the workshop, roughly half of the conference participants. The workshop was divided in two sections: in the first one, attendants were asked to vote with clickers the significance and the novelty of the topic selected the precedent day.
Then, in the second section, six contemporary focus groups were organized. They lasted one hour in total. Participants were divided in small groups of 5/6 people to explore, share ideas and opinions on a specific topic. This number allowed an easy circulation of ideas without being a constraint. According to Denscombe (2014) focused groups have to be characterised by:

- Focus on a certain topic
- Participants have similar knowledge
- Participants share their thoughts and experiences
- The conversation has to be facilitated rather than led
- Attention on the group dynamics and interaction

Participants were divided in 6 groups of 5 or 6 people. Each of the groups had to comment one on the topics, discussing whether they were drivers or constraints for the adoption of modularisation and in which extent. The discussions were organized dividing the six topics in two groups the first three topics, those with higher value (see Table 7 – characteristics ranking) were treated first. Basically two groups discussed the first topic (e.g. we assigned to the group 1 and 2 the topic: Level of predictability and certainty achievable) two the second and the last two the third. Successively the same procedure was applied with the other three topics (those underlined in yellow in the above table). This was done in order to have at least two groups discussing a topic; this made comparisons feasible and generated exhaustive data. Participants were asked also to write down the main themes treated and the conversations were recorded (see Appendix E – ECI workshop).

4.5.6 Consistency of the data

The aim at the very beginning of the research was to implement a rigorous research methodology, limiting to the minimum the bias and error sources. To do so, an accurate data gathering process was established. As suggested by Creswell (2008), the adoption of the following strategies were used to check the accuracy of the findings:

1. Data gathered were triangulated determining the spread evidence over the collected methods used. This circulating procedure, since it involved progressively the researcher and all the supervisors, (those in UK and in Italy) was useful to build a coherent justification for the findings.
2. Continuous exchange of opinions and ideas with the supervisors. The supervisors checked each step of the research driving the focus on the relevant targeted area. For example, having more experience on the field, supervisors were useful to comprehend the nature of some ambiguous experts' declarations during the interviews.
3. A member-checking technique between the questionnaire and interview phase was used, in fact an overall analysis of the questionnaire was sent to participants and discussed during the first part of the interview.
4. A rich and thick explanation of the findings was adopted, describing in details all the inferences and sometimes literally citing testimony gathered.

The adoption of a mixed method approach enabled the usage of triangulation technique between the different steps of the research to boost the validity of the findings.

Triangulation was used after the interviews and on the occasion of the ECI conference. In both circumstances the actors involved was the literature review a quantitative data collection method and a qualitative one.

Below the triangulations are represented:

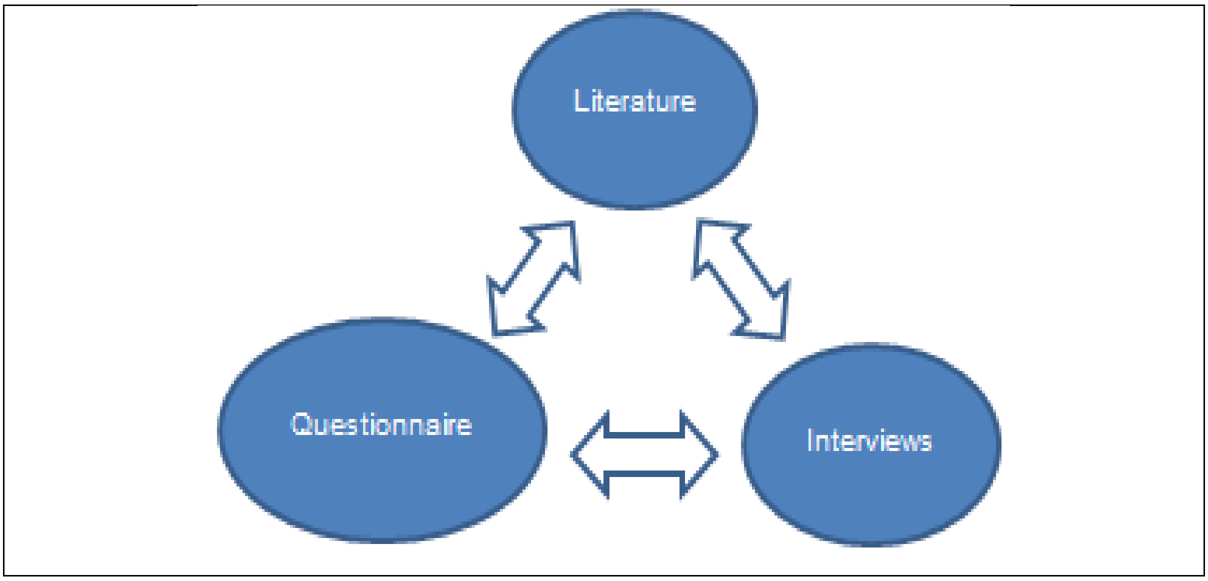


Figure 17 - Triangulation of the findings (web-based questionnaire, interviews and literature)

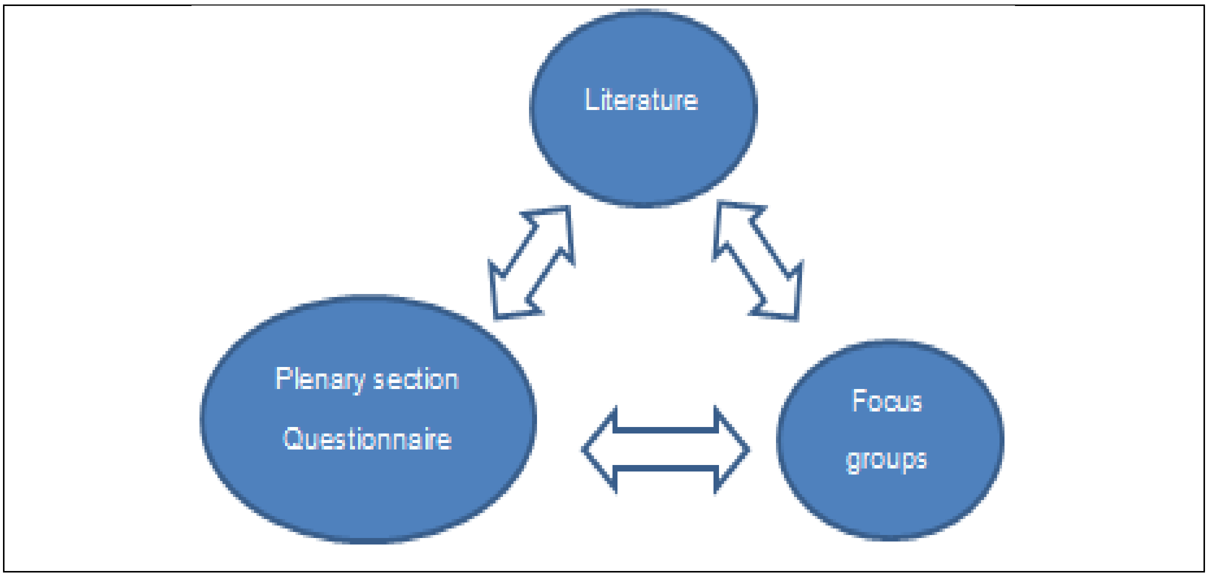


Figure 18 - Triangulation of the findings (plenary section questionnaire, focus groups and literature)

5 Findings and discussion

5.1 Web-based questionnaire data analysis

5.1.1 Section one: general questions

The web application BOS was useful both to develop the questionnaire and process the data.

The answers of the demographic questions are below represented:

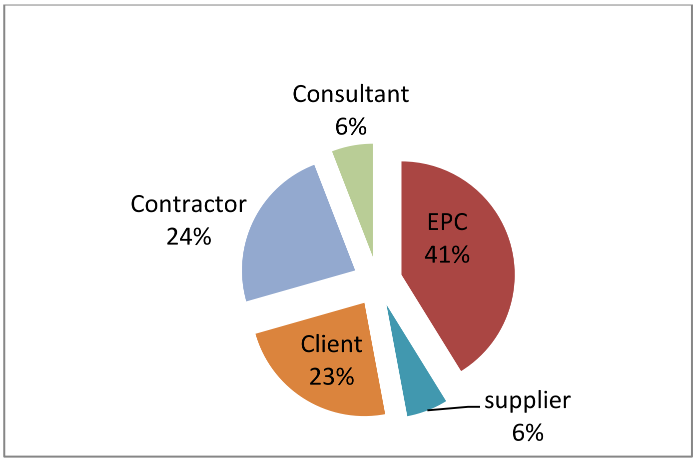


Figure 19 - general questions: organisation role

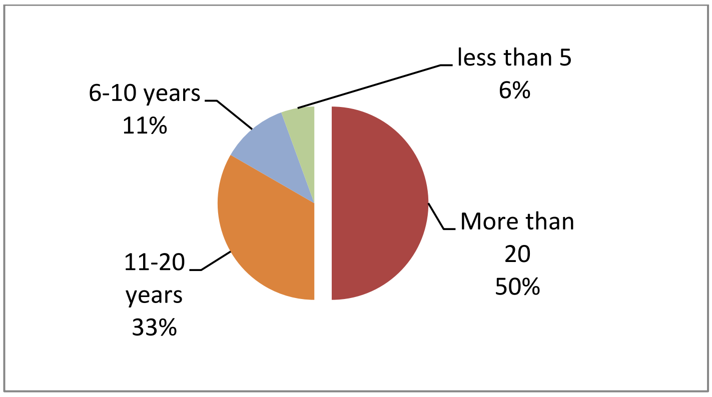


Figure 20 - general questions: years of industrial experience

The range of the roles and years of expertise is quite spread, so it is possible to say that the respondents fairly represents the market. Notice that it is positive to have a higher number of EPC, clients and contractors because these figures are more involved in the decision process project execution.

5.1.2 Second section

After the answers were received they were downloaded directly from the online software into the excel spread sheet. Looking at the questionnaire (see Appendix A) it is easy to notice that the answers are in a text format (always, often, never etc.), this was done to facilitate the completion of the questionnaire. Unfortunately text is not conductive to easily execute the data analysis, so in the spread sheet it has been converted in a numeric value. The answers were qualitatively converted in the following values:

Table 8 – benefits/drawbacks answer's text conversion

answer	conversion
Never	0
Sometimes	3
Often	6
Always	9

The Figure 22 shows the comparison between EC sector expert judgements and literature review data. It was realized simply comparing the average of the judgments of the experts in the questionnaire and the estimated occurrence of the advantages expressed in the literature (see Table 1and Table 2).

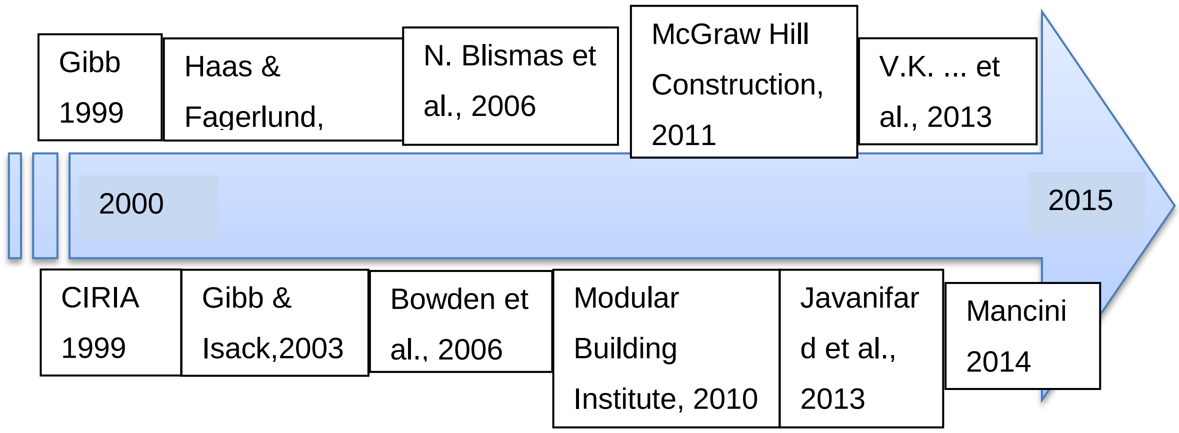


Figure 21 – time line of the references

As the time table shows, a heterogeneous group of references was collected; in this way a representative view of the advantages and disadvantages of the method was obtained. This was done to facilitate the comparison of results between the two sources of data.

It is worth to point out that the literature values were qualitatively estimated reviewing many documents in different points in time, but they might be incomplete or not exhaustively representative, since a systemic review was not carried out.

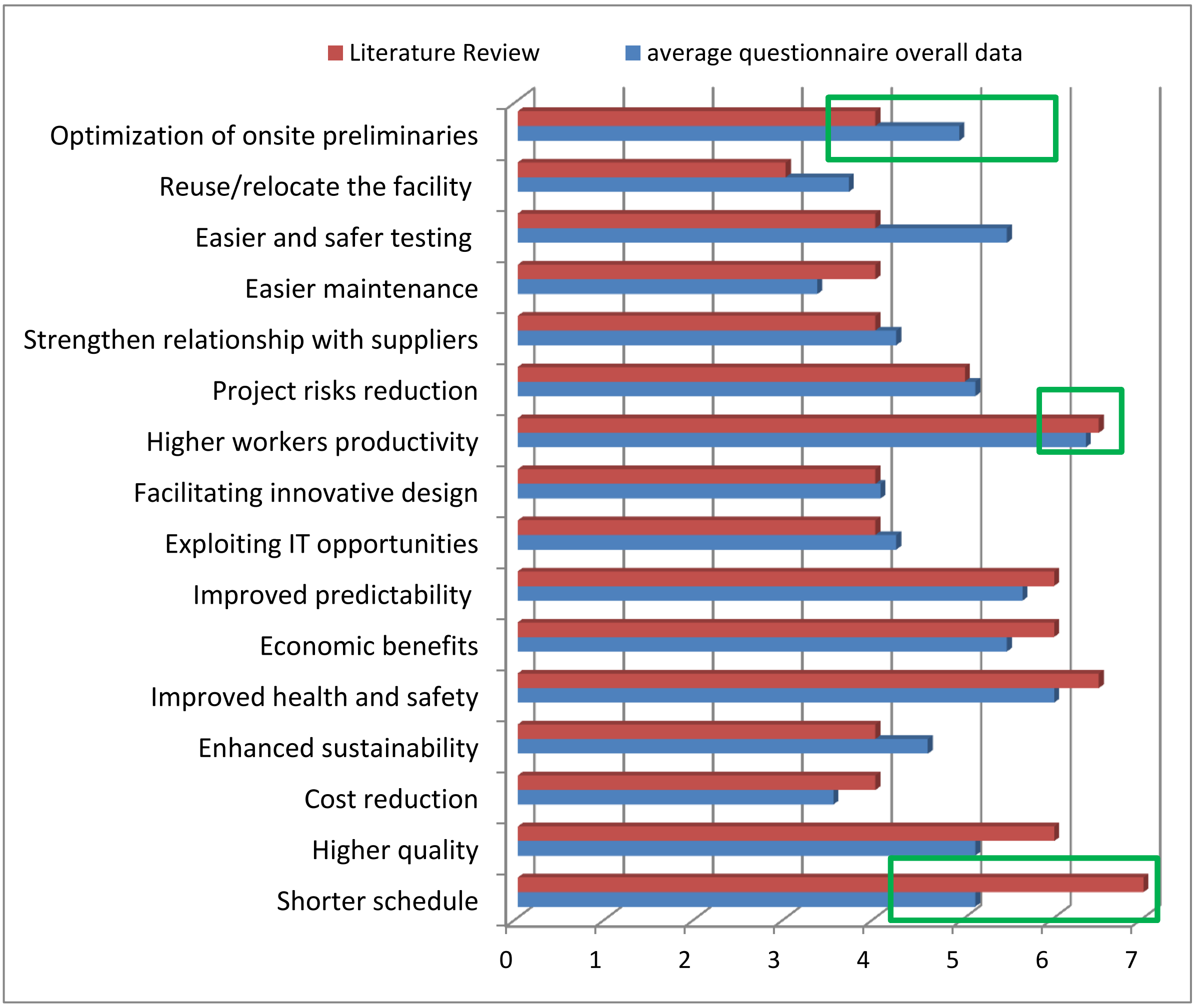


Figure 22 – questionnaire and literature, comparison on modularisation benefits

It is evident a matching between the advantages claimed in the literature and the experts opinions. The green boxes indicate interesting results. The shorter schedule was not pointed as the first benefit of adopting modularisation; the gap with the literature underlines this information. The first benefit is the “higher workers’ productivity”. “Easier and safer testing“ was valued more than in the literature, this is probably due to the nature of the EC sector.

The Figure 23 shows a comparison of the disadvantages.

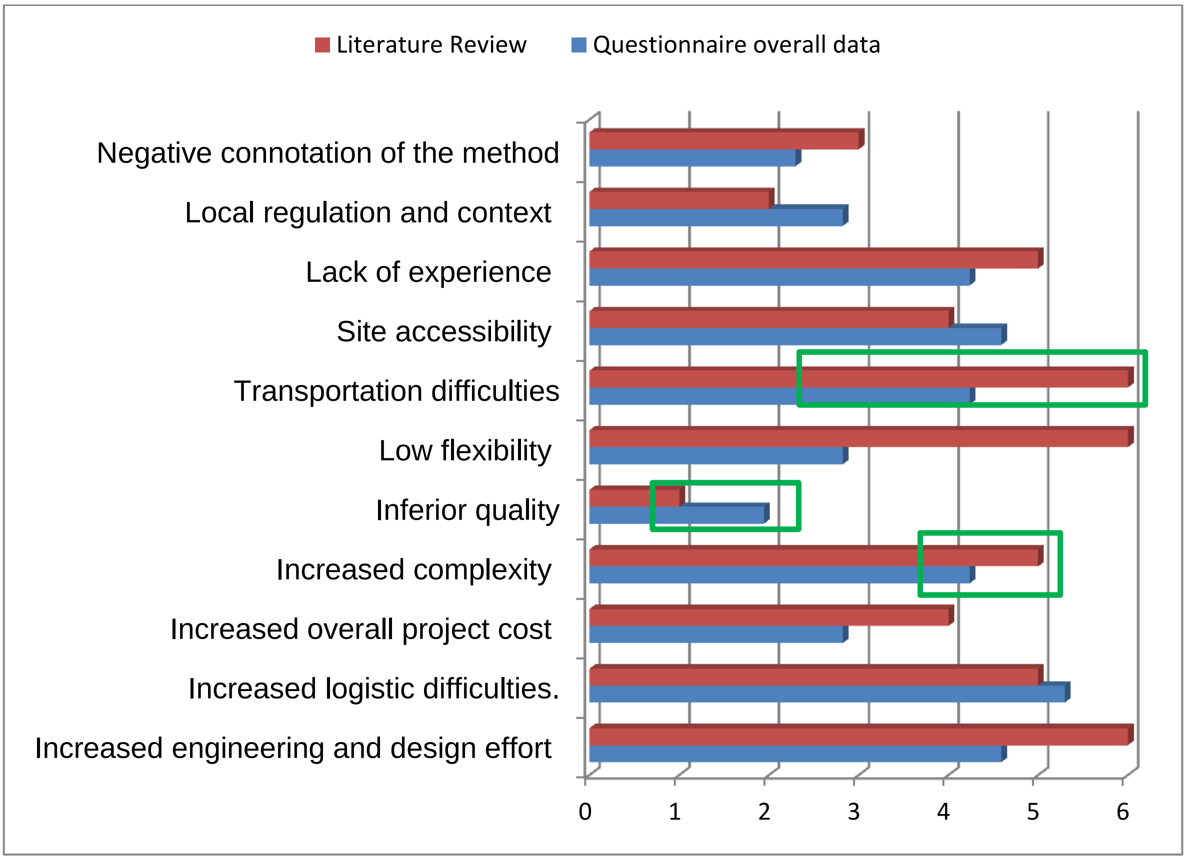


Figure 23 - questionnaire and literature, comparison on modularisation drawbacks

The graph denounces a higher gap between the literature and the questionnaire data. First of all the “low flexibility” of the method is not perceived as disadvantage with the same intensity that it is perceived in the literature data. This is reasonably due to the fact that in the EC sector the concern for wider design solutions covers a marginal role in the selection of the construction method. As regards the inferior quality, it was rarely mention as a drawback of the method in the literature, but questionnaire data reveals that sometimes modularisation quality is not appropriate. Moreover the higher disadvantage is deemed to be the “increased logistic effort”, instead of the more claimed “increased engineering and design effort”. All evidences will be double checked during the interview section in order to draw a clearer picture of the experts’ opinions.

5.1.3 Third section

In order to analyse the data of the second section of the questionnaire a similar conversion was adopted:

Table 9 – drivers/hindrances answer's text conversion

answer	conversion
Strong hindrance	-9
Weak hindrance	-3
Indifferent	0
Weak driver	+3
Strong driver	+9

The metric was chosen to emphasize the strong positive or negative influence of experts' opinions, in fact only in few circumstances, really significant, the judgements were strongly positive or negative. This section concerns in finding the drivers that pushes towards the use of modularisation and constraints that blocks its adoption. All the 35 factors individuate in the literature, affecting the adoption of modularisation, was divided in three main categories:

- Client requirements factors
- Site requirements factors
- Project management factors

The results are presented showing the overall average of the responses and the average of the clients, EPC and contractors and others (one supplier and one consultant) judgments. Moreover, a presentation of the results based on the years of experience of the respondents is presented.

The following couple of graphs shows the experts evaluation in terms of client requirements factors:

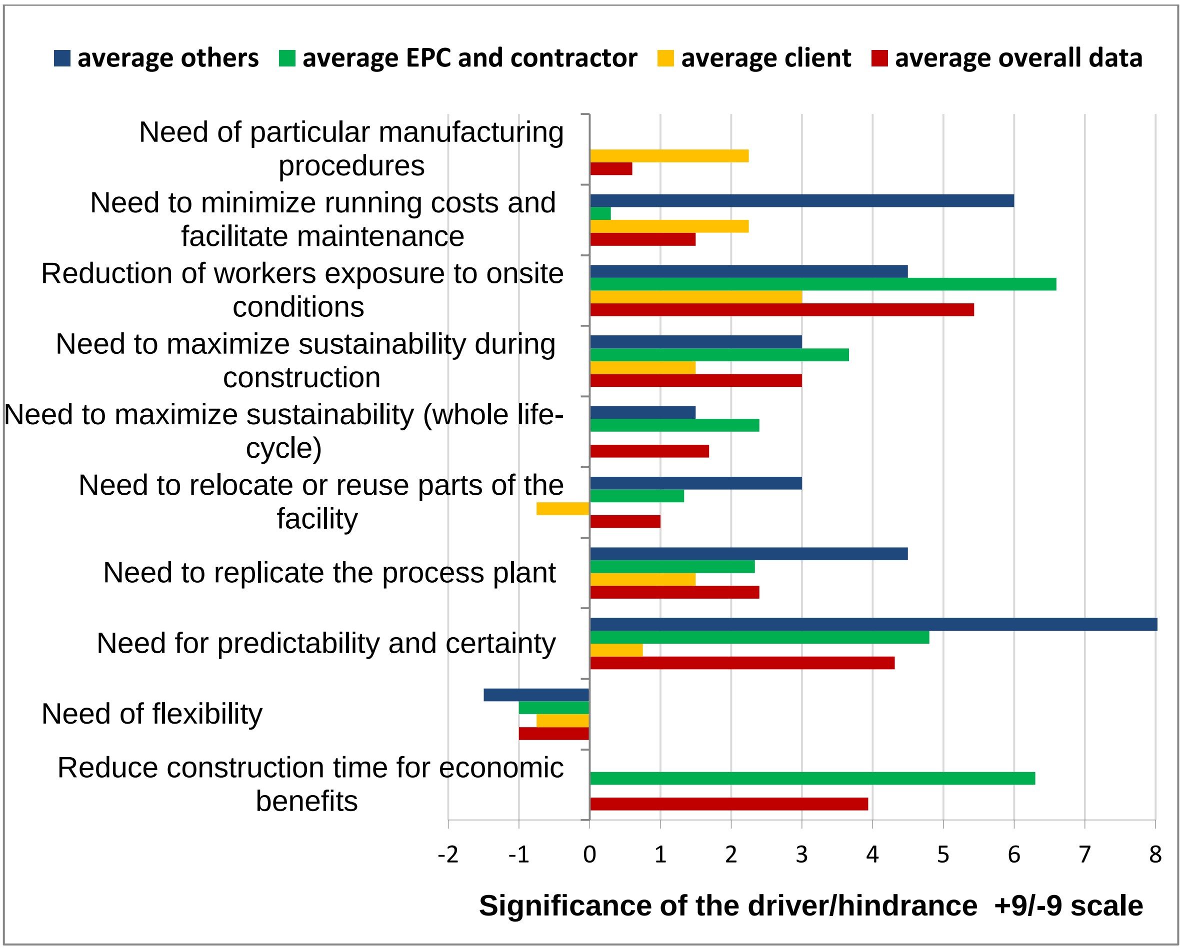


Figure 24 - Client requirements factors, respondents' comparison

The clearer picture of the factors is provided by the overall average, for example the line related to "others" judgement, is the result of the average of only two evaluations; this means that carefulness has to be taken to deem factors as strong drivers. Most of the above requirements are catalogued as drivers from the participants, but It is evident that clients are more reluctant than other experts to attribute a high significance, (see yellow line) they even deem some factors as hindrances when recognized drivers by the majority (e.g. "Need to relocate of reuse parts of the facility"). About the sustainability maximisation need, it is deemed a driver by most of the respondents. Conversely clients don't recognize the higher sustainability opportunities achievable with modularisation. This is probably due to a lack of information; the factor will be further investigated in the interview section. In many factors the EPC and contractors provide positive evaluation about factors, with the "green" that is above the red one. This suggests an impulse given to modularisation by the EPC experts interviewed: this phenomenon can be the results of various reasons that will be investigate in the interviews. Another interesting result from the graph is the difference of opinions concerning the “reduction of construction time to achieve economic benefits”; it seems that clients don’t consider this factor a driver. Further investigation is needed.

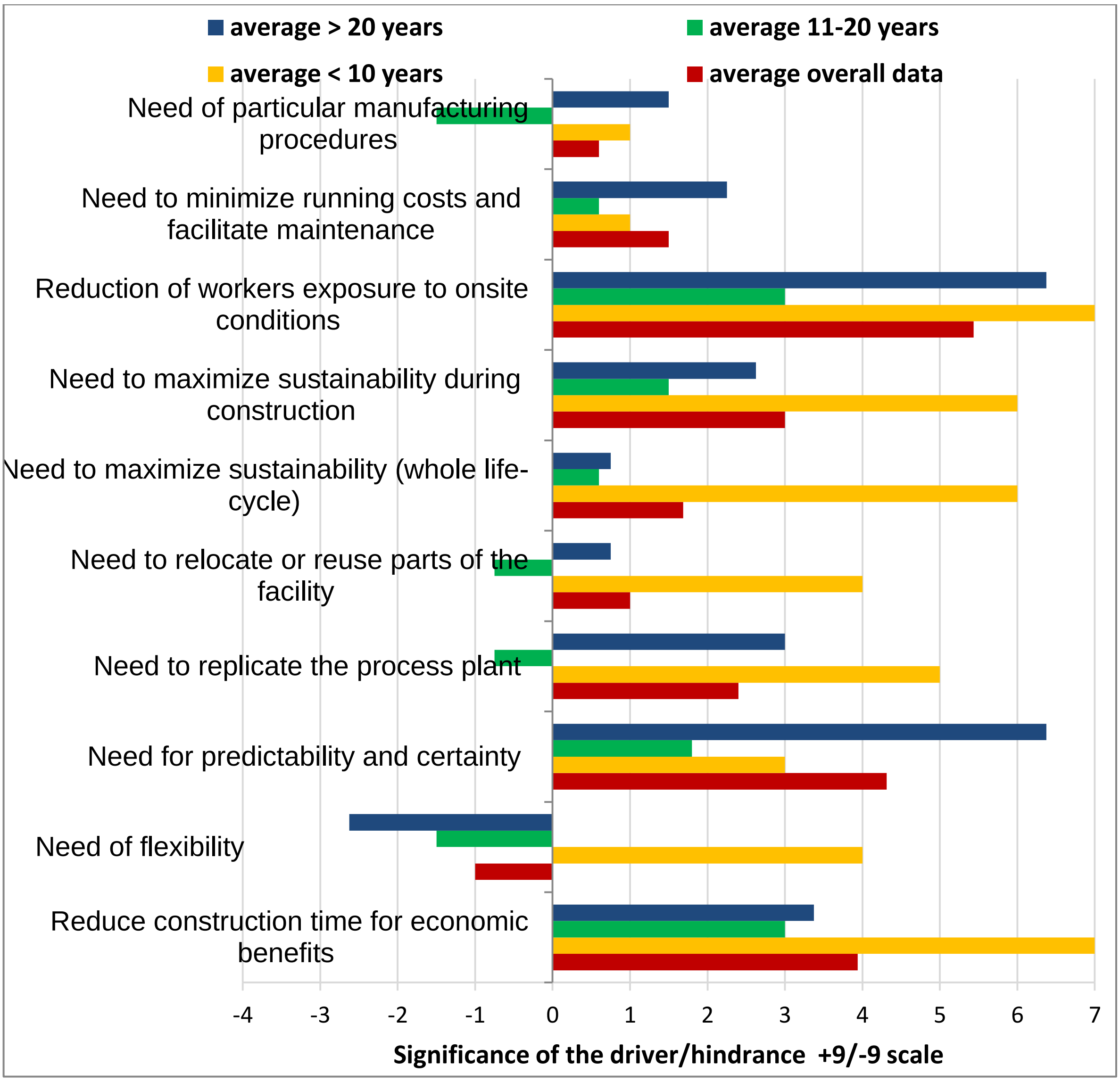


Figure 25 - Client requirements factors, years of experience comparison

Respondents with higher experience (>20 years) tend to be more conservative in their drivers and constraints. Moreover the “older” respondents attributed to the “need of flexibility” a higher level of hindrance: this result can be explained either considering the higher visibility and competences in the industry or by the prejudicial idea of general low flexibility of modularisation, in particular this second one could be related to the reluctance of the industry to embrace changes and adopt new technologies claimed in the next graph. Conversely the less experienced experts gives high value to drivers of modularisation, they think that the lack of flexibility could be a driver for the method, the nature of this factor will be investigate during interviews. As regards the 11-20 years of experience respondents, their evaluations lay often in the middle. This is perfectly reasonable due to their intermediate position between the two extremes. An interesting data is the evaluation of three factors that only this category of experts deemed a constraint for the adoption of modularisation: Need to replicate the process plan, reuse the facility and need of particular manufacturing procedures. An investigation of their experiences will be carried out during the interviews to shed lights on the singularity.

The following couple of graphs shows the experts evaluation in terms of site requirements factors:

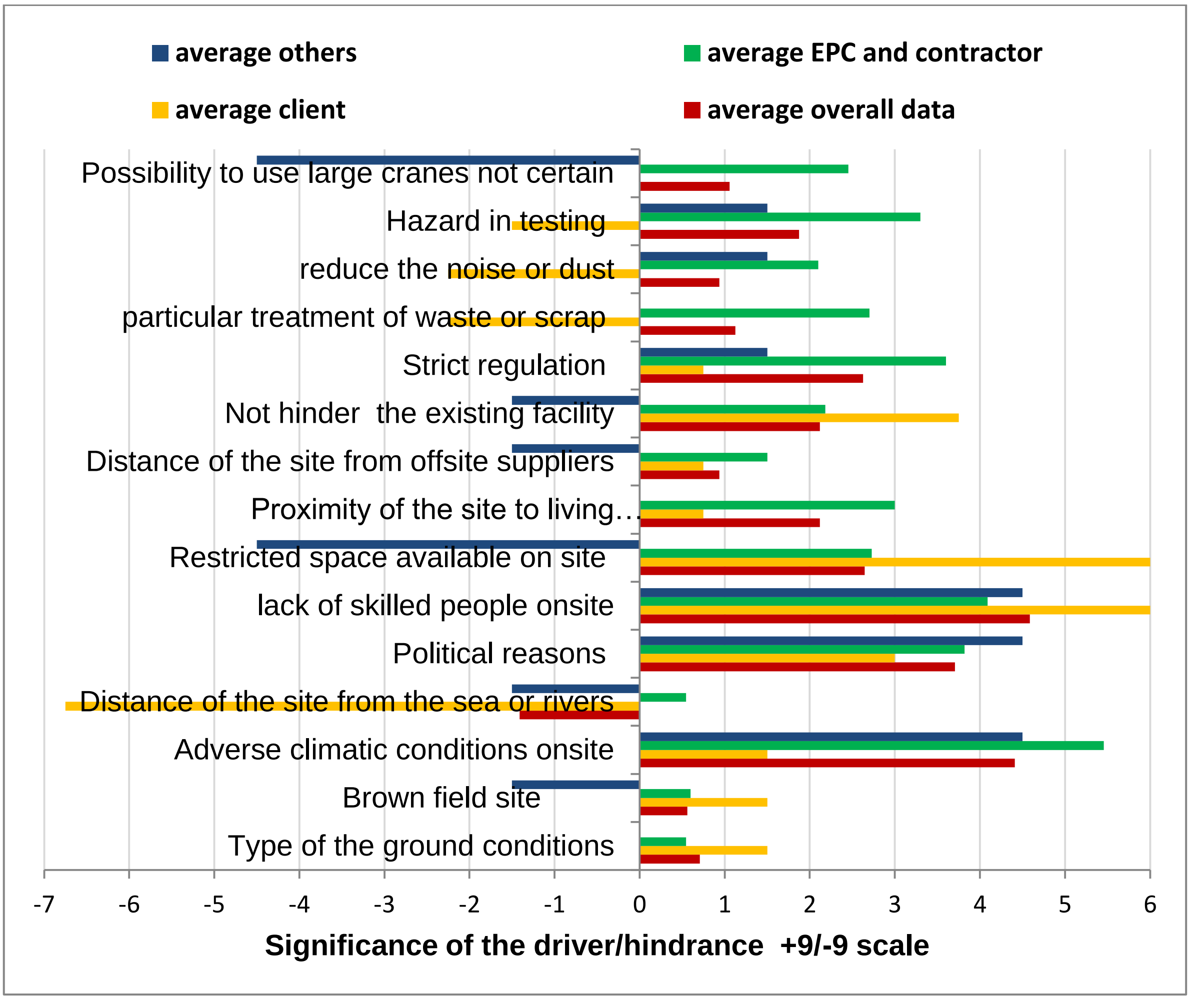


Figure 26 - site requirement factors, respondents' comparison

Overall the experts recognized more drivers than hindrances; this is due to the fact that some questions are set in modularisation terms (e.g. lack of skilled people onsite, instead of availability of skilled workers onsite). In this graph there is a higher divergence of opinions than in the precedent graph. In some questions the answers range from strong hindrance to strong driver, although this might be done to conflicting assessments it can be also the result of not clear questions or experts' understanding or even limited competences and visibility of the questionnaire participants. Moreover, in three factors "clients" opinion is the opposite of the average evaluation and in five circumstances the "others" evaluation is conflicting with the overall results. These inferences will be further investigated in the interviews to have a definitive view, because the site characteristics seems to be crucial to comprehend which features leads to selection of modularisation.

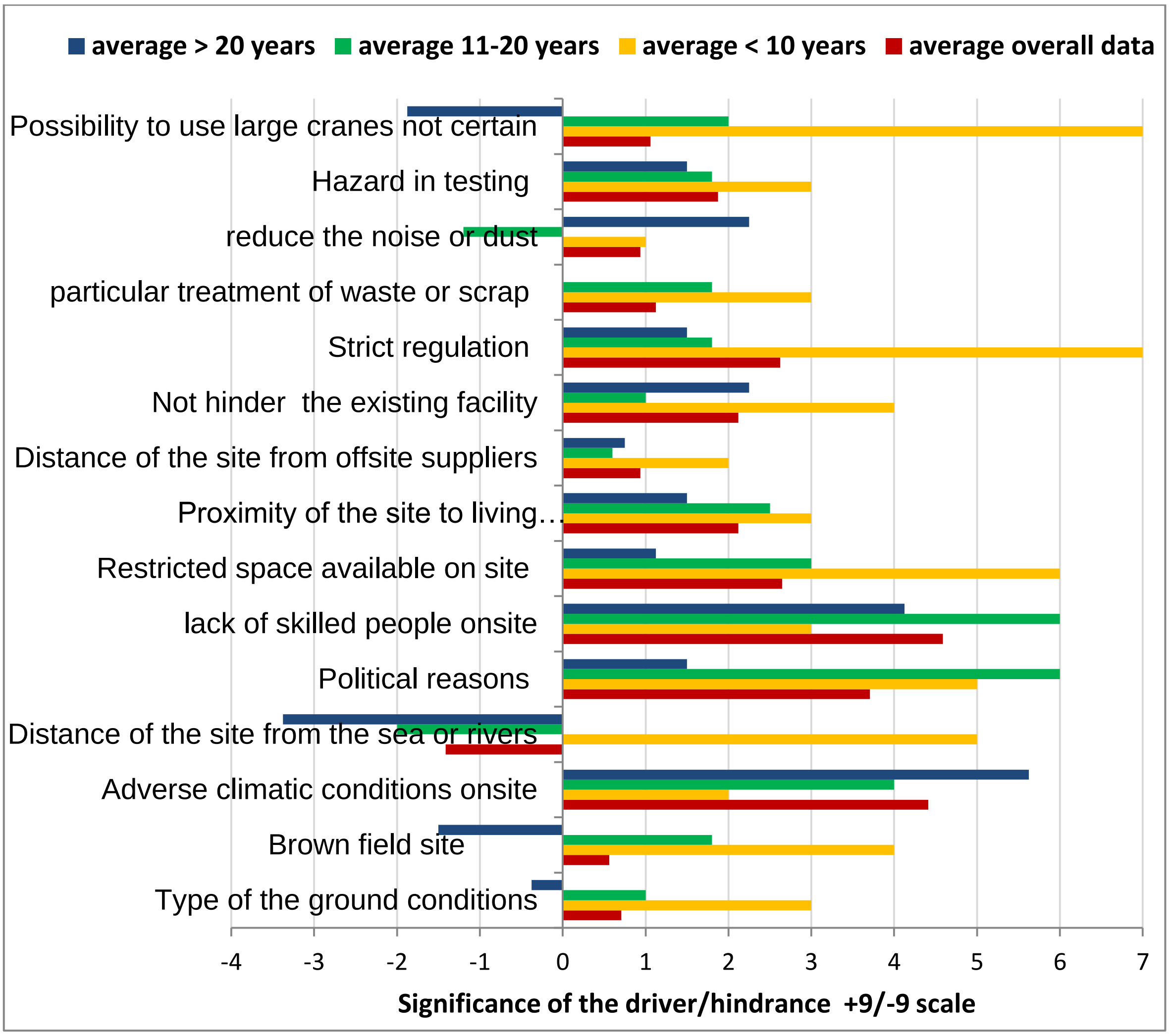


Figure 27 - site requirement factors, years of experience comparison

Like in the precedent graph the more experienced respondents are conservative in their drivers and hindrances. Moreover, they recognized particular hindrances like: Limitations in cranes availability, brown field sites and type of ground conditions. About the less experienced respondents, the tendency of "promoting" modularisation continues, the responses are on average more positive in pushing drivers and less negative in recognizing hindrances. The difference of judgments confirms an asymmetry of perception of modularisation between the participants of the questionnaire. This divergence gives insights about the actor's judgments but inhibits the generalisation of findings. The intermediate experts' opinions also in this graph lay in the middle, resulting in a close matching with the overall questionnaire data. An important aspect to consider is the deficiency of the questionnaire design, in fact sometimes the ambiguity of questions led to misunderstanding and lack of homogeneity of the answers. For example, the "distance of the site from sea" it is considered a driver by the less experienced respondents, but this factor is clearly a constraint of the method. The misunderstanding is due to the wrong conception of the questionnaire; it misses the specification of "long" or "short" distance from the site.

The following couple of graphs shows the experts evaluation in terms of site requirements factors:

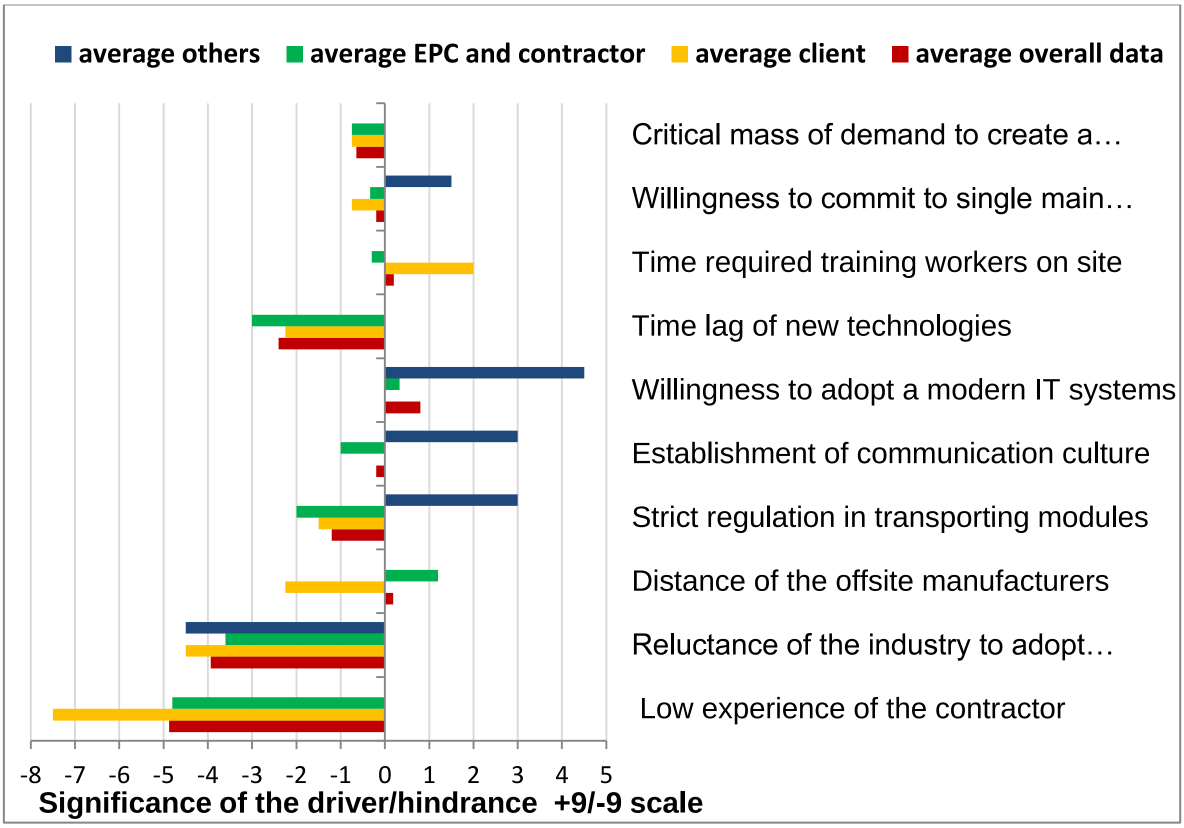


Figure 28 – project requirements factors, respondents' comparison

The first thing that it is possible to notice is the higher number of hindrances (negative values); most of the project management factors are considered constraints for the adoption of modularisation. It is possible to suppose that higher problems and risks in implementing a modular approach lead to doubts in selecting the approach. This endorsed by the high level of the “reluctance of the industry to adopt modules”. Moreover the overall results can be a signal that the method is not understood from the client and the contractors. In this graph more factors are close to the zero line, this means that they are less important to consider in the selection of modularisation because not differential. The real interesting features seem “the time lag of technologies” and the last factors. Responses are in most of the cases homogenous, except for the three central factors, where the “others” judgment goes against the overall evaluation. This is probably due to the fact that the “others” category comprises one supplier of IT solutions for construction projects, being only two the individuals in this subgroup this boosted the ratio of “willingness to adopt modern IT system” and “establishment of communication culture”.

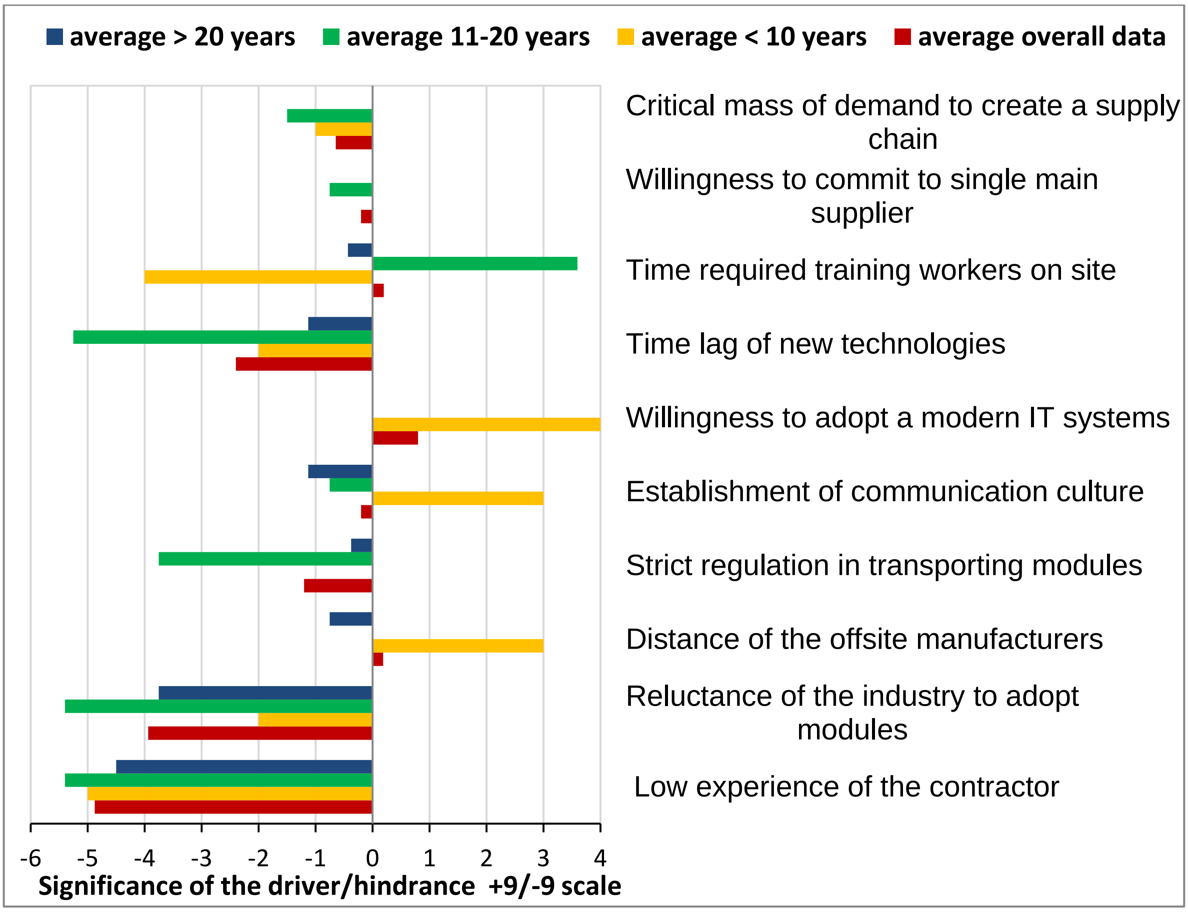


Figure 29 - project requirements factors, years of experience comparison

The more experienced respondents are the most conservative, their responses are always below the average. The only true constraints deemed by this category are the last two factors. The less experienced respondents provide evaluate some factors as drivers in opposition with the overall evaluation. The intermediate level deems constraints with a higher rate, but the evaluation is in most of the cases conform with the overall judgement. Generally there are some peaks of drivers and constraints, but the overall evaluation is more homogenous than the previous experience comparison graph. Also in this part of the questionnaire a lack of specificity in the questions is registered, for example the "time to train workers onsite" misses to define, long time or shorter time, this led to controversy testimony. Along the questionnaire this phenomena inhibited the generalisation of findings, forcing to ask the confirmation of the evaluation in the next interview section.

The following graphs resume the more significant drivers and hindrances emerged from the questionnaire.

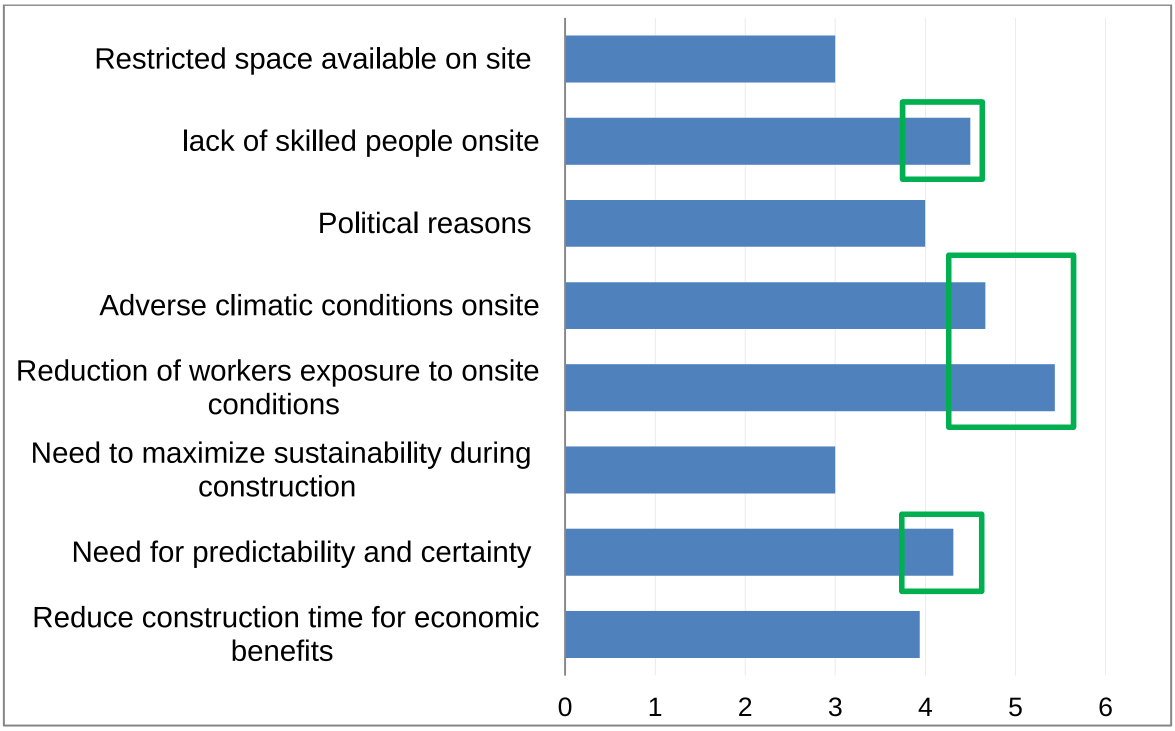


Figure 30 – more significant drivers

The graph shows that the higher driver occurs when there is necessity to reduce the workers' exposure to onsite weather conditions or risky working environments. The second most important driver is the absence or lack of skilled people onsite, this pushes towards a moving the construction away from the site. Another significant driver is the “the need of predictability and certainty”, may be clients are more interested in certainty than lower prices or shorter time, the impact of this factor was further investigate in the interview section.

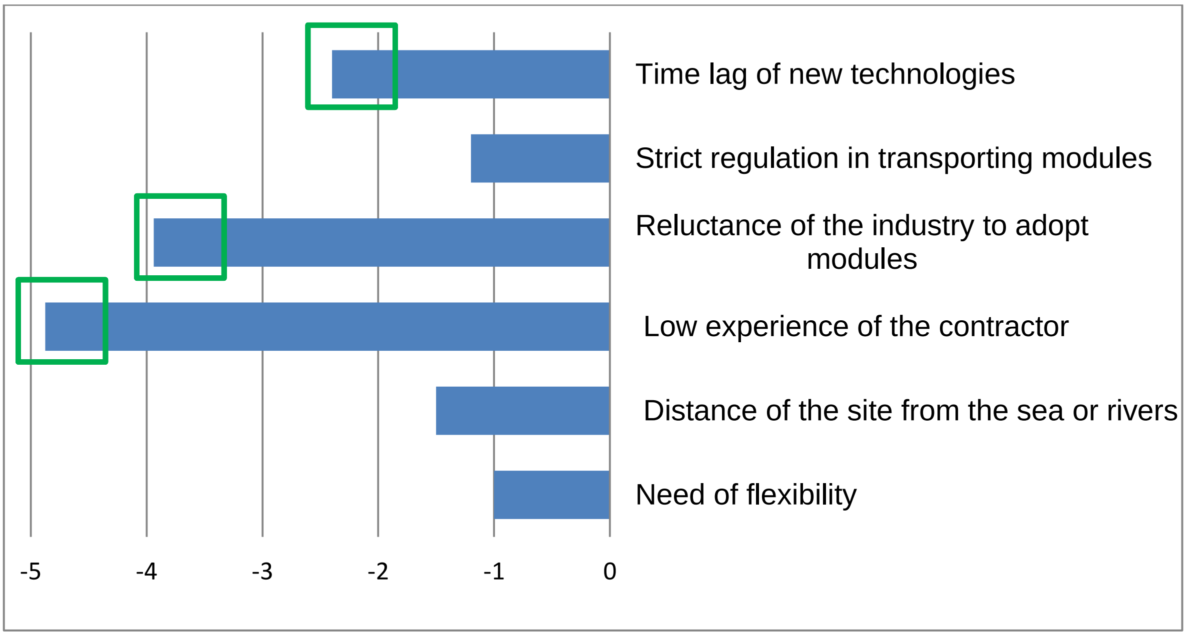


Figure 31 – more significant hindrances

Nowadays the higher constraint of the adoption of modularisation is the “lack of experience of the contractors” and the “Reluctance of the industry to adopt modularisation”, both reasons are related to the mentality of the industry and not to specific features of the method, the first hindrance in this sense is “distance from the sea”. From one side clients are unwilling to adopt modularisation, probably both for the negative connotation of the method and for the higher complications deriving from a “new” approach. On the other side contractors, since the method is not widely used are not able to build competences required to proper manage modular projects. This generates a vicious process that inhibits the uptake of the method. Moreover, experts Stress the necessity of new technologies in the construction world and denounce that the existing innovations requires long time to be learned and assimilated by the industry players.

5.2 Interviews data analysis

In the below table the interviews resume is provided. Five EPC representative were interviewed, three contractors, three clients and one supplier and consultant for a total of thirteen interviewees.

Table 10 – Interviews resume

Topics	EPC 1	EPC 2	EPC 3	EPC 4	EPC 5	CONTRACTOR 1	CONTRACTOR 2	CONTRACTOR 3	CLIENT 1	CLIENT 2	CLIENT 3	SUPPLIER	CONSULTANT
SHORTER SCHEDULE	Right procure and delivery, no rework, to have shorter schedule	It is a driver. Clients care about early business start			Driver, due to parallel activities	Biggest advantage		Strong driver, in order to get economic benefits	First driver compress schedule due to parallel working	With repeatable project is improved. Only installation time is shorter, more engineering hours, the total time is higher.	Easy achievable, strong driver	Strong driver	
COST OF THE PROJECT	Clients want to maximise NPV. Look at the margin cost of production	It is the strongest concern	First concern	Difficult to predict cost benefits, is neutral rather than cost benefit	Driver, e.g. reduced cost due to less people onsite		Biggest concern, Modularisation is not always cost savings	Driver, if you locate your offsite facility in cheap labour locations		Driver, can help to save money, but in some location is cheaper (local workforce)	Driver, it is often possible to achieve a better budget	Strong concern	Is the most important driver (in selection the construction method), client cares about ROI
QUALITY OF THE STRUCTURE				IT is possible to achieve a better quality, depends on the location	Always higher quality, due to better working equipment and technology	Offsite facility is more conductive to achieve better quality			Advantage, depending on the offsite facility location	Achievable benefit, depending on the offsite facility location	Sometimes not adequate level. E.g. second hand still frame		Better quality achievable

PRODUCTIVITY & OFFSITE EFFCIENCY	More productivity offsite due to less climatic hindrances					Higher productivity and efficiency	More complexity of the project and interfaces to prepare			Advantage of testing equipment offsite	The offsite facility has to provide reliable quality, also during installation phase	Offsite are available tools and working instruments e.g. laser cut, that onsite is not available	Testing procedures are faster and safer
CERTAINTY AND PREDICTABILITY				Big driver, more cost and schedule certainty, clients want to mitigate risks getting certainty.							Predictability of the schedule is a strong driver	Important for the time to market	
H&S AND WORKERS EXPOSURE TO ONSITE CONDITIONS	It is a driver. e.g. the building process onsite created a dangerous gas		In some projects is important to reduce labour at the job site	It is a driver	Improved with modular solutions professional workers, (onsite not)	Offsite facility is a better manufacturing environment		Better offsite, usually is a driver only if dangerous onsite	Driver, when narrow and dangerous working places	Driver, surely improved since people are less expose to site risks and climate conditions	I		
SUSTAINABILITY	Reduced footprint enhances sustainability (in broad terms)	It is usually not a driver	Smaller footprint leads to less material and less waste. Usually stakeholders don't perceive it.	The client doesn't perceive it as a driver (they don't want to pay for it)	Sustainability is improved with M. client understand it and it can sometimes be a driver	Growing trend, growing importance driver	Growing trend, no consistent understanding of it, some clients asks for it some doesn't	Everybody is speaking about it but not considered in practice (operative level), may be at strategic yes	Increasing awareness, but you cannot have the whole process visibility, you should also look to suppliers processes	M. doesn't bring direct benefits, some indirect may be. For sure not in terms of construction procedures	Improved, because with M. adopts more eco-friendly construction procedures. Easier recycling	More awareness, clients are monitoring the situation	Lighter steel structure, less material used and less process scrap and better energy efficiency

INNOVATION AND HI-TECH SYSTEMS	Usage of new tech. during projects adoption of new solutions	Constant research and investments e.g. bigger and bigger modules, new technology to move and lift. e.g. new footprint, better efficiency and optimised layout	Mix of people in the team, more like to come up with new solutions	M. can be an opportunity to think out of the box and make things differently	New tools to do engineering and automation, opportunity to introduce new hi-tech systems	Can boost the introduction of new technologies in the working procedures	Introduction of new unified tools can help to overcome problem of multiple interfaces used	Increased R&D in US and Asia not in EU	It is probably more an inspiration, but M. doesn't introduce more innovation than other methods	Opportunity to introduce new managing systems, but since the industry works with one-off projects is difficult to keep truck of the manage improvement	Introduction of good methods, like BIM, can boost the adoption of M. e.g. Asian countries invests more in R&D: energy efficacy panels in Singapore	With M. is necessary to introduce new tools and instruments. Need of systems to facilitate design and support transport	Few investments in the sector. The hope is that M. can bring new solutions and systems
MAINTENANCE			It is possible to understand better future maintenance expenses	You think about maintenance at an early phase (engineering).							Can be better, only if the client is provided with the instructions	Can be improved, because better disassembling the module (but no visibility)	A better quality of the module might lead to less future maintenance
DESIGN FLEXIBILITY				Low flexibility because you freeze design and make decision earlier	Low flexibility, but it depends on the type of project and requirements of the client			Low flexibility, due to early freeze of the design					

ENG/DES EFFORT AND EARLY DECISIONS	e.g. don't shift engineering design risk to the fabrication engineering	Increase in the steel work and complexity of the design process. Early engineering and accelerate decisions		Early focus, but not more effort, only detailed engineering a little more.	You don't have enough information when you freeze the design, at the end you have to do some minor works onsite	Early involvement of the client can be a driver	With M. unique design, instead stick build sometimes different design and different tools used. Early involvement of the client needed	Decisions and design freeze too early sometimes	Higher design effort, design must take into account transportati on	Much higher engineering and design working hours	The effort is more or less the same	Design to transport.	Advantage because you can have earlier data, that helps in the realisation of the design
TRANSPORT ISSUES		Transport issues have to be addressed from the beginning. e.g. avoid to build roads to transport the module.	Transportati on hindered sometimes by local constraints	Transport difficulties, you have to forecast it, and consider all drawbacks.	Strong hindrance	Strict regulation, e.g. we had difficulties in getting equipment and moving modules		Highest risk, shipping is the most dangerous in case of accidents	Strong hindrance		Strong hindrance	Design to transport. Think about transport issues from early phases. Cranes availability is crucial.	Strong hindrance
LOGISTIC INFRASTRUC _TURE	Can be a hindrance	Has to be conductive to move large modules		Huge hindrance to build logistic to transport	Issues related to logistic	Main hindrance from a client point of view	In EU better infrastructure in transporting modules			Poor infrastructur e hinders offsite and cost increases	hindrance	Logistic industry is investing a lot in methods to support M.	Avoid to construct roads and logistic infrastructur e,
SITE CONDITIONS	Brownfields, can be a hindrance building on existing equipment and moving modules	Brownfields restricts, forecast constraints to move modules (look at sizes and weights)	In brownfield sites the accessibility of modules is a limitation			Brownfield, small space and working sections might hinder the installation and movement of big modules	Footprint of the site and cranes availability can be barriers e.g. crane inside a building to move module	Living environment can hinder the movement and installation of modules					

SITE LOCATION	Remote locations, no workers availability, can be a driver or a hindrance	Few skilled people onsite is a driver to go modular	Driver for remote locations due to poor workers availability and climatic conditions	Sometimes lack of availability of skilled people onsite. E.g. redo work (welding), pipe felt	e.g. close to big cities, no M. due to availability of workers, if no too expensive, infrastructure and close supply		can be a hinder to adopt M.	Availability of workers is crucial e.g. no in Siberia Climatic conditions (time to work)		Every project is different in different areas the drivers change. E.g. somewhere is cost in other places may be schedule		Position of the site can be a problem for the transport	Availability of skilled workers is crucial
LACK OF CONTRACTOR EXPERIENCE	Critical to manage information, and to get the right item at the right time	Due to maturity of information available when you take decisions. High risk, catastrophic impact if module lost	you have to solve different issues and find new solutions		Poor local and small contractors,				Procuring a module is not like procuring materials, client has to put work in assuring this		Difficult to manage exchange of information and relationships between teams	Lack of detailed studies. M gives benefits only if projects managed properly	
LACK OF KNOWLEDGE AND UNDERSTAN_DING OF M. IN THE INDUSTRY	Mentality and commitment of the Project mng. and client team to adopt M.	Depend on the project. E.g. two close projects with different teams had different understanding. Depends on what the client wants.	Client willingness to use M. is crucial, different clients, also organizations commitment to embrace changes	Poor knowledge, reluctance to use M driven by no awareness of pros and cons. Clients perceive it more expensive and only for offshore.	M is not a new approach but is still not understood	Some clients are aware of M. but not of logistic and lifting possibilities Often we have to share knowledge to convince them. Usually poor understanding of the method	Asymmetry of understanding of the method in within the industry	Conservative industry, projects started with stick build in mind			Method perceived new, it requires time to learn the procedures		

COMMUNICA_TION AND COORDINATION	Is a barrier, M. is a "new" method, teams might be tempted to follow easy paths		Adopting M. reduces the client effort in coordinating the work on site, but increases the project manageme nt coordination needed.							Should help to bring foreword innovations and solutions introduced by the team	There is a high number of interfaces to coordinate	Is crucial in M. much more than in stick build	
POLITICAL AND SOCIO-ECONOMIC SITUATION								If unstable country you have to work outside e.g. Nigeria					You cannot freely higher different culture people due to troubles in the construction area
DEVELOPE LOCAL CONTENT		Legacy: government asks to use a ratio of local labour, to train them.						Pressure to use local workers and companies		Government asks to employ local workers e.g. Kazakhstan		Barrier for M. Owners might ask for % of material supplied by local companies	Sometimes you have to hire local workers
REPEATABILITY AND STANDARDISA_TION		Past clients ask new projects, introduction some standardisat ion for future	Possibility to replicate solutions of a project into another one.						Could be achievable, but you usually don't go for repetition, just one off module	Difficult to introduce standardisat ion every project is different	Few buildings or process equipment can be reused		Possibility to introduce standardisat ion for similar future projects

FOERCAST OF FUTURE ADOPTION OF MODULARISA _TION	Increase the adoption, fostered by new innovations and technologie s	Increase, more mega projects, remote locations, lack of skilled workforce	More adoption, people will understand it more, better project manageme nt, easier to achieve cost reduction	Increase adoption, only a matter of time	Increase adoption	Constant adoption, percentage in the industry will remain the same	Increase adoption, due to more understanding of possibilities	Increase adoption, due to more projects, in more remote locations, in unstable countries	More adoption in the future	Increase, more projects in countries where there is lack of skilled workers	Can increase, it will require time, it has to be understood by the industry	Surely increase	Increase adoption

The topics discussed by each of the interviewee are the results of the questions asked (see Appendix B). The semi-structured approach has led to receive feedbacks in terms of sustainability, innovations and new hi-tech solutions and forecast for future adoption of the method from all the respondents. Most of the information gathered during the questionnaire were confirmed and integrated with previous material, generating a better comprehension of the dynamics affecting modularisation projects. In some cases it turned out that the questionnaire wasn't clear in all its parts and interviewees modified their responses providing the misunderstanding reasons and further explanations.

The drivers strongly confirmed were:

- Shorter schedule (except from one interviewee)
- Reduction of workers' exposure to onsite conditions
- Higher workers' productivity
- Higher predictability and certainty

Respondents expressed these judgments in accordance with the fact that the majority of the modular working activities is carried out in an organized and protected facility.

The constraints strongly confirmed were:

- Reluctance of the industry to adopt modularisation
- Experience of the contractors
- Transport issues

New (or higher emphasis) constraints were:

- Lack of knowledge and understanding of modularisation in the industry
- Communication and coordination
- Develop local content
- Socio economic problems

One of the most important findings from the interviews is that the Industry still has a poor comprehension of the modularisation benefits and drawbacks. This problem can be related to a limited number of projects tackled with a modular approach or a misconception that the method can be adopted only for off-shore and remote locations. The introduction of innovations and new hi-tech solutions was seen neither as a driver nor as a constraint but as an enabler of modularisation. If the whole industry will embrace changes and reduce the time lag of new systems, modularisation will be easily implementable. According to the respondents the adoption of modularisation brings less flexibility, not in terms of design features, but concerning the introduction of changes during the development of the project. The reduced importance of the "low flexibility" as a constraint was previously identified in the questionnaires, the direct considerations of the experts helped to delineate the nature of the feature. About the site location and conditions, these two factors were considered quite variable in supporting or inhibiting modularisation. It is always possible to choose a modular approach, even if the conditions are not favourable, but constraints have to be carefully identified and evaluated. This finding tells us that each project is different and it is not possible to identify and catalogue unique situations. Projects are always a combination of variable factors and it is important to identify all the relevant drivers and constraints and their interrelationships (in this respect see 3.5.2).

The qualitative findings of interviews concurred to determine a significant percentage of the overall research findings; the table is further discussed in the following sections (see 5.4.1).

5.2.1 Plenary section questionnaire analysis

In the Figure 32 the average of the drivers ranking is presented. The question asked to the respondents was: “Rank the following drivers according to their importance in choosing Modularisation with respect to conventional stick build construction “. The driver raked first received 8 points instead the last one ranked eighth received 1 point. A simple average function was used to calculate scores that varies between 1(not important) to 8 (very important). Data are presented in a clustered column bar chart indicating the mean for each driver and relative standard deviation (black segment on the right of each bar).

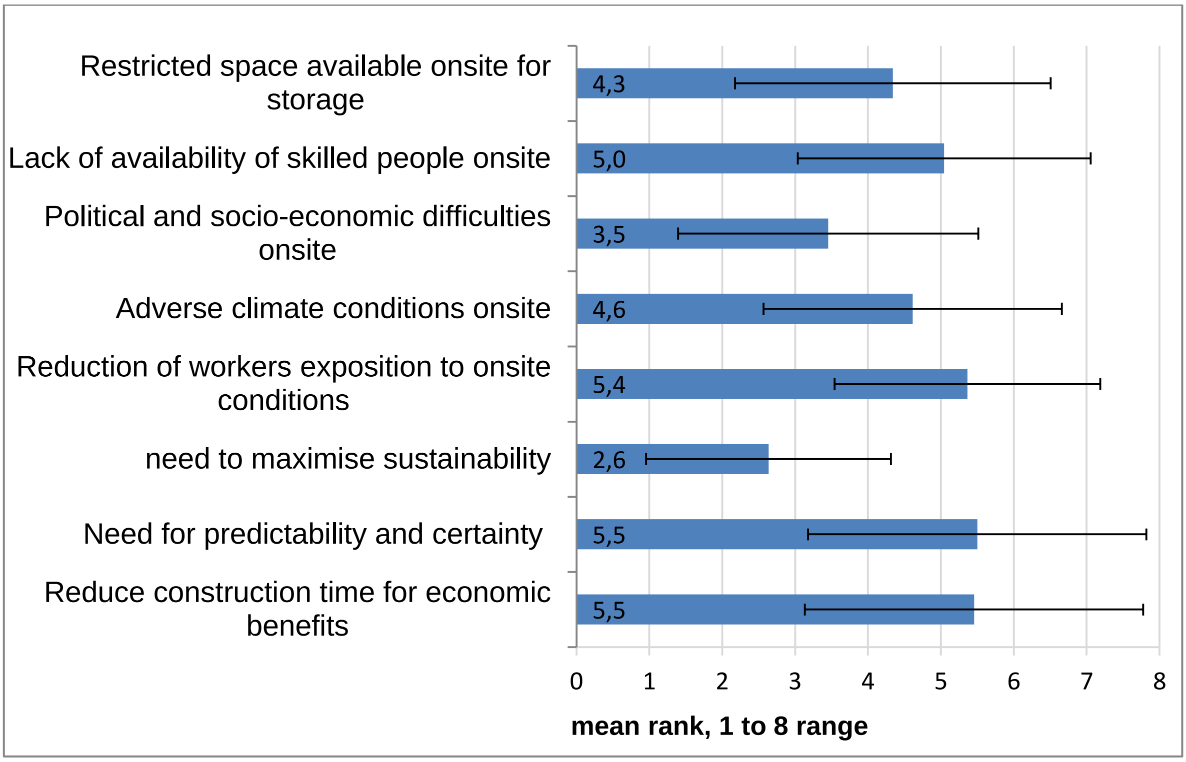


Figure 32 - Drivers ranking mean

In this second graph is presented the mean of the barriers ranking. The methodology adopted is the same as above and the question asked to the respondents was: “Rank the following constraints according to their importance in NOT choosing Modularisation, with respect to conventional stick build construction”.

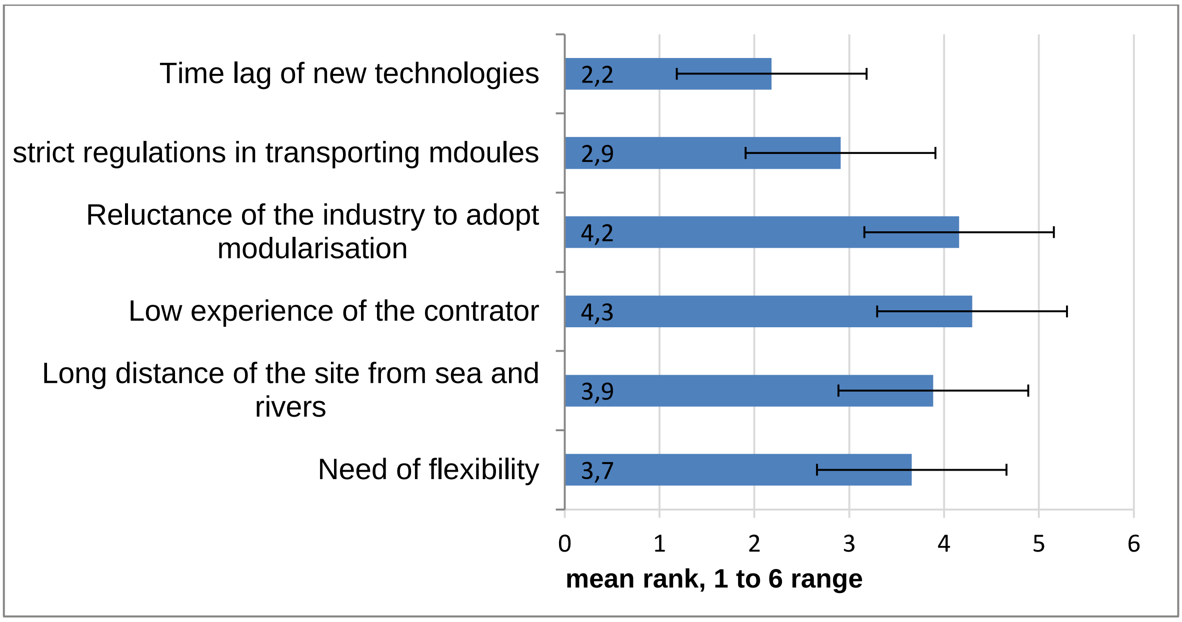


Figure 33 - constraints ranking mean

Main findings:

1. The adoption of modularisation is driven by the aim of having a shorter schedule to achieve economic benefits and gaining in time and cost certainty. The availability of skilled workers is also quite important as well as minimizing the workers' exposure to adverse onsite working conditions.
2. The need of sustainability is the last ranked driver; this means that according to respondents modularisation doesn't encompass the ability to achieve more sustainable results
3. The highest hindrances of the method are the "low experience of the contractor" and "the reluctance of the industry to adopt modularisation". This means that and the industry culture is quite old and slow in reacting to changes and embrace new construction methods. This finding confirms the insights received from the web-based questionnaire.
4. About the measured standard deviation of the results, the dispersion of the sets of data from theirs mean is regular (this is due to the fact that the questions asks to rank drivers), but the values are quite high (the standard deviation is around the value 2, which is high considering a population of 8 elements) this means that the data are quite spread.

Further analysis of the data was performed considering working sector, years of experience and level of familiarity with modularisation of respondents. The differential results were set against the average global mean. These three groups were divided in as much sub-groups:

Working sector:

- Oil & Gas
- Pharmaceutical
- More sectors (companies operating in various sectors simultaneously)

Years of working experience:

- <10 years exp.
- 11 to 20 years exp.
- <20 years exp.

Level of familiarity with modularisation:

- Low level = 1 or 2 fam. (familiarity)
- Middle level = 3 fam. (familiarity)
- High level = 5 fam. (familiarity)

These graphs were realized isolating the data coming from each of the sub-group considered. Each bar (different colour) represents the average of the sub-group. This method of representation was chosen in order to figure out the most significant differences between the global mean and the single sub-groups mean and the sub-groups itself. The graphs of this analysis are presented in the Appendix C. Most of the data are consistent over sub-groups, although there are few significant differences. Below a resume of the findings that is possible to evince is provided:

1. The pharmaceutical industry is the one that mostly searches for schedule efficiency in order to both realize economic benefits and have predictability and certainty on the project completion.
2. The less experienced operators of the industry (<10 years exp.) perceive with less emphasis the reluctance of the industry to adopt modularisation as a barrier. This could be due to the low level of visibility at high decision level or simply by the low amount of project in which they participated. Moreover, this category does not recognize the importance of the availability of skilled people onsite. Conversely they are more keen to attribute to sustainability drivers more importance, with respect to the global average.
3. In the last set of graphs there is a quite diffuse pattern of difference of judgement between the non-familiar with modularisation and the familiar one. This divergence

of opinions is mostly represented by the different significance attributed by the two groups to the “need of flexibility” and “long distance of the site from sea and rivers”.

5.3 Workshop data analysis

5.3.1 Clickers results

Initially a set of demographic questions were asked (see Appendix E – ECI workshop). Then for each of the six factors data about the level of significance and novelty was collected (see Appendix E – ECI workshop).

Precisely, the meaning of the requested significance and novelty was:

- Significance: How important is the characteristic in affecting the selection of modularisation, independently whether they want to adopt it or not (because the conditions that enable or not the selection of the construction method, were asked in the second section)?
- Novelty: How this characteristic changed in the last 10-20 decades? Is it something that the client is asking for now, more than in the past? Basically, how new is the consideration of this characteristic?

The results indicate that the most significant characteristics are related to the location and condition of the site, and both the characteristics have a low level of novelty (the lowest value belongs to “site conditions” with 69% of votes on “no novelty”). The workers’ exposure to onsite conditions is deemed “very significant”, and this confirms the previous data collected with the questionnaire and interviews. The interesting new information is that it is considered fairly novel, which means that over the years the concern on this factor increased and consequently the attention and investments. One of the clients request with high significance is the need of certainty and predictability which has a somewhat level of novelty. A similar trend has the political and economic situation, this characteristic gained in significance over the years, but from the previous data we expected to receive as feedback a higher level of novelty, instead stabilized on “somewhat novel”. The reason of a low level of novelty can be a misunderstanding of the question that leads to not consider the recent increased government political pressure for local development (in some developing areas), the feature was regularly identified during the focus groups section (see 3.3.2). The characteristic with higher novelty is the need to maximize sustainability (the average stands in “novel”), but the results indicate that it is not so significant when considering the selection of the construction method (the average judgement stands between “somewhat significant” and “significant”). Results mean that sustainability is not usually a factor that industry players consider during the selection phase; this can be either due to the fact that there is not visibility on the higher suitability performance of the modular approach or the decision makers don't care about better sustainable performance because the market is not mature in this sense and so there is not a return in using greener procedure.

5.3.2 Workshop focus groups

Each of the 6 topics was discussed by the focus groups; below there is a schematic resume of the discussion, some pictures of the workshop and flip charts collect during the activity can be found in the Appendix E – ECI workshop.

1. **Level of predictability and certainty achievable (schedule, cost, risk reduction...)**

It is often the first concern of the owner, in order to get predictability and certainty it is necessary to:

- Manage the working environment
- Have a stable workforce
- Reduce time on site risk
- Reduce changes on upfront delays
- Adopt parallel working

It influences the three main characteristics of the project management (quality, time, cost) plus flexibility. It doesn't influence the health and safety aspect (usually).

Quality
- Controlled conditions
- Inspections
- Automation
- Testing

Time
- Higher level of productivity
- Weather conditions
- Transport and logistics

Cost
- Wider market
- Extra and early design
- Corporate Social responsibility of the employment

Flexibility
- Earlier decisions
- Earlier planning
- Earlier procurement
- Design changes management

About the novelty the participants stated: “the focus may have changed, but the principle is not new”

2. Location/Position of the site (weather conditions, distance from sea/rivers, closeness to big cities)

The location of the construction site has a strong impact on:

- Health and safety of the workers
- Logistic infrastructure
- Cost of the transportation
- Schedule of procurement
- Accessibility of the site
- Cost of the local workforce
- Legal procedures and fiscal taxes
- Development of the engineering design (specifications to respect)
- Size and dimension of the construction

Participants distinguished between the geographical areas, basically where the location can (usually) be a driver or a hindrance for the adoption of modularisation. They clearly stated that each project is different and should be carefully evaluated with respect to a considerable amount of characteristics:

Geographical area			
+	Nordic and artic	-	Middle east
+	Canada	-	Asia
+	Australia (some areas)		
+	Africa (near the coast)		

Delegates didn’t express judgements about USA and South America, Instead Euro zone was deemed too variable to be catalogued in one of the two areas.

In each project the location should be carefully studied in terms of advantages and disadvantages, the following factors can be either a pro or cons of the location:

- Weather conditions
- Productivity of the workforce
- Quality of the work (availability of skilled people)
- Availability of local companies (procurement of original pieces conform to design specifications)

- Distance of the site from the sea (the speed of the trucks is limited, close to 3 km/h)

3. Reduction of workers' exposure to onsite conditions

It is the first concern of the organisations: to guarantee security to workers and reduce risks on site was deemed crucial by all the experts. The adoption of modularisation surely improves the health and safety of the workers.

The factors positively affecting the health and safety related with the adoption of modularisation are:

- Better working condition
- Less exposure to weather conditions
- Reduce trade stacking
- Reduce local workforce employed (often not skilled)
- Reduce work at height
- Schedule optimisation
- Reduce workers relocation

The attention for health and safety increases moving towards western countries due to higher legal pressure and strict regulations.

4. Condition of the site (type of ground, closeness to living environment, space availability)

The site conditions have a central role in the decision making process. One of the factors to consider is the brown field site: for example, an existing business can hinder the movement of modules. As a support of this idea one of the participants is quoted as saying "the movement of huge and heavy modules may require the adoption of large cranes, not always available", moreover "in some circumstances large cranes cannot be used onsite for security reasons".

Concerning the site and working environment a particular attention covers the:

- Environmental regulation
- Presence of protected areas
- Waste management
- Ground conditions (refurbishment or chemical treatment)
-

In the table below there is the list of factors affecting the adoption of modularisation:

Drivers and hindrances of modularisation	
+ Reduce impact on neighbours or local residents	- More difficult to move modules
+ Avoid restriction of working hours	- Need of large cranes
+ Bypass storage problems	- Need of permissions
+ Boosts accessibility to the site	- Increase risks
+ Improves the schedule of the work	

5. Political and socio-economic situation in the site area

Concerning this factor the experts spoke both about the local development and political problems of the countries where the construction site was located. The former is related with the exigency of the government to boost the local economy promoting the professional growth of the workers. The latter refers to the political and social problems affecting all the phases of the project. Below a list of this complication is provided:

- Volatile local workforce
- Lack of energy, water and resources available
- Higher labour cost
- Embargo
- Logistic complications
- Transportation problems and risks
- Reduced security

Concerning the development of the local content the government can impose a number of constraints, the main examples are:

- Procure in local companies
- Hiring and training local (unskilled) workers
- Outsource part of the work to local companies

All these conditions represent a hindrance for the adoption of modularisation.

6. Maximise sustainability (during construction and the whole life cycle of the plant)

The discussion of the topic followed tow diverging paths in the two groups listened.

One of the two groups of experts clearly stated that “sustainability is not that significant for the decision making process”, it means that sustainability is not yet recognized differential in the decision making process. Even though is not usually considered the adoption of modularisation it surely helps to boost the sustainability from different perspectives:

- Energy efficiency
- Reduced pollution and CO_2 emissions
- Decommissioning
- Less material wastage
- Lean approach is easier to apply
- Embodied carbon footprint
- Lead to innovative design
- Reduces vehicle movement
- Less water requested onsite

The cost is a controversial topic in terms of sustainability: some of the experts claim that embracing green procedure increases costs of design, production and instalment of such instruments. Conversely some of the experts deem that this initial price is higher due to a lack of spread adoption of green procedure and states that the cost should be evaluated over the long run of the plant. The selection of sustainable equipment can help to decrease the cost of the plant in the future. This view is supported by an expert statement "the plants that are built now will live for 30 or more years" the sustainability question is getting momentum and restrictions might become tighter in the future. The adoption of modularisation increases the pollution for the transportation of the modules but decreases the overall CO_2 emissions because reduces the movements of the tracks onsite and the procurement routes.

About the novelty, only one of the two groups that discussed the topic recognized a global higher awareness and concern on sustainability. The group of experts' spoke about three novel areas:

- Carbon footprint
- Increasing client awareness
- Higher priority in future market

Delegates' discussion confirmed the responses provided electronically with clickers. Particularly it was useful to have a clearer view in terms of political and socio-economic view of the project and to identify challenges of sustainability. The centrality ot workers exposure, predictability and site conditions and location was confirmed. Most of the factors affecting the selection of the construction method were previously identified during previous phases of the research, this section helped to corroborate previous findings.

Data from the discussion was qualitatively analysed and competed to be included in the overall research findings (see 3.5).

5.4 General findings

5.4.1 Characteristics findings

Below the findings for each of the main characteristics emerged from the data gathering process is explained. The neutral term "characteristic" indicates that each object in consideration can be either a driver or a constraint for modularisation.

Project schedule

The shorter schedule is the main advantage of the modular approach, thanks to simultaneous work the onsite duration of the project is dramatically reduced. During the *interviews*, often this aspect was linked to business drivers; one of the clients interviewed stated "it is a strong driver due to the possibility to realize earlier economic benefits". Moreover, it is evident from the *conference questionnaire*, that reducing the construction time in order to get economic benefits is the driver that mostly directs the client towards the choice of modularisation. This finding is supported by the literature; many publications stress the concept that the shorter schedule is the main benefit of adopting modularisation. An interest outcome rising from the experts interviewed is that, inadequate project management behaviour can ruin the shorter schedule achievable. Furthermore, in case of repeatability of the project, standardisation features and learning mechanisms lead to a shorter completion time driven by a reduction of the design and engineering phase.

Cost of the project

It is evident from the interviews that the primary concern for the client is the overall cost of the project, but when the question is: *"can modularisation help to achieve a better budget?"* the opinions diverge. Respondents are cautious in saying that modular approach can save money; they rather believe that adopting modularisation generates roughly the same cost budget or even slightly higher. The workforce cost was identified as one of the most important division to determine whether the approach will be cheaper or not. The data evidences that depending on the specific project the total cost can either be a driver or a constraint: to have a clear view of the costs indeed a great number of factors and variables should be took in consideration. In the literature, more emphasis is given to the "cons" aspect of the total cost. It is also suggested to not consider exclusively a direct cost element comparison because lacks the analysis of the indirect benefits associated to the method.

Quality of the structure

The offsite facility is more conductive to achieve a higher quality. Respondents agree on the fact that the offsite facility is better organized in terms of footprint and equipment to support the workers during the daily activities. Moreover, the stable workforce employed offsite is more qualified and is not hindered by the variability of weather conditions. In the *first questionnaire* for example, the data suggests that the adverse climatic conditions onsite highly pushes towards the adoption of modularisation. A common claim of the *interviews* was that the location of the offsite facility is crucial to determine the achievement of a better quality. Low labour cost locations, like Asia countries, were perceived lacking in terms of labour skills and material quality. For example *"The possibility to achieve a better quality depends on the location",* and *"Sometimes not adequate level, due to second hand steel framework"*. The finding is supported by the literature; the offsite environment facilitates the work procedures and promotes higher quality products.

Offsite facility efficiency

A clear advantage of moving labour offsite, observed both in the questionnaires and interviews is the higher productivity of the workforce. Data shows that this achievement is crucial for project managers, for example *"higher productivity and efficiency is possible to achieve, due to the higher offsite availability of instruments, e.g. the automatic laser cut, is usually not obtainable onsite".* Another advantage of the offsite facility is the possibility to run a safer and faster test of the process equipment. This finding is supported by all the research methods used. About the operations of the process plant after the completion of the project, data shows that the adoption of modularisation doesn't provide any differential advantage in terms of efficiency of material used and management of waste substances. It is worth to point out that the initial questionnaire provided an undefined output, but the following interviews clarified the experts' point of view. A similar consideration can be done about the maintenance procedures. Interviewees were generally reluctant to recognize a clear and sure improvement, two of them admitted that they don't have visibility on the process operations, but can suppose that a *"better quality leads to less forced maintenance"* and *"easier disassembling of the module, can facilitate the* *maintenance"*, Moreover some interesting considerations can be pointed out from the data:

- Due to early focus on engineering, is possible an early and better understanding of the extent of future expenditures on maintenance.
- An improvement might be possible if the maintenance instructions are provided to the client.

<u>Certainty and predictability</u>

This is one of the strongest drivers that leads to the adoption of modularisation. Data shows that the client in certain occasion is keener to obtain certainty of the expenditures rather than a lower overall cost. All the research methods used shows that certainty and predictability are improved when using modularisation; interviewee stressed that usually clients want to mitigate risks and get the plant as soon as possible in order to start repaying the investment. Moreover, evidence from the workshop reveals that in some circumstances the certainty and predictability of the cost and schedule is more important than the overall cost and schedule of the project.

<u>Health and Safety</u>

The adoption of modularisation surely facilitates the working operations due to a better manufacturing environment, *"H&S is surely improved since workers are less expose to onsite risks and climatic conditions"*. This is an important driver for the client, all the data reveals that reducing risks and facilitating the working conditions is one of the firsts concerns for the client and managers in general. Even though the modular approach meliorates the workers' health and safety, this factor is usually not differential in choosing modularisation. In fact due to higher number of controls and regulation onsite, prevalently in western countries, the sites working environment are becoming safer and safer. What data shows is that the need to improve health and safety of workers leads to the adoption of modularisation only if it's crucial to reduce the workers exposition to onsite extreme conditions: for instance if the onsite work is dangerous due to harmful substances, narrow and precarious spaces, adverse climatic conditions, unstable political situation etc. An interviewee provided an example, *"We had to move as much work offsite as possible, because the building process onsite created a dangerous gas".*

<u>Sustainability</u>

Most of the data shows that modularisation can help to achieve higher sustainable construction and plant processes. In the interviews is clearly stated that modular construction improves sustainability in a broad range, on this it is possible to cite an expert: *"a reduced footprint, achieves many sustainable benefits"*, these includes reduction of pollution and environmental impact, energy efficiency, reduction of wastes and water consumption. The attention to sustainable practices is not homogenous all over the world. For example, in Asian countries recent constructed buildings aim to achieve significant sustainable results. Surely the global trend is getting momentum and many experts believe that the adoption of modularisation, thanks to greener processes, can increase over the next years. From the workshop data, sustainability is perceived as one of the novel concepts in the construction industry, but is usually not significant in the selection of the construction method. The reason, basically, is that the client is not ready to pay for it, as an interviewee states*" it is a growing trend, but there is not a consistent understanding, some clients asks for it some doesn't"*, another affirms *"everybody is speaking about sustainability, but at operative level I don't perceive it, may be it is declared just at a strategic level"*. Another interesting point raised by interviewees is that, in order to advertise sustainability construction companies should guarantee that also suppliers embrace greener missions. Due to the low propensity of the construction industry to embrace changes, at the moment the sustainable dimension is far from being a crucial driver during the selecting of the construction method, but it is an important aspect to consider since more and more clients are asking for it. Moreover, the global awareness is rapidly growing and the adoption of modularisation will consequently benefit.

<u>R&D innovation and new hi-tech systems</u>

Although the level of innovation and investments in R&D in the construction industry is quite low, interviewees claimed that the introduction and establishment of new construction methods like modularisation can definitely foster the introduction of new hi-tech solutions. The new systems and tools will be useful both during the design and engineering phase to properly manage the growing project complexity and to support the managerial activities along with the project development, facilitating transportation and lifting of heavier and heavier modules. One of the interviewee states that the adoption of modularisation gives both the opportunity to introduce new innovative methods and the heterogeneity of the project teams easily leads original solutions. Again the level of investments across the globe is not homogeny, in fact Asian countries and US are the biggest investors. Data suggests that the adoption of modularisation will intensify the introduction of new tools in the industry and contemporary the embracement of these new systems will foster and support the usage of modular solutions.

Design flexibility

In the Engineering construction sector the design flexibility is recognized as a weak constraint. This is mainly because the building is just seen as an envelope of the process plant. The first concern for the client is the functioning of the process. Conversely in the civil building sector the aesthetic of the building is more important to the client, and on this the literature gives insights about the low design flexibility as strong constraint for the adoption of modularisation. The data show that the early freezing of the design is a strong restriction; in fact the maturity of the information during the early phase is usually limited, this can contribute to mistakes and inaccurate decisions.

Engineering and design effort

One of the drawbacks of the adoption of modularisation is the increased engineering and design effort. The interviewees clarifies that mostly the detailed engineering requires more focus and has more complexity, while the conceptual one is roughly the same. Data show that this problem is due to the high number of feature to design at an early phase when the amount of information is not always sufficient to take optimal decisions. An advantage of this anticipated procedure is the earlier involvement of the client, this can help to get in time data for the design, one of the interviewees is cited as saying *“earlier data helps to realize an integrated design, this must be done considering the transportation and installation”*. The last quote introduces the higher risk and complexity that often accompany the modular engineering process. In order to face the increased complexity and prevent risks it is crucial to put the right team and effort on the design, in fact “shifting the risk from the engineering design to the fabrication engineering” could be very dangerous during the last phases of the module installation. About the tools used to execute the engineering and design phase, the data shows that new ones like BIM can help and support designers facilitating the process. Moreover the necessity for an integrated tool is pointed out, for example an interviewee said “the problem with stick build design is the usage of different tools that brings to distinct models”.

Transport issues and infrastructure

This is one of the strongest constraints of the adoption of modularisation. Transportation requires always an accurate planning and a special attention during design. The final transportation of the modules is very risky, since the module lost or damaged highly influence the economic expenditures; but, like an interviewee states *“We are aware about this risk since the very beginning of the project, we always take up risk assessments and risk addressing techniques”*. Another problem related to the transportation of heavy modules is the availability of heavy lifting cranes, both in the port during shipping and in the site for the placement. During the workshop one of the experts pointed out the necessity to “design to transport”; hooking the module and finding the right way to lift it after the realisation could be challenging and risky. Moreover, in order to finalise the transportation an efficient infrastructure is required. Data show that in the US and EU the infrastructure to transport modules are more efficient, instead in some Asian countries and remote locations are often deficient. We can quote one interview *“it is crucial to acquire knowledge about the transport infrastructure, e.g. if you have to build roads and bridges, the overall cost could be unbearable”*. We have evidence from the questionnaire that the transportation is hindered by the long distance of the site from sea or rivers; heavy module transportation is both risky and expensive and current land tracks have limited speed. Moreover, the expenditure list includes all the regulations and permissions to pay to the local authority.

Site conditions

The site conditions can be either a driver or a constraint. In case of brownfield sites the living operations of the existing facility are hindered by onsite works, this is a driver to adopt modularisation since moves activities and workers offsite. However, a brownfield site has more restrictions in terms of motion of modules; this is constraint during the transportation and installation of the modules. Another aspect to take into account is the availability of material storage space onsite; in case of limited capacity the procurement can be better organised offsite. Data gathered during the workshop show that the possibility to use heavy lifting cranes onsite is not always assured, in fact “the placement of the crane must be safe, in case of problems if it falls mustn’t hit essential/dangerous process equipment”. Moreover, experts described the working footprint onsite, “sometimes, small space and working section hinders the execution of the activities”.

<u>Site location</u>

The location of the site can be either a driver or a constraint. One of the interviewee commented "In different areas, the drivers are different"; the data shows that this is a crucial factor to look at when evaluating the selection of the construction method. The position of the site goes to impact the critical aspects of the project in a number of ways: labour availability, labour cost, closeness to cities, political situation, distance from sea or rivers, climatic conditions; each of them depending on the type of project has a different impact in the selection of modularisation. In all the research methods used the availability of skilled workforce was signalled as one of the most important factors to consider, of course an expensive or lacking skilled workforce will enable modularisation. The adverse climatic conditions onsite will push to move as much of the work offsite. Conversely the main factor that hinders the selection of modularisation is the long distance from the sea or rivers. During interviews, more than in other methods, the experts observed that the contingent political situation is important to evaluate when selecting the construction method, because it goes to affect key project operations, like daily work schedule, procurement, energy and water supply etc.

<u>Lack of contractor experience</u>

As firstly evidenced by questionnaires and then confirmed by the interviews, the lack of contractors experience is the strongest constraint to the adoption of modularisation. This is because the managerial experience and competence goes to impact all the areas of the projects, from the concept design to the decommissioning. A well planned and organized management of the modularisation activities has to be carried out because *"I see to many improvised solutions"* comments one of the EC sector managers at the workshop. In order to get the uptake of the method there is the necessity of higher contractor's experience, *"modularisation gives benefits only if the project is managed properly"*. An interest result come from the questionnaires, the majority of the client requirements and project characteristics was seen as potential drivers to use modularisation, but the project management factors were all seen as a constraint, this implies that the market perceive that EPC and contractors are not able to manage properly the challenges that presents a modular approach, ending up in ruing advantages achievable.

<u>Lack of industry understanding of modularisation</u>

The client understanding of benefits and constraints of modularisation is crucial to establish the uptake of the method in the industry. For "industry", we mean all the project operators in a broad sense, from the client team to the suppliers. *“Most of the times clients came with a feasibility plan already done, and stick build in mind”* reports an expert; at that stage is difficult to convince them to take in consideration different options; in fact continues the expert *“clients perceive modularisation more expensive and exclusively adoptable for offshore plants”.* The workshop data supports the interview data asserting that the willingness of the client towards adopting a modular approach is crucial and the industry still doesn’t recognise modularisation advantages. This finding is coherent with the literature; the necessity of a more spread and higher knowledge about modularisation is advocated by many publications.

Coordination and communication

The coordination required to manage modularisation projects is surely higher than in the stick build approach, interviewees has underlined the necessity of modern and advanced communication and coordination methods to better connect all the people operating in the working program. From the questionnaires emerges that the adoption of the modular approach increases the complexity of the engineering phase and the design of the interphases; accordingly, experts suggest innovations and introduction of advanced systems to keep instantly up-to-date the appropriate project operators. An interest point raised in the workshop is that modern systems should be able to keep track of the successful communication and coordination method used by the team, because in the EC sector one-off projects are the normality, so bringing forward the knowledge developed by the team, after the split apart, could be fundamental to implement successful integration techniques for future teams.

Develop local content

Called in different ways by interviewees, develop local content, legacy, generate local economic growth, infrastructural expansion; they all agree in defining this factor as a strong constraint for the adoption of modularisation. When the government wants to use big projects to develop local workers skills and provide work for local companies, the adoption of modularisation is highly hindered due to the fact that moves work offsite. Still a percentage of the plant can be modularised but the percentage is surely reduced. This finding firstly come out during interviews and was successively strongly confirmed by the final questionnaire and the workshop. Moreover, the literature often forgets to give the right consideration to this strong constraint.

Repeatability and standardisation

Often in the literature is promoted the possibility to reuse or relocate part of the plant elsewhere. This could be a strong driver for the adoption of modularisation, but the data show that rarely this happens; a client stated *“usually we don’t go for repetition, just one-off module”*. Moreover, client/owner of the project doesn’t attribute value, during the selection period, to the future utilisations and the residual value of the plant at the end of the life-cycle. Questionnaire data displays that the adoption of modularisation can help to achieve a higher final end-life value of the process plant; if the client attention and understanding of modularisation would be higher this could be a driver to go modular. The second topic touched by experts during interviews regards the standardisation opportunity, on this, it has been observed contradictory views, for example a client declared “it is difficult to introduce standardisation, every project is very different”, instead an EPC and a contractor asserted “it is possible to introduce some standardisation for future similar projects”. The client view is important, in fact all projects are different, especially when we consider huge EC projects, but the visibility of the contractors on the engineering phase leads to believe that in the EC sector some of the process features can be repeated and learning from past projects can help to streamline the design and the engineering phase of the future similar projects.

Forecast about future adoption of modularisation

Most of the interview respondents see an increase in the adoption of modularisation in the close future, some of them clarifies that this increment will occur only if the industry will understand the benefits and drawbacks of the method. This higher adoption will be boosted by the growth of mega projects all over the world, mainly in remote locations or developing countries where the availability of skilled workforce is limited. Moreover, one of the interviewees specified that, ”*the more the method will be used the more its adoption will grow”.* In fact companies will improve their management skills in directing modular projects and this will help to achieve cost and risk reduction that will foster the expanding trend.

5.4.2 Inter-relationship table

This matrix can be used to identify where the client requirements or project characteristics or managerial techniques that characterize the execution of a project support or impede one another. The level of interrelationship between the factors is represented by the symbols:

Strong positive relationship: ◎
Weak positive relationship: ○
Weak negative relationship: ▬
Strong negative relationship: ✖

In order to read the table, it has to be kept in mind that symbols represent how the factors on the rows affect those on the columns. This tabular form was adopted to respect the nature of the relationship between factors; in fact it is often not a two-way correspondence. This means that if the factor “a” increases and “b” increases the opposite is not given for granted. The question asked at each consideration of the couple of characteristics was:
“Does the improvement of this requirement/characteristic/technique cause DETERIORATION or an IMPROVEMENT in the other one?”
Where the answer is “deterioration “a trade-off exists and the relationship is negative, otherwise the relationship is positive.

	shorter schedule	lower project cost	lower facility running cost	hihger plant quality	hihger offsite productivity	improved certainty/ predictability	higher H&S	higher project complexity	hihger project risks	higher sustainability	hihger innovation and R&D	new hi-tech systmes	easier and safer maintenance	less flexibility and chnages	earlier decisions	higher engineering/design effort	more transportation problems	poor logistic infrastructure	brownfield site	limited site storage space	lack of cranes availability	lack of skilled workforce onsite	high skilled workers cost	adverse climate onsite	long distance from sea/rivers	site closeness to big cities	lack of contractors' experience	lack of modular. understanding	hihger communication required	political issues	project repeatability
shorter schedule		*						O	O						◎	O	O														
lower project cost	*																														
lower facility running cost																															
hihger plant quality		✖	◎							O																					
hihger offsite productivity	◎	*		O		O	◎						O			–	–														
improved certainty/ predictability	–	–																													
higher H&S		–							–																						
higher project complexity	–	–		–		–			O					–			O												◎		
hihger risks							✖	◎								O	O												◎		
higher sustainability		–	◎																												
hihger innovation and R&D		✖										◎					–				✖										
new hi-tech systmes		–				O		*								✖	–												O		O
easier and safer maintenance			O				◎																								
less flexibility and changes	◎	O				◎										–													–		
earlier decisions	◎													◎			–														
higher engineering/design effort	O	–						O					O				✖														O
more transportation problems	✖	✖						O	◎						O	O													O		
poor logistic infrastructure	–	–				–											◎														
brownfield site																	◎			O	O										
limited site storage space																															
lack of cranes availability	–					✖		✖	✖								◎														
lack of skilled workforce onsite																							◎								
high skilled workers cost		✖																													
adverse climate onsite	✖	–		✖		✖	✖		✖								◎														
long distance from sea/rivers								✖	✖						◎	◎	◎														
site closeness to big cities																		–		O	–	✖									
lack of contractors' experience	–	–		–		–											–														
lack of modular. understanding																											◎		O		
hihger communication required																															
political issues	✖	✖		–		✖	✖		◎																						
project repeatability	◎															✖													–		

Figure 34 – inter-relationship matrix

As a general rule a positive correlation stands for a proportional relationship between factors (an increase of the factor "a" corresponds to an increase in the factor "b"), instead a negative correlation stands for an inverse relationship. For a better comprehension some examples are provided. The "lack of skilled workforce availability" decreases with the increasing "closeness of the site to big cities" because presumably there is more availability of skilled workforce near big cities. Higher "earlier decisions and higher engineering and design effort" leads to "higher risks and project complexity", in this case there is a proportional relationship. The "shorter schedule" is referred to a shorter time of the project in case of adoption of modularisation; for this reasons for example an improvement of the factor increases the "transportation and lifting issues". Another example can be the “higher productivity”, the matrix stresses the fact that the working activities occurs offsite, this for example, does not generate impact with “adverse climatic conditions onsite”. In the matrix there are four boxes with symbol “*” this means that either a positive correlation or a negative one can occur, this is due to a dual reading opportunity. An example is the “introduction of new hi-tech systems” it will have a dual effect on the project complexity, from one side it increments the complications deriving from the adoption of a new technology, but from the other side it helps to overcome some problems before not solvable with the previous instruments. Moreover, there is one factor, “request to develop local content”, which is not impacted and does not impact any other factor, it was not included in the table because it is a stand-alone factor but still has a strong impact during the construction type selection process.

The inter-relationship represents the first step for the later development of the overall findings (see 5.4.3). For example the “higher productivity offsite” concurred to the determination of several factors within the “client objectives” and “project circumstances”. Therefore, the matrix was used to develop the early decision support tool, it was crucial to determine the systemic grid behind the first level of client requirements and project characteristics (see 6.2).

5.4.3 Overall findings

From the data gathered during the research it turns out that the most important characteristics to look at, when evaluating the adoption of modularisation with respect to conventional stick build can be organised in four main groups:

1. Client objectives
2. Site characteristics
3. Project execution and management approach
4. EPC, contractor and industry players status

Below there is the description of all the characteristics, it is worth to mention that the list doesn’t aim to be exhaustive, in fact based on the type of project, the list of factors to consider can be hugely increased. Moreover, an impact of each of the elements that contribute to determine the characteristic was assigned; the aim is to point out a rough weight system based on the data collected for the EC sector projects, but it is important to keep in mind that each project is different and has different parameters that leads to different impact of the factors of the specific characteristics. Obviously the impact level reflects the researcher judgement of the overall data collected on the specific factor. This table will be used to provide a global view of the drivers and constraints affecting the selection of the construction method.

Letters: H for high impact, M for medium impact and L for low impact was used to indicate the impact of the driver/constraint on the characteristic.

- H: It is a driver/constraint that has a strong impact on the characteristic
- M: it is a driver/constraint that can be strong or weak depending on the type of project and the effectiveness of managerial methods adopted
- L: it is a driver/constraint that has a weak impact on the characteristic

The terminology used in this table is representative of the nature of the characteristics:

- **Driver**: factors, elements, characteristics that pushes towards the realisation of a process, project or event.
- **Constraint**: hinders and put obstacles on the realisation of a process, project or event. The project is feasible but has some complications to solve, that can result in higher expenditures.

Driver and constraint were used due to their meaning indicating better the nature of each characteristic in relation to the adoption of modularisation in EC projects, rather than enabler and barrier.

- **Enabler**: support, complete and facilitate a process, project or event.
- **Barrier**: inhibits, prevent and impede the realisation of a process, project or event. Basically the project is not feasible.

Table 11 – client objectives

Characteristics	Drivers	Constraints	Balance
Cost of the project	H: lower onsite cost : - less workers - shorter work duration - less accommodation expenses H: lower labour cost per unit due to higher productivity offsite. M: higher financial	H: higher engineering and design cost due to higher working hours required H: transportation cost of the	**Can be either a driver or a constraint** This is usually the main objective of the client, but it is not easy to predict if modularisation is cheaper than stick build. The cost of the project is highly affected by the type, location and constraints of the project.

	benefits due to shorter schedule: - reduced interest charged - earlier business (ROI) - reduced disruption to the existing locality or existing business L: less material and reworks reduction L: lower onsite preliminaries cost L: savings on external consultant for design L: lower transportation cost of all the equipment onsite L: lower testing cost	module M: higher material supply cost, due to better offsite quality (if considering a direct comparison) M: expenses to set the infrastructure for the transportation to the site (warranties, insurances, local taxes) L: higher cost of the skilled workers, stably employed in the offsite facility L:Higher expenses on implementing sustainable equipment and processes	A direct comparison of the costs between the two methods is superficial and incomplete due to the high project complexity and huge number of factors and items to examine. Moreover, in order to have the clear picture, indirect benefits associated to the adoption of modularisation should be considered and transformed in cost-based elements. The client shouldn't stop to the simple cost element comparison, but should deeply consider advantages of the adoption of modularisation even if looks a slightly more expensive option.
Running cost of the plant	M:Improved sustainability of plant		**Weak driver** The client should be aware

	process L: Higher quality can lead to less business stops L: easier and faster maintenance procedure (less hinder for the existing business) L:higher residual value at the end of the life of the process modules (reuse and refurbishment)		that the selection of the construction method will have a long term impact on the functioning of the plant, and so, on the business. Considering the entire life-cycle of the plant the modular approach encompasses several benefits, that during the early conception of the project is not easy to transform in cost related items, but in the long term can produce better plant functioning conditions
Schedule time	H: parallel working M: diminished delays and work slowdown in the offsite facility M: higher productivity in the offsite facility	L: more detailed engineering effort (considering also transportation and risk mitigation) L: higher team organisation, coordination effort	**Strong driver** The shorter schedule, achieved by the overlapping of off-site and on-site activities, is the main advantage of selecting a modular approach. This benefit can be erased by a poor management ofthe project, due to lack of experience and competencies. (e.g. transportation issues, delays during installation, lack of coordination between interphases, long time to communicate right information, failure of risk mitigation)

Quality of the plant	M: More organized and optimized working footprint in the offsite facility M: better trained workers M: testing of the whole process equipment (not just parts of it but the entire piece) M: better quality of the material due to probable long term relationship with suppliers: - Materials conform to specifications - Quality assurance and control techniques in place - Certifications controls	M: location and poor organisation of the offsite facility can inhibit the drivers (cheap labour localities, recent opening) M: second hand material adoption	**Weak driver** Usually with modularisation is possible achieve better results in terms of quality, but in order to achieve this outcome, the reliability and expertise of the contractor are crucial.
Certainty and predictability	H: higher schedule predictability due to simultaneous work H: higher certainty of offsite facility cost (e.g. labour cost, supply, transport) H: early freeze of design and decisions	M: higher risk (e.g. during transportation and installation) M: higher necessity of coordination between the	**Strong driver** Surely the certainty and predictability of the outcome is improved, this is particularly useful when the client wants to achieve a short time to market.

	H: less hinders by external conditions (e.g. climatic)	project phases and individuals	
Health and safety	H: reduced risk and workers' exposure to onsite working conditions (dangerous activities, adverse climate) H: higher trained workforce offsite H: improved footprint, activities schedule and equipment organisation		**Strong driver** This is one of the strongest drivers of modularisation. It is crucial to assure the best working conditions and reduce workers risk exposure, so becomes imperative to move workforce offsite when onsite working procedures involves dangerous activities or hazardous procedures.
Sustainability	M: less pollution (due to less vehicles movement onsite) L: more environmental friendly offsite working procedures L: Less material usage, energy and water consumption L: less material waste L: facilitate recycling	L: higher pollution during the transport of modules	**Weak driver** The market is still not ready to pay for this benefit, but adopting modularisation can help to achieve better sustainable results. Global trends are moving towards more and more sustainable construction. (It is perceived as a driver at a strategic level, but from interviews we have indications that at an operative level there is a lack of implementation and effective adoption of sustainable activities)
Develop local content		H: government asks to	**Strong constraint** When the government wants to use big projects to develop

		employ local workers H: government asks to use as suppliers local companies (or % of supply has to come from local companies)	local workers skills and provide work for local companies the adoption of modularisation is highly hindered due to the fact that moves work offsite.

Table 12 –Site characteristics

Characteristics	Drivers	Constraints	Balance
Site conditions	H: restricted space for material storage (stock) H:Brownfield site, hinder living environment M: not conductive working footprint onsite	H: restrictions on usage and placement of cranes M: reduced space for the movement of modules	**Can be either a driver or a constraint** An analysis of the particular site conditions of the project is required to understand if the modular approach is hindered by unfeasibility of lifting and moving modules. (client advices missing)
Site location	H: lack of skilled workforce onsite H: too expensive	H: long distance of the site from sea or rivers H: adverse onsite	**Can be either a driver or a constraint**

	onsite workforce M: closeness to living accommodation of the construction site (necessity to reduce noise, dust, congestion of the site) M: problematic political situation in the construction area: - Work not assured - Supply hindered - Lack of stable workers - Energy and water provision not reliable	climatic conditions H: availability of skilled workforce at a fairly price in the construction site M: closeness to big cities of the construction site (good infrastructural systems): - Good network for supplier - Workers own accommodatio n - Energy and water providers	The site location is one of the most important aspects of the project to consider, it includes different aspects that can either enable or hinder modularisation. The client should have a clear view of the advantages and disadvantages of building in a certain area. As the table shows is difficult to have all benefits, so the selection of the construction method should be done focusing on the objectives that the client wants to achieve. (client advices missing)
Transport infrastructure		H:lack of transport infrastructure: - Ship availability and port facility - Roads and bridges availability and capacity H: heavy lift cranes	**Can be a weak or a strong constraint** It can be very expensive to face transportation infeasibilities due to lack of infrastructure at a late stage of the project. A careful forecast of future

		not assured M:permits and legal legislation barriers on module movements	unfeasibility should be done from the first phase of the project, because this kind of problem can ruin the benefits achieve with the modular approach up to that moment.

Table 13 – project execution and management approach

Characteristics	Drivers	Constraints	Balance
Engineering and design	M: possibility to introduce standardisation for project replication M:early involvement of the client and key project players L:Early focus on design issues (resolution of infeasibilities)	H:limited late changes due to early freeze of design and decisions M: high engineering and design effort, mainly detailed engineering, necessity to design for transportation and maturity of the information at the early stage	**Weak constraint** The main aspect of considering this characteristic a constraint is related to the higher detailed engineering effort and to the early decision making. In the engineering construction sector the lack of design solutions is not perceived as a constraint (e.g. it was never mentioned during interviews). The flexibility is perceived as a constraint for the limited opportunity of changes. Moreover there are some advantages in anticipating this phase.

Complexity and risk	M: opportunity for an early planning and mitigation of risks (e.g. during transportation) L: few opportunities to introduce changes during the project, that reduces the cost and time scope changes.	H:high transportation risk (module damaged or lost) M:increased engineering complexity L:early procurement might lead to higher logistic complications L:risk allocation shift (e.g. from engineering design to engineering construction)	**Weak constraint** The higher risk and complexity is related to the design, transportation, installation and management of the project interphases. However, this constraint is mainly related to the lack of experience and competencies in managing modular projects.
Coordination and communication	L:increased relationship with suppliers due to the increased contacts	M:higher coordination and communication required during transportation and installation M: more effective communication and coordination required between project operators L:higher requirements for suppliers	**Weak constraint** The level of coordination and communication required to properly manage modular projects is surely higher, but the recent technological advancement can help and provide new generation hi-tech tools to support the most critical phases of the project and establish an efficient communication network. However the industry is quite slow in embracing changes and adopting new solutions.

Table 14 – EPC, contractor and industry players status

Characteristics	Drivers	Constraints	Balance
EPC propensity to go modular	H: economic interests in advising a modular approach (e.g. design hours payment) H: strong relationship with network of subcontractors	H: economic interest in advising a stick build approach H: interests in not advising a modular approach due to lack of knowledge and experience	**Can be either a driver or a constraint** Often the main contractor has more advantage in advising one solution or another. This leads to distortion of the real features of benefits and drawbacks. In order to have a clear picture, the client should acquire knowledge about the status of the industry and mechanisms that steers it. Moreover, they should be aware that usually cost comparisons are biased. One solution could be to not focus on the cost features but understand which advantages and which objectives fulfils each construction method.
Experience of the contractor		H: lack of consolidate methods and management procedures in facing modular projects	**Strong constraint** When selecting the contractor, it is not possible to surely predict his performances and the level of service. However, it is crucial for

		H: lack of critical information management H: lack of risk evaluation and mitigation (e.g. during transportation and installation) M:lack of coordination and communication methods	the client to acquire knowledge about expertise and competences of the contractor as well as, his experience and the number of modular project he managed. A well planned analysis and management of the project makes the difference between a successful execution and a poor one.
Industry understanding of modularisation		H:client's lack of understanding of pros and cons of modularisation H: lack of project operators knowledge about modularisation	**Strong constraint** In the last years the real uptake of the method has been hindered by the reluctance of the industry to embrace changes and by the lack of knowledge about this "new" construction technique.

6 Early decision support tool

The ultimate step of the all data gathering process, calculation execution, and findings deduction is the early-phase decision support tool constitution. The characteristic findings served as identifying the nature, either unique or double of the characteristics affecting the selection of the construction method. The inter-relationship matrix was built extrapolating elements from the characteristic findings. This matrix was crucial for the tool creation, establishing the influence that the second level factors exercise on the first level one. Finally, the most important conclusions useful for the tool creation were the overall findings tables. As it is possible to notice (see 5.4.3) the tables are divided in four groups, providing for each category the inner factors, if the factors are drivers or constraints and the level of impact. All this information was used in the tool development, both at the first level and the second one.
The early-phase decision support tool was nominated “MasterMOD”.

6.1 MasterMOD conceptual design

Research data and literature information led to the understanding that the client executes a set of strategic studies prior to the feasibility study, selecting the construction method. One of the EPC experts is quoted as reporting during the interviews that *“the client comes with the selection of the construction method already in mind, often happens that he just asks for a stick-build feasibility study” he continues stating that “*at this stage it is difficult to propose a modular approach, since the client does not know and understand this construction method”. The first aim of the tool is to support the client during the initial strategic evaluation of the construction method, avoiding entering in the process too late. The second purpose is to support the client at a pre-feasibility study phase highlighting the critical constraints and confirming the drivers of the execution of a modular approach. MasterMOD was conceptualised in two levels:

3. Strategic level
4. Pre-feasibility level

The strategic level was tackled both to intervene in the process selection as early as possible and because of the too variable nature of the tactical level. The factors to consider and elements interdependencies to evaluate in the tactical level are higher than the strategic one and are not easy to forecast due to the specificity of the project.

Moreover as explained in the literature review the adoption of modularisation should be considered as soon as possible to realize benefits of the method (Gupta et al., 1996),(CIRIA, 1999),(Gibb & Isack, 2003). In this phase the tool objectively assesses the goodness of the selection of modularisation. The purpose is to promote a productive discussion between the operators involved in the selection phase, understanding benefits and drawbacks that lead to the selection method promoting a structured decision process. This is fundamental since the literature denounces the lack of methodological decisions (Pan et al., 2008),(Salman Azhar et al., 2013). Prior to the feasibility study, the second level aim is to assess the feasibility and main constraints of a modular approach in the specific project. This evaluation is useful for the client both to comprehend the main critical areas of the project execution and ask to the EPC Corporation that will lately do the feasibility study which mechanisms and relative cost will be used to overcome the constraints.

6.2 MasterMOD first level design

A weighting factor method was deemed to be appropriate for the design of the first strategic screening of the construction options. The selection of a relative weighting system seemed reasonable due to high number of factors affecting the selection process. The process is intuitive for the client, since it is based on the same decision-making criterion that governs the decisions of the industry experts. In fact managers often rely on different parameters weighted in terms of importance according to their experience, to judge opportunities. Moreover, the client can understand the specific impact of each of the factors, realizing which of them is a driver and which a constraint. One of the hidden accomplishments of the utilization of the tool is the acknowledgment of the client on the modularisation practices. The lack of industry understanding of modularisation was one of the most stressed hindrances for the uptake of the method (see Table 10 – Interviews resume). Conversely, relative weights depends on the quality of questions and reflects the individual judgement and experience of the respondent (Cigolini & Castellano, 2002), therefore the answers depend on the level of understanding of the client. This might be a limit of the system adopted, because it might be problematic for the user to provide an exhaustive evaluation of all the asked factors (see 6.3.2). But individual judgments have to be made to take decisions, and personal objectives have to be the foundation for the selection process. Moreover a weighting system is more suitable than a fixed one, to follow the variability of the various projects.

6.2.1 Strategic level: algorithm

The overall expression of the algorithm is:

$$M = \pm C * X1 \pm \mathrm{FE} * \mathrm{X2} \pm T * X3 \pm Q * X4 \pm CP * X5 \pm RWE * X6 \pm S * X7 \pm D * X8$$

Legend:

M: the final result of M gives indication on the goodness of adoption of modularisation, the higher the result the higher percentage of modularisation is advised (for a deeper understanding see 6.2.3 and 6.2.4).

C: total project cost

FE: future expenditures, running facility cost

T: time schedule of the project

Q: quality of the plant

CP: certainty and predictability of expenditures and completion time

RWE: reduction of workers exposure to onsite working conditions

S: sustainability factor

D: develop local content

The “$\pm$" indicates that each factor can be either positive or negative, this depends on the level of applicability of the elements composing the factors to a specific project, see 6.2.2 and 6.2.3). The X values represent the relative weights given by the user. The client chooses a percentage to attribute to each of the factors; obviously the sum has to be 100%. Each of the X values refers to the factors listed above: X1 refers to C, X2 to FE and so on.

$$X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 1$$

The client will have a grid in which through a drop down menu can choose the value to attribute to each factor. This value will be a percentage, facilitating the user’s weights insertion. Later percentages will be transformed into decimals values. For a deeper understanding see 6.2.3).

6.2.2 Strategic level: elements of the factors

As it is possible to notice the first level factors are the one that appears in the first table of the overall findings: client objectives (see Table 11 – client objectives). Each of these factors comprehends several elements; these elements are listed in the overall findings tables under the columns of drivers and constraints of the Table 11 – client objectives. For the calculation of the first level factors the client judges the level of applicability of each of these elements to the project (see 6.2.3). In this way only the elements applicable to the specific project will concur to the determination of the first level factors. For example, the elements composing the "C" factor are listed below, see Table 15.

The purpose of the tool is to be neither too simplistic nor too detailed, so the elements of the factors lay in the strategic level. The tactical and operative level consideration is out of the scope of the current tool since often at these stages a cost-comparison evaluation governs the decision-making process. Moreover, it is arduous to figure out the exact number and extent of elements concurring to determine the relevant factors of these detailed phases, due to the high project variability and projects' diversity.

Below the list of the basic elements composing the first level factors is outlined. The level of impact (H, M and L) and the sign, "+" for drivers and "-" for constraints is reported. It is important to point out that the nature of the elements composing the factor and its intensity in terms of impact on the factor is the result of the research data. With nature it is intended if the element is driver or a constraint for modularisation. So, the client will judge the applicability of each element to his project, but he cannot choose the elements and the impact of them in the determination of the value of the single first level factor (see 6.2.3).

Table 15 – C first level factor

total project cost
+H: Reduced overall project cost due to lower onsite cost, because of both less number of total workers due to shorter schedule and less accommodation expenses
+H: Reduced overall project cost due to lower labour cost per unit as a result of higher productivity offsite
+M: Reduced overall project cost due to higher financial benefits because of shorter schedule (e.g. reduced interest charged, earlier business (ROI), reduced disruption of the existing business)
+L: Reduced overall project cost due to less material and reworks reduction
+L: Reduced overall project cost due to lower onsite preliminaries
+L: Reduced overall project cost due to savings on external consultant for design
+L: Reduced overall project cost due to lower transportation cost of all the materials and equipment in the offsite facility (otherwise to send onsite)

+L: Reduced overall project cost due to easier and cheaper testing phase
-H: Increased overall project cost due to higher engineering and design working hours required
-H: Increased overall project cost due to transportation cost of the module
-M: Increased overall project cost due to higher material supply cost as a result of better offsite quality (if considering a direct comparison)
-M: Increased overall project cost due to higher expenses to set the infrastructure for the transportation to the site (warranties, insurances, local taxes)
-L: Increased overall project cost due to higher cost of the skilled workers, stably employed in the offsite facility
-L: Increased overall project cost due to higher expenses on implementing sustainable equipment and processes

The logic followed relies on the "applicability" to the project. For example, "*Increased overall project cost due to higher cost of the skilled workers, stably employed in the offsite facility*" it does not mean that this element occurs in all projects with this impact, in fact the offsite workers can cost less or more than the onsite one depending on the onsite location. This feature is asked to the client in order to understand the level of applicability of this element to the specific project. In case of high applicability of this feature it means that for this project the client has visibility on the labour cost in the offsite yard. Regarding terms like "*preliminaries*", that are technical and might be misunderstood by the user, it is established they are integrated with notes on the right of the paper providing the definition and explaining the meaning. This will be done in the case of an implementation of the tool in a software application.

Table 16 – FE first level factor

Future expenditures, facility running cost
+M: Reduced facility running cost due to improved sustainability of the plant processes
+L: Reduced facility running cost due higher quality of the equipment (less business stops)
+L: Reduced facility running cost due easier and faster maintenance procedure
+L: Reduced facility running cost due higher residual value of the process modules at the end of the life (reuse and refurbishment)

Table 17 – T first level factor

time schedule of the project
+H: Reduced time schedule due to parallel working
+M: Reduced time schedule due to diminished delays and work slowdown in the offsite facility
+M: Reduced time schedule due to higher productivity in the offsite facility
+L: Increased time schedule due to higher detailed engineering and design effort (considering also higher transport configurations and risk mitigation effort)
+L: Increased time schedule due to higher organisation and coordination requirements

Table 18 – Q first level factor

quality of the plant
+M: increased plant quality due to more organized and optimized working footprint in the offsite facility
M: Increased plant quality due to better trained workers
+M: Increased plant quality due to better testing of the whole process equipment (not just parts of it but the entire process)
+M: Increased plant quality due good quality of the material as a result of long term relationship with suppliers (materials conform to specifications, quality assurance and control techniques in place, certifications controls)
-M: Decreased plant quality due to the location of the offsite facility (cheap labour localities, recent opening)
-M: Decreased plant quality due to second hand material adoption

Table 19 – CP first level factor

certainty and predictability of expenditures and completion time
+H: Increased certainty and predictability of the completion time due to simultaneous work
+H: Increased certainty and predictability of the expenditures due to higher visibility on the offsite facility costs (e.g. labour cost, supply, transport)
+H: Increased certainty and predictability of the expenditures and completion time due to less hindrances from the external conditions (e.g. climatic)
+M: Increased certainty and predictability of the expenditures and completion time due to early freeze of the design and anticipated decisions

-M: Decreased certainty and predictability of the expenditures and completion time due to higher risk (e.g. during transportation and installation)
-M: Decreased certainty and predictability of the expenditures and completion time due to higher necessity of coordination between the project phases and individuals

Table 20 – RWE first level factor

reduction of workers' exposure to onsite working conditions
-H: Reduction of workers' exposure to onsite working conditions due to reduced risk and workers' exposure dangerous activities and/or adverse climatic conditions
-H: Reduction of workers' exposure to onsite working conditions due to higher trained workforce offsite
-H: Reduction of workers' exposure to onsite working conditions due to improved footprint, activities schedule and equipment organisation (in the offsite facility)

Table 21 – S first level factor

Sustainability factor
+M: Increased sustainability due to less pollution (because of less vehicles movement onsite)
+L: Increased sustainability due to more environmental friendly offsite working procedures
+L: Increased sustainability due to less material usage, energy and water consumption
+L: Increased sustainability due to less material waste
+L: Increased sustainability due to facilitated recycling process
-L: Decreased sustainability due to higher pollution during the transport of modules

Table 22 – D first level factor

develop local content
-H: government requests to employ local workers
-H: government requests to use as suppliers the local companies (or a % of the supply has to come from local companies)

6.2.3 Strategic level: calculation of the factors' value

As explained before, the list of elements composing the first level factors is fixed. Moreover, the researcher decides both the impact (H, M, and L) of each element determining the factor and the nature of the element: if it is a driver (e.g. *Increased sustainability due to etc.*) or if it is a constraint (e.g. *Decreased sustainability due to etc.*) for the adoption of modularisation. The user can decide only the applicability of each of the elements on his specific project, this process is done by answering to the following question for each of the elements composing the factor:

To which extent is the … (changing phrase)… applicable to this specific project?

An example of this question is: To which extent is the *Reduction of workers' exposure to onsite working conditions due to reduced risk and workers' exposure to dangerous activities and/or adverse climatic conditions,* applicable to this specific project?
The list of possible answers to this question is provided to the user in the form of options. The user has the possibility to choose between the following answers:

- *I do not have visibility*
- *Not applicable*
- *Somewhat applicable*
- *Applicable*
- *Extremely applicable*

Each of the options above is associated with a value:

- *
- *0*
- *1*
- *2*
- *3*

The "*" symbol indicates that the algorithm will associate to a value zero. For a further explanation of the factors on which the client has not visibility see MasterMOD pre-feasibility level design.

Keeping in mind that each element has an impact (H, M and L) and a nature (driver or constraint) given by the researcher, this is translated in the algorithm with the following features:

Driver, High impact	+9
Driver, Medium impact	+3
Driver, Low impact	+1
Constraint, Low impact	-1
Constraint, Medium impact	-3
Constraint, High impact	-9

The calculation process of the first level factors (C, FE, T, Q, CP, S, RWE and D) is represented below:

$$\sum_{i,j}^{i=n,j=m} Ri * Aj \; = first\ level\ factor\ k$$

Legend:

R: Relevance and impact set by the researcher (+9, +3, +1, -1, -3 or -9)

A: Applicability selected by the user (*, 0, 1, 2 or 3)

k: index of the first level factor

i: index of the researcher's relevance

j: index of the user's applicability

n=m for each factor the number of items is the same

In order to show the procedure an example of the calculation of the T factor value (see Table 17 – T first level factor) calculation can be presented (for an overall process example see 6.4.1). The questions related to the time schedule of the project factor are:

Element questions	Selected applicability
To which extent is the reduced time schedule due to parallel working, applicable to this specific project?	Applicable
To which extent is the reduced time schedule due to diminished delays and work slowdown in the offsite facility, applicable to this specific project?	I do not have visibility
To which extent is the reduced time schedule due to higher productivity in the offsite facility, applicable to this specific project?	Somewhat applicable

To which extent is the increased time schedule due to higher detailed engineering and design effort (considering also higher transport configurations and risk mitigation effort), applicable to this specific project?	Extremely applicable
To which extent is the Increased time schedule due to higher organisation and coordination requirements, applicable to this specific project?	Not applicable

Notice that that user has visibility only on the question, the nature and the level of the impact of the elements is not provided during this initial phase. Based on the fixed relevance of the elements and the selected applicability, the equation determining the T factor value can be determined:

$$T = (+9) * 2 + (+3) * 0 + (+3) * 1 + (-1) * 3 + (-1) * 0 = +18$$

This T factor will be multiplied by the relative weight (X3) given to this factor (see 6.2.1). The same procedure has to be adapted with the other factors contributing to the first level analysis. The sum of all the results gives the value of the M factor. The interpretation of the "M" outcome is explained in the below section.

6.2.4 Strategic level: presentation of the result

The aim of this level results' presentation is to clarify if a modular approach can bring benefits to the client, a further detailed analysis on the feasibility of the approach will be executed in the second level. Based on the user's answers the final report is provided. It is composed of a statement resuming the goodness of the adoption of modularisation (see Table 23) plus a couple of tables including the list of elements that promotes the adoption of modularisation. The first table shows both all the driver elements that received an "Extremely applicable" level of applicability on the specific project and the constraint elements that received "not applicable" as applicability on the specific project. The second table shows all the elements that received "I do not have visibility" on the specific project. In the representation, the list of elements is divided according to the first level factor to which each element belongs. The value of the M factor reflects the goodness of the adoption of modularisation. The higher the value the more suitable is the project to the adoption of modularisation.

According to the value of the M factor different messages, advising diverse levels of modularisation are displayed to the user:

Table 23 – M factor value explanation

M<0	*Based on the information that you have provided, the project should gain limited benefits from the adoption of modularisation. The adoption of basic amount of modularisation, common to all projects now days, is advised. The suggestion is to get the required information to answer to all the questions that you do not have visibility on (in this case see also terminology help box).*
0<M<10	*Based on the information that you have provided, the project should gain benefits from the adoption of a modular approach. A partial amount of modularisation is advised. For a further pre-feasibility study of the project tackle the second level analysis.*
10<M<20	*Based on the information that you have provided, the project would gain benefits from the adoption of a modular approach. A considerable amount of modularisation is advised. For a further pre-feasibility study of the project tackle the second level analysis.*
20<M<30	*Based on the information that you have provided, the project would definitely gain benefits from the adoption of a modular approach. An intensive adoption of modularisation is advised. For a further pre-feasibility study of the project tackle the second level analysis.*
M>30	*Based on the information that you have provided, the project would surely gain benefits from the adoption of a modular approach. The higher possible amount of modularisation is advised. For a further pre-feasibility study of the project tackle the second level analysis.*

In case of the implementation of the tool in a software application, it will be possible to "click" on a symbol indicating a technical terminology and a help box that provides the explanation of the terminology adopted opens. This process is fundamental, since not all the users (presumably clients/owners) have the right competences, or simply are not familiar with the terms used to describe the project features. The results presentation comprehends also a message in which the user can see the factors that highly affected the final M score. Moreover the user is invited to go to the final table total factors value to understand the impact of each factor; the three most incisive factors are listed in the message. After the result presentation, in order to get acquainted with the algorithm logic the user can go through the answers provided. The relevance of the elements in terms of nature and selected level of impact are provided. In this way the user can understand why the feature selected led to the specific result.

6.3 MasterMOD pre-feasibility level design

The objective of the second level of the tool is to provide the level of feasibility of the project. It outlines which are the major drivers of the approach and which are the constraints that hinder a modular approach providing to the user a list of critical elements to focus on in order to overcome implementation hindrances. The aim is to acknowledge the client on the relevant strategic area of the implementation of the project, in order to deal with the feasibility study and interact with the EPC contractors in a productive way.
As with the first level, this second level is composed of a list of factors that appears in the tables of to the overall findings (see 5.4.3).

These factors are:

- Site conditions
- Site location
- Transport infrastructure
- EPC (and contractor) propensity to go modular
- Experience of the contractors
- Project management, execution practices and systems

It is possible to argue on the fact that also these second level factors should contribute to the evaluation of goodness of the adoption of modularisation, since also the project characteristics or project management factors concur to the selection process. However, the distinction between the two levels is clear, the first level provides an evaluation based on the client needs in terms of objectives to accomplish with the process plant, instead the second level is a further detailed analysis that serves as support to evidence the feasibility of the modular approach, highlighting the constraints that might hinder the execution of the project. The client might be interested in some features that a modular approach can accomplish in a better way than stick-built construction (e.g. reduce worker exposure to onsite conditions, need of completion certainty, higher level of sustainability etc.). In this case the strategic level of the tool suggests the adoption of a substantial amount of modularisation and the second level outlines which are the eventual critical area to focus on for a straight execution of the project. Even if there is a significant constraint, that presumably increases the cost of the project, the client can always select the modular approach, the pre-feasibility study will strengthen the contact with EPC and support the project execution. Moreover, it is wrong to assert that second level factors have no impact on the M factor, in fact many elements that influence the first level factors are related tot the project characteristics and project management practices likely to be adopted. Some examples are:

- Increased overall project cost due to higher expenses to set the infrastructure for the transportation to the site (warranties, insurances, local taxes)
- Reduction of workers' exposure to onsite working conditions due to reduced risk and workers' exposure dangerous activities and/or adverse climatic conditions
- Decreased certainty and predictability of the expenditures and completion time due to higher necessity of coordination between the project phases and individuals

6.3.1 Strategic level: logic

It is different from the algorithm adopted for the strategic level of the tool, that calculates a score (M). In this pre-feasibility study, since the benefit from the adoption of modularisation has been already claimed, each single element belonging to the second level factors will flow into one of the following groups:

- Strong drivers
- Weak drivers
- Mild constraints
- Critical constraints
-

The calculation process of the value of the elements and the score that lead to one or another group are presented in the section 6.3.3.

6.3.2 Strategic level: elements of the factors

Below the list of the basic elements composing the second level factors is outlined. As in the strategic level, also here the nature of the elements composing the factor and its intensity in terms of impact on the factor is the result of the research data. Reminding that with nature it is intended if the element is driver or a constraint for modularisation. So, the client will judge the applicability of each element to his project, but he cannot choose the elements and their impact.

Table 24 – site conditions second level factor

Site conditions
+H: restricted space for material storage (stock)
+M brownfield site that hinders site living environment
+M: not conductive working footprint onsite
-H restrictions on usage and placement of cranes
-M: reduced space for the movement of modules

Table 25 – site location second level factor

Site location
+H: lack of skilled workforce onsite
+H: too expensive onsite workforce
+H: adverse onsite climatic conditions
+M: problematic political situation in the site construction area (work not assured, supply hindered, lack of stable workers, energy and water provision not reliable)
+M: closeness to living accommodation of the construction site (necessity to reduce noise, dust, congestion of the site)
-H: long distance of the site from sea or rivers
-M: closeness to big cities of the construction site (good infrastructural systems, good network for supplier, workers own accommodation, energy and water providers)

Table 26 – transport infrastructure second level factor

Transport infrastructure
-H: lack of ship availability and port facility and/or roads and bridges capacity
-H: heavy lift cranes not assured
-M: permits and legal legislation barriers on module movements

Table 27 – EPC propensity to go modular second level factor

EPC (and contractor) propensity to go modular
+H: EPC economic interest in advising a modular approach (e.g. design hours payment)
+H: EPC relationship with network of subcontractors
-H: EPC economic interest in advising a stick build approach
-H: EPC interest in not advising a modular approach due to lack of knowledge and experience

Table 28 – experience of the contractor second level factor

Experience of the contractors
-H: lack of consolidate methods and management procedures in facing modular projects
-H: lack of critical information management (during design, employees communication, transportation and installation)
-H: lack of risk evaluation and mitigation techniques, during transportation and installation
-M: lack of coordination and communication methods

Table 29 – project management second level factor

Project management, execution practices and systems
+M: possibility to introduce standardisation for project replication
+M: opportunity for an early planning and mitigation of risks (e.g. during transportation)
+L: increased relationship with suppliers due to the increased contacts
-H: limited late changes due to early freeze of design and decisions
-H: high transportation risk (module damaged or lost)
-M: increased engineering complexity
-M: more effective communication and coordination required between project operators
-L: early procurement might lead to higher logistic complications
-L: risk allocation shift (e.g. from engineering design to engineering construction)
-L: higher requirements for suppliers

This factor is composed by a mix of the most relevant elements of the overall findings table of the project execution and management approach (see Table 13 – project execution and management approach). These elements were omitted to avoid repetition of influencing elements on the second level factors.

6.3.3 Pre-feasibility level: calculation of the elements' value

The procedure followed to determine the value of the elements is the same described in the strategic level; in fact the list of elements composing the first level factors is fixed. Moreover, the researcher decides both the impact (H, M, and L) of each element determining the factor and the nature of the element: if it is a driver (e.g. site location favourable to modularisation due to etc.) or if it is a constraint (e.g. site location unfavourable to modularisation due to etc.) for the adoption of modularisation. The user can decide only the applicability of each of the elements on his specific project, and this process is done by answering to the following question for each of the elements composing the factor:

To which extent is the … (changing phrase)… applicable to this specific project?

The phrase is the same of previous levels. In order to not repeat the description of the calculation process, the list of possible answers to the questions, and the pointing system is exactly the previously stated one.
Regarding the calculation of the overall factor value, in this phase it is not necessary, because the singular elements composing the factors will flow into one of the four groups. For completeness the element's value calculation process is reported below.

$$Ek = Ri * Aj$$

Legend:
E: Elements of the second level factors
R: Relevance and impact set by the researcher (+9, +3, +1, -1, -3 or -9)
A: Applicability selected by the user (*, 0, 1, 2 or 3)
k: index of the elements
i: index of the researcher's relevance
j: index of the user's applicability

In order to show the procedure an example of the calculation of the elements related to the transport infrastructure factor can be presented (for an overall process example see 6.4.1and 6.4.2).
The questions related to the time schedule of the project factor are:

Element questions	Selected applicability
To which extent is the lack of ship availability and port facility and/or roads and bridges availability and capacity, applicable to this specific project?	Applicable
To which extent is heavy lift cranes not assured, applicable to this specific project?	I do not have visibility
To which extent is the permits and legal legislation barriers on module movements, applicable to this specific project?	Somewhat applicable

Also in this step of the second level phase the user has visibility only on the question, the nature and the level of the impact of the elements is not provided. Based on the fixed relevance of the elements and the selected applicability, the equation determining the elements' value can be determined:

E1 (lack of ship availability and...) = (-9)*2 = -18

E2 (heavy lift cranes not assured) = (-9)*0 = 0

E3 (legal legislation barriers ...   ) = (-3)*1 = -1

In order to understand which and how these elements will flow into the four groups see Table 30.

6.3.4 Pre-feasibility level: presentation of the result

As previously outlined, the single element flow into one of the four "boxes" reporting the type of driver or constraint. The purpose is to show the drivers that push towards the realisation of a modular approach, and in particular to shed lights on the constraints that hinder the feasibility of modularisation. The following table shows for which values of the E, the element flows in one or the other group.

Table 30 – elements group allocation

$E \geq 18$	STRONG DRIVER
$6 \leq E < 18$	WEAK DRIVER
$-6 \leq E < -18$	WEAK CONSTRAINT
$E \leq -18$	STRONG CONSTRAINT

In the case of the implementation of the tool in a software application, the four groups will be presented to the user with the above colours. This is done to emphasize the intensity of the driver/constraint. Observing the calculation process and the tables of the factors of the second level it is possible to notice that only the elements ranked with a high impact (H) by the researcher and judged at least "Applicable" by the user can reach the minimum score to enter in the critical area. Since these are the most relevant constraints (the one that hiders the most the project feasibility), in the case of presence of one of these factors in the critical area an ad hoc message, each message for each constraint appears in the final result presentation.

The table below resumes the constraints with high impact and the relative messages in case of "applicable" judgment by the user.

Table 31 – suggestions for strong constraints

Element	Suggestions
restrictions on usage and placement of cranes	Try to investigate the nature of the restriction, check if it is a permanent situation due to the configuration of the site or a temporary one. In the occasion of the feasibility plan ask the EPC or contractor for a procedure to tackle the problem, understanding the expected cost of it. If there are no solutions available or they are too expensive, keep in mind that the restriction of usage of cranes can cause the unfeasibility of the modular approach.
Long distance of the site from sea or rivers	Be sure to the real distance (in terms of road kilometres) of the site from navigable waters. Investigate the available speed of the trucks, both for small and heavy modules (notice that the common speed for trucks is near 2 or 3 km/h for very heavy modules), investigate which are the standards in terms of weights and tracks transportation capacity (they change according to the type of plant). Evaluate with the contractor during the feasibility study if it possible to transport the module to the site at a reasonable price and time. Be aware of this huge hindrance, which causes the unfeasibility of the modular approach in case of excessive distance of the site from navigable waters.
Lack of ship availability and port facility and/or roads and bridges availability and capacity	Investigate the ship and port capacity, check if it is a permanent situation due to the configuration of the site or a temporary one. Complete a simulation of the forecasted path of the modules controlling the roads and bridges capacity. During the feasibility plan ask the EPC or contractor for a procedure to tackle the problem, understanding the expected cost of it. If there are no solutions available or they are too expensive, keep in mind that this constraint can cause the unfeasibility of the modular approach.

<table>
<tr><td>Heavy lift cranes not assured</td><td>The heavy lift cranes are necessary both during the transportation of the modules (for loading and unloading phases) and during the onsite installation. Investigate with the contractor, during the feasibility plan, possible solutions to the problem, with the relative price. This constraint can cause the unfeasibility of the modular solution.</td></tr>
<tr><td>Permits and legal legislation barriers on project movements</td><td>This can be a hostile constraint if not properly and early addressed in the project management. It might happen that due to political or socio-economic problems, well established transportation routes results not available. Check if the contractor can assure a feasibility transportation route for your modules, having the movement of modules blocked and delayed can enormously increase the overall time and cost of your project.</td></tr>
<tr><td>Economic interest in advising a stick build approach</td><td>Often EPC and contractors have interest in advising one or the other type of construction. This can be done to the type of investments on the industry, the nature of assets owned and the relationship network with small contractors. Try to investigate on the market dynamics and don’t let the adoption of modularisation be hindered during the feasibility study by this aspect.</td></tr>
<tr><td>Interest in not advising a modular approach due to lack of knowledge and experience</td><td rowspan="3">The experience of the EPC and contractor are crucial for the success of the project. This is due to the fact that the managerial experience and competence goes to impact all the areas of the projects, from the concept design to the decommissioning. Get acquainted with the level of experience of the EPC and contractors studying the market. Identify the EPC companies that have experience with modularisation, this are reasonably better to face the complexity of the modular approach. An advice could be to weight the feasibility studies according to the level of experience and reputation of the company.</td></tr>
<tr><td>Lack of consolidate methods and management procedures in facing modular projects</td></tr>
<tr><td>critical information management (during design, transportation and installation)</td></tr>
</table>

limited late changes due to early freeze of design and decisions	This is a fundamental characteristic of modularisation, in fact if the projects require decisions to be made at a relatively late stage. However it is possible to fix some parameters of the design, testing, production and delivery without freezing the whole design and leaving some marginal decision for later phases. Keep in mind that in order to exploit the full advantages of the modular approach an early freeze of the design should be done, if this is not possible the approach might be unfeasible.
High transportation risk (module damaged or lost)	The transportation risk is due to the dangerous path of the transportation of the module, this danger is incentivised if the contractor has poor experience with modular approach. Often risk mitigation practices are adopted by EPC and contractor companies. Control the experience of the contractor and check the transportation plan in the feasibility study. With the modular approach this is a risk that is always present.

Another important aspect to stress is necessity to get acquainted with the elements that the client has not visibility on. In the result presentation a table including the list of the elements on which the client has not visibility on will be presented. Moreover, the elements of this list that figure as constraints will be highlighted, indicating with a note the following phrase:

"it is crucial to establish the applicability of the "highlighted" elements, because they can result in a strong constraint for the feasibility of the project, the most important elements to pay attention on are the following:

- *Restrictions on usage and placement of cranes*
- *Long distance of the site from sea or rivers*
- *Lack of ship availability and port facility and/or roads and bridges availability and capacity*
- *Heavy lift cranes not assured*
- *Economic interest in advising a stick build approach*
- *Interest in not advising a modular approach due to lack of knowledge and experience*
- *Lack of consolidate methods and management procedures in facing modular projects*
- *Critical information management (during design, transportation and installation)*

- *Limited late changes due to early freeze of design and decisions*
- *High transportation risk (module damaged or lost)*

Of course in the message will appear the list of the elements that the client selected “I do not have visibility”. Exhaustive examples of the operation of the tool are presented in the section 6.4).

6.4 MasterMOD validation

6.4.1 MasterMOD example 1

EC projects are characterised by uncertainty and complexity, long-term construction, high expenditures, strict scheduling and huge amount of workers employed. Therefore it is not easy to exhaustively resume all the relevant aspects. In this section a general picture of the strategic level characteristics of an EC project is presented. The purpose is to test the tool with a plausible project. It is worth to mention that this is just a simulation, the client objectives and project characteristics are not relative to a real case study.

Project presentation, client objectives and project characteristics:
The project target is to build a natural-gas processing plant in the recently discovered natural gas deposit in the Illizi basin in Algeria by a consortium of energy provider companies (including Enel). Although the project born in an area where these companies already operates, it is unique and requires a “make to order” approach in the main phases. The construction time is crucial, in fact an earlier construction means a faster running of the business; due to financial reasons the companies involved are interested in faster construction of the plant. The construction project is complex and involves a great number of individuals and competencies from different departments. So, the right mechanisms of coordination and communication should be adopted. Moreover, it is crucial to properly manage the risks and the uncertainty. The companies involved are interested in reducing the overall budget of the project, but their main concern is the certainty and predictability of the expenditures, since publicly traded. The sustainability aspect is not a primary driver of the companies, but the players involved are keen to evaluate new opportunities that boost this factor, this is due to the recent global growing concern in green processes. Regarding the location, the site based in the Illizi basin is far from the navigable waters, the only viable option is too enter in Tunisia and go through the Azhar el Jarid gulf. Moreover the roads and the logistic infrastructure are deficient to transport big modules. The skilled workers availability is scarce, and the presence of the desert limits the number of cities around the site. The region climate is hot; workers cannot operate

during the hottest periods and critical hours of the day. The plant will rise in a Greenfield site. The client is not interested in achieving levels of quality beyond the regular standard. The government does not put particular pressure to the client requesting the development of the local content during the realisation of the project. For the feasibility study and the consequent execution of the project the consortium of companies is thinking to contact an EPC company leader in the sector (e.g. Flour Corporation).

Below a simulation of the tool is executed. The responses inserted are qualitatively estimated in a reasonable way by the researcher. The phrases in italic are presented to the user of the tool.

MasterMOD execution, strategic level

Please weight in terms of importance, according to the objective that you want to maximise with the realisation of this project, providing the percentage relevance percentage of the following client objective factors (keep in mind that the sum has to be 100%).

Client/owner objectives	**Weighting score**
C: total project cost	25%
FE: future expenditures, running facility cost	0%
T: time schedule of the project	20%
Q: quality of the plant	10%
CP: certainty and predictability of expenditures and completion time	35%
RWE: reduction of workers exposure to onsite working conditions	5%
S: sustainability factor	5%
D: develop local content	0%
Total	100%

After this voting phase, the numbers adopted for the calculation of the M factor are decimal values obtained dividing by 100 the weighting scores.

Please answer the following questions on the applicability of the elements to your specific project.

For of brevity reasons only the first element selection of the user is provided:

To which extent is the reduced overall project cost due to lower onsite cost, because of both less number of total workers due to shorter schedule and less accommodation expenses, applicable to this specific project?

- ☐ *I do not have visibility*
- ☐ *Not applicable*
- ☐ *Somewhat applicable*
- X *Applicable*
- ☐ *Extremely applicable*

C Element questions	**Selected applicability**
To which extent is the reduced overall project cost due to lower onsite cost, because of both less number of total workers due to shorter schedule and less accommodation expenses, applicable to this specific project?	Applicable
To which extent is the reduced overall project cost due to lower labour cost per unit as a result of higher productivity offsite, applicable to this specific project?	Not applicable
To which extent is the Reduced overall project cost due to higher financial benefits because of shorter schedule (e.g. reduced interest charged, earlier business (ROI), reduced disruption of the existing business), applicable to this specific project?	Extremely applicable
To which extent is the Reduced overall project cost due to less material and reworks reduction, applicable to this specific project?	I do not have visibility
To which extent is the Reduced overall project cost due to lower onsite preliminaries, applicable to this specific project?	Somewhat applicable
To which extent is the Reduced overall project cost due to savings on external consultant for design, applicable to this specific project?	Not applicable
To which extent is the Reduced overall project cost due to lower transportation cost of all the materials and equipment in the offsite facility (otherwise to send onsite) , applicable to this specific project?	Applicable
To which extent is the Reduced overall project cost due to easier and cheaper testing phase, applicable to this specific project?	Applicable

To which extent is the Increased overall project cost due to higher engineering and design working hours required, applicable to this specific project?	Somewhat applicable
To which extent is the Increased overall project cost due to transportation cost of the module, applicable to this specific project?	Extremely applicable
To which extent is the Increased overall project cost due to higher material supply cost as a result of better offsite quality (if considering a direct comparison), applicable to this specific project?	I do not have visibility
To which extent is the Increased overall project cost due to higher expenses to set the infrastructure for the transportation to the site (warranties, insurances, local taxes), applicable to this specific project?	Extremely applicable
To which extent is the Increased overall project cost due to higher cost of the skilled workers, stably employed in the offsite facility, applicable to this specific project?	Not applicable
To which extent is the Increased overall project cost due to higher expenses on implementing sustainable equipment and processes, applicable to this specific project?	Somewhat applicable

The table relative to the FE factors is not outlined to the client since he indicated zero points to the weight of this factor.

T Element questions	Selected applicability
To which extent is the Reduced time schedule due to parallel working, applicable to this specific project?	Extremely applicable
To which extent is the Reduced time schedule due to diminished delays and work slowdown in the offsite facility, applicable to this specific project?	Applicable
To which extent is the Reduced time schedule due to higher productivity in the offsite facility, applicable to this specific project?	Not applicable
To which extent is the Increased time schedule due to higher detailed engineering and design effort (considering also higher	Extremely applicable

transport configurations and risk mitigation effort) , applicable to this specific project?	
To which extent is the Increased time schedule due to higher organisation and coordination requirements, applicable to this specific project?	Applicable

Q Element questions	Selected applicability
To which extent is the increased plant quality due to More organized and optimized working footprint in the offsite facility, applicable to this specific project?	Applicable
To which extent is the Increased plant quality due to better trained workers, applicable to this specific project?	Extremely applicable
To which extent is the Increased plant quality due to better testing of the whole process equipment (not just parts of it but the entire process) , applicable to this specific project?	Applicable
To which extent is the Increased plant quality due good quality of the material as a result of long term relationship with suppliers (materials conform to specifications, quality assurance and control techniques in place, certifications controls) , applicable to this specific project?	I do not have visibility
To which extent is the Decreased plant quality due to the location of the offsite facility (cheap labour localities, recent opening) , applicable to this specific project?	Not applicable
To which extent is the Decreased plant quality due to second hand material adoption, applicable to this specific project?	I do not have visibility

CP Element questions	Selected applicability
To which extent is the Increased certainty and predictability of the completion time due to simultaneous work, applicable to this specific project?	Somewhat applicable
To which extent is the Increased certainty and predictability of the expenditures due to higher visibility on the offsite facility costs (e.g. labour cost, supply, transport) , applicable to this specific project?	Extremely applicable

To which extent is the Increased certainty and predictability of the expenditures and completion time due to less hindrances from the external conditions (e.g. climatic) , applicable to this specific project?	Applicable
To which extent is the Increased certainty and predictability of the expenditures and completion time due to early freeze of the design and anticipated decisions, applicable to this specific project?	Not applicable
To which extent is the Decreased certainty and predictability of the expenditures and completion time due to higher risk (e.g. during transportation and installation), applicable to this specific project?	Extremely applicable
To which extent is the Decreased certainty and predictability of the expenditures and completion time due to higher necessity of coordination between the project phases and individuals, applicable to this specific project?	Applicable

S Element questions	**Selected applicability**
To which extent is the Reduction of workers' exposure to onsite working conditions due to reduced risk and workers' exposure dangerous activities and/or adverse climatic conditions, applicable to this specific project?	Extremely applicable
To which extent is the Reduction of workers' exposure to onsite working conditions due to higher trained workforce offsite, applicable to this specific project?	Somewhat applicable
To which extent is the Reduction of workers' exposure to onsite working conditions due to improved footprint, activities schedule and equipment organisation (in the offsite facility), applicable to this specific project?	I do not have visibility

RWE Element questions	**Selected applicability**
To which extent is the Increased sustainability due to less pollution (because of less vehicles movement onsite), applicable to this specific project?	Applicable

To which extent is the Increased sustainability due to more environmental friendly offsite working procedures, applicable to this specific project?	I do not have visibility
To which extent is the Increased sustainability due to less material usage, energy and water consumption, applicable to this specific project?	Applicable
To which extent is the Increased sustainability due to less material waste, applicable to this specific project?	Applicable
To which extent is the Increased sustainability due to facilitated recycling process, applicable to this specific project?	Not applicable
To which extent is the Decreased sustainability due to higher pollution during the transport of modules, applicable to this specific project?	Applicable

The table relative to the D factors is not outlined to the client since he indicated zero points to the weight of this factor.

At this stage the algorithm executes the first level factors value calculation:

Factor calculation	Total value
C = (+9)*2+(+9)*0+(+3)*3+(+1)*0+(+1)*1+(+1)*0+(+1)*2+ (+1)*2 +(-9)*1+(-9)*3+(-3)*0+(-3)*3+(-1)*0+(-1)*1= 32-47	-15
FE = (+3)*2+(+1)*0+(+1)*2+(+1)*0 = 6+2	8
T = (+9)*3+(+3)*2+(+3)*0+(-1)*3+(-1)*2 = 33-5	28
Q = (+3)*2+(+3)*3+(+3)*2+(+3)*0+(-3)*0+(-3)*0 = 21-0	21
CP = (+9)*1+(+9)*3+(+9)*2+(+3)*0+(-3)*3+(-3)*2 = 63-15	48
RWE = (+9)*3+(+9)*1+(+9)*0 = 36	36
S = (+3)*2+(+1)*0+(+1)*2+(+1)*2+(+1)*0+(-1)*2 = 10-2	8
D = (-9)*0+(-9)*0= 0	0

The M value is calculated, and the relative message box is displayed to the user.

$$M = (-15) * 0.25 + (+8) * 0 + (+28) * 0.2 + (+21) * 0.1 + (+48) * 0.35 + (+36) * 0.05 + (+8) * 0.05 + (0) * 0 = -3.75 + 0 + 5.6 + 2.1 + 16.8 + 1.8 + 0.4 + 0 = \mathbf{22.95}$$

The result of the information provided led to the following result:

Based on the information that you have provided, the project would definitely gain benefits from the adoption of a modular approach. An intensive adoption of modularisation is advised. For a further pre-feasibility study of the project tackle the second level analysis

In order to understand and have visibility on the positive and negative factors and those that highly affected the final result look at the factors total value. The most incisive factors are (the positive values pushes the adoption of modularisation the negative inhibit it): *+16.8 certainty and predictability of expenditures and completion time* *+5.6 time schedule of the project* *-3.75 total project cost*

It is worth to mention that the final calculation of the total factors value and the M factor are displayed to the user, in this way he can have visibility on the positive and negative factors and those that highly affected the final result. Moreover, an important aspect to consider is that going through all the questions the owner and his team have the possibility to get acquainted with critical variables and rise questions that otherwise would have been hidden.

MasterMOD execution, pre-feasibility level

Please answer the following questions on the applicability of the elements to your specific project.

For of brevity reasons only the first element selection of the user is provided:

To which extent is the restricted space for material storage (stock), applicable to this specific project?

- ☐ *I do not have visibility*
- X *Not applicable*
- ☐ *Somewhat applicable*
- ☐ *Applicable*
- ☐ *Extremely applicable*

Site conditions element questions	Selected applicability
To which extent is the restricted space for material storage (stock), applicable to this specific project?	Not applicable
To which extent is the brownfield site that hinders site living environment, applicable to this specific project?	Not applicable
To which extent is the not conductive working footprint onsite, applicable to this specific project?	I do not have visibility
To which extent is the restrictions on usage and placement of cranes, applicable to this specific project?	I do not have visibility
To which extent is the reduced space for the movement of modules, applicable to this specific project?	Somewhat applicable

Site location element questions	Selected applicability
To which extent is the lack of skilled workforce onsite, applicable to this specific project?	Extremely applicable
To which extent is the too expensive onsite workforce, applicable to this specific project?	Not applicable
To which extent is the adverse onsite climatic conditions, applicable to this specific project?	Applicable
To which extent is the problematic political situation in the site construction area (work not assured, supply hindered, lack of stable workers, energy and water provision not reliable), applicable to this specific project?	Somewhat applicable
To which extent is the closeness to living accommodation of the construction site (necessity to reduce noise, dust, congestion of the site) , applicable to this specific project?	Not applicable
To which extent is the long distance of the site from sea or rivers, applicable to this specific project?	Extremely applicable
To which extent is the closeness to big cities of the construction site (good infrastructural systems, good network for supplier, workers own accommodation, energy and water providers) , applicable to this specific project?	Not applicable

Transport infrastructure element questions	**Selected applicability**
To which extent is the lack of ship availability and port facility and/or roads and bridges availability and capacity, applicable to this specific project?	Extremely applicable
To which extent is the heavy lift cranes not assured, applicable to this specific project?	I do not have visibility
To which extent is the permits and legal legislation barriers on module movements, applicable to this specific project?	Applicable

EPC (and contractor) propensity to go modular element questions	**Selected applicability**
To which extent is the EPC economic interest in advising a modular approach (e.g. design hours payment), applicable to this specific project?	I do not have visibility
To which extent is the EPC relationship with network of subcontractors, applicable to this specific project?	Applicable
To which extent is the EPC economic interest in advising a stick build approach, applicable to this specific project?	I do not have visibility
To which extent is the EPC interest in not advising a modular approach due to lack of knowledge and experience, applicable to this specific project?	Not applicable

Experience of the contractors Element questions	**Selected applicability**
To which extent is the lack of consolidate methods and management procedures in facing modular projects, applicable to this specific project?	Not applicable
To which extent is the critical information management (during design, transportation and installation), applicable to this specific project?	I do not have visibility

To which extent is the lack of risk evaluation techniques (e.g. during transportation and installation), applicable to this specific project?	I do not have visibility
To which extent is the lack of coordination and communication methods, applicable to this specific project?	I do not have visibility

Project management, execution practices and systems element questions	**Selected applicability**
To which extent is the possibility to introduce standardisation for project replication, applicable to this specific project?	Applicable
To which extent is the opportunity for an early planning and mitigation of risks (e.g. during transportation) , applicable to this specific project?	Somewhat applicable
To which extent is the increased relationship with suppliers due to the increased contacts, applicable to this specific project?	Not applicable
To which extent is the limited late changes due to early freeze of design and decisions, applicable to this specific project?	Somewhat applicable
To which extent is the high transportation risk (module damaged or lost), applicable to this specific project?	Applicable
To which extent is the increased engineering complexity, applicable to this specific project?	Somewhat applicable
To which extent is the more effective communication and coordination required between project operators, applicable to this specific project?	I do not have visibility
To which extent is the early procurement might lead to higher logistic complications, applicable to this specific project?	Not applicable
To which extent is the risk allocation shift (e.g. from engineering design to engineering construction), applicable to this specific project?	I do not have visibility
To which extent is the higher requirements for suppliers, applicable to this specific project?	Not applicable

Based on the information provided the elements are grouped in four main categories, among which the most important are the "strong constraints" and the "strong drivers".

STRONG DRIVERS

1. lack of skilled workforce onsite
2. adverse onsite climatic conditions
3. EPC relationship with network of subcontractors

WEAK DRIVERS

1. possibility to introduce standardisation for project replication

WEAK CONSTRAINTS

0

STRONG CONSRAINTS

1. long distance of the site from sea or rivers
2. lack of ships availability, port facility and/or roads and bridges availability and capacity
3. permits and legal legislation barriers on module movements
4. high transportation risk (module damaged or lost)

According to the emerged strong constraints a parallel set of boxes is displayed:

Based on the emerged strong constraints for the realisation of the project, look at the following boxes:

Element	***Pay attention to:***
Long distance of the site from sea or rivers	*Be sure to the real distance (in terms of road kilometres) of the site from navigable waters. Investigate all the available transportation routes and the available speed of the trucks, both for small and heavy modules (notice that the common speed for trucks is near 2 or 3 km/h for very heavy modules, the speed available increases for lighter modules). Concerning the seed pay attention to the road conditions. Investigate which are the standards in terms of*

	weights and tracks transportation capacity (they change according to the type of plant). Evaluate with the contractor during the feasibility study if it possible to transport the module to the site at a reasonable price and time. Be aware of this huge hindrance, which causes the unfeasibility of the modular approach in case of excessive distance of the site from navigable waters.
Lack of ship availability and port facility and/or roads and bridges availability and capacity	*Investigate the ship and port capacity, check if it is a permanent situation due to the configuration of the site or a temporary one. Complete a simulation of the forecasted path of the modules controlling the roads and bridges capacity. During the feasibility plan ask the EPC or contractor for a procedure to tackle the problem, understanding the expected cost of it. If there are no solutions available or they are too expensive, keep in mind that this constraint can cause the unfeasibility of the modular approach.*
Permits and legal legislation barriers on project movements	*This can be a hostile constraint if not properly and early addressed in the project management. It might happen that due to political or socio-economic problems, well established transportation routes results not available. Check if the contractor can assure a feasibility transportation route for your modules, having the movement of modules blocked and delayed can enormously increase the overall time and cost of your project.*
High transportation risk (module damaged or lost)	*The transportation risk is due to the dangerous path of the transportation of the module, this danger is incentivised if the contractor has poor experience with modular approach. Often risk mitigation practices are adopted by EPC and contractor companies. Control the experience of the contractor and check the transportation plan in the feasibility study. With the modular approach this is a risk that is always present.*

It is crucial to establish the applicability of the "highlighted" elements, because they can result in a strong constraint for the feasibility of the project, the most important elements to pay attention on is the following:

- *Restrictions on usage and placement of cranes*
- *Heavy lift cranes not assured*
- *Economic interest in advising a stick build approach*
- *Critical information management (during design, transportation and installation)*
- *Lack of risk evaluation techniques (e.g. during transportation and installation)*

The tool results presentation concludes with the above last remindings. As in the previous level the user can go through its answers and comprehend the system that led to the final four groups configuration. This second level of the tool is designed to support the client prior to the feasibility study. In this way a productive discussion with the EPC and contractors can be put in place, aimed at solving infeasibilities and understanding the relative costs.

6.4.2 MasterMOD example 2

Project presentation, client objectives and project characteristics:
The project target is to build a chemical processing plant in the Great Southern region in the western part of Australia. The plant will transform feedstock chemicals into products. The client is interested in replicating in smaller industrial scale the plant based in USA; for the purpose of processing different materials and widening the range of products offered. Therefore, the client growth programme is driven by the following market factors:

- Business opportunities, tackle the Australian and Asian market.
- Business enlargement programme
- Advanced engineering competencies both during the construction and along the plant life-cycle.

The project has to be executed in an area where the climate is moderate and similar to the Mediterranean countries. The infrastructure network both in terms of suppliers and roads and port facility is well organised. Moreover the plant will rise relatively close to the city of Albany. The client main concern is the limitation of the overall project cost. Moreover, in order to effectively schedule the penetration of the Asian and Australian market, there is interest both in the speed of construction and certainty and predictability of the completion time. In order to execute the project there is the need to access to a large high skilled labour force. The skilled workforce availability in the targeted area is considerable, this is also heightened by the closeness to big cities, but the Australian wages in the construction industry are deemed to be quite high. The government does not put particular pressure to the client requesting the development of the local content during the realisation of the project. The client's idea is to entrust the feasibility study and the execution and management of the project to an Australian corporation. The contractor is relatively new in the execution of modular projects. According to the sustainability concern, the client wants to maximise the sustainability of the chemical process during the whole life cycle of the plant, advertising green procedure, proper waste management and energy efficiency of the plant. The client is not interested in achieving levels of quality beyond the regular standard.

Below a simulation of the tool is executed. The responses inserted are qualitatively estimated in a reasonable way by the researcher. The phrases in italic are presented to the user of the tool. Since the whole tool operating process was presented in the example 1, thinner tables will be presented in this section. The purpose is to present in a light way the differences with the precedent example.

<u>MasterMOD execution, strategic level</u>

Please weight in terms of importance, according to the objective that you want to maximise with the realisation of this project, providing the percentage relevance percentage of the following client objective factors (keep in mind that the sum has to be 100%).

Client/owner objectives	**Weighting score**
C: total project cost	40%
FE: future expenditures, running facility cost	5%
T: time schedule of the project	20%
Q: quality of the plant	10%
CP: certainty and predictability of expenditures and completion time	20%
RWE: reduction of workers exposure to onsite working conditions	0%
S: sustainability factor	5%
D: develop local content	0%
Total	100%

After this voting phase, the numbers adopted for the calculation of the M factor are decimal values obtained dividing by 100 the weighting scores.

Please answer the following questions on the applicability of the elements to your specific project.

C Element questions	**Selected applicability**
To which extent is the reduced overall project cost due to lower onsite cost, because of both less number of total workers due to shorter schedule and less accommodation expenses, applicable to this specific project?	Applicable
To which extent is the reduced overall project cost due to lower labour cost per unit as a result of higher productivity offsite, applicable to this specific project?	I do not have visibility
To which extent is the Reduced overall project cost due to higher financial benefits because of shorter schedule (e.g. reduced interest charged, earlier business (ROI), reduced disruption of the existing business), applicable to this specific project?	Applicable
To which extent is the Reduced overall project cost due to less material and reworks reduction, applicable to this specific project?	Applicable
To which extent is the Reduced overall project cost due to lower onsite preliminaries, applicable to this specific project?	Somewhat applicable
To which extent is the Reduced overall project cost due to savings on external consultant for design, applicable to this specific project?	Not applicable
To which extent is the Reduced overall project cost due to lower transportation cost of all the materials and equipment in the offsite facility (otherwise to send onsite) , applicable to this specific project?	Extremely applicable
To which extent is the Reduced overall project cost due to easier and cheaper testing phase, applicable to this specific project?	Applicable
To which extent is the Increased overall project cost due to higher engineering and design working hours required, applicable to this	Applicable

specific project?	
To which extent is the Increased overall project cost due to transportation cost of the module, applicable to this specific project?	Somewhat applicable
To which extent is the Increased overall project cost due to higher material supply cost as a result of better offsite quality (if considering a direct comparison), applicable to this specific project?	Applicable
To which extent is the Increased overall project cost due to higher expenses to set the infrastructure for the transportation to the site (warranties, insurances, local taxes), applicable to this specific project?	Somewhat applicable
To which extent is the Increased overall project cost due to higher cost of the skilled workers, stably employed in the offsite facility, applicable to this specific project?	Not applicable
To which extent is the Increased overall project cost due to higher expenses on implementing sustainable equipment and processes, applicable to this specific project?	I do not have visibility

FE Element questions	**Selected applicability**
To which extent is the Reduced facility running cost due to improved sustainability of the plant processes, applicable to this specific project?	Extremely applicable
To which extent is the Reduced facility running cost due higher quality of the equipment (less business stops) , applicable to this specific project?	I do not have visibility
To which extent is the Reduced facility running cost due easier and faster maintenance procedure, applicable to this specific project?	Extremely applicable
To which extent is the Reduced facility running cost due higher residual value of the process modules at the end of the life (reuse and refurbishment), applicable to this specific project?	Not applicable

T Element questions	**Selected applicability**
To which extent is the Reduced time schedule due to parallel working, applicable to this specific project?	Applicable
To which extent is the Reduced time schedule due to diminished delays and work slowdown in the offsite facility, applicable to this specific project?	Somewhat applicable
To which extent is the Reduced time schedule due to higher productivity in the offsite facility, applicable to this specific project?	I do not have visibility
To which extent is the Increased time schedule due to higher detailed engineering and design effort (considering also higher transport configurations and risk mitigation effort) , applicable to this specific project?	Applicable
To which extent is the Increased time schedule due to higher organisation and coordination requirements, applicable to this specific project?	I do not have visibility

Q Element questions	**Selected applicability**
To which extent is the increased plant quality due to More organized and optimized working footprint in the offsite facility, applicable to this specific project?	Applicable
To which extent is the Increased plant quality due to better trained workers, applicable to this specific project?	Applicable
To which extent is the Increased plant quality due to better testing of the whole process equipment (not just parts of it but the entire process) , applicable to this specific project?	Applicable
To which extent is the Increased plant quality due good quality of the material as a result of long term relationship with suppliers (materials conform to specifications, quality assurance and control techniques in place, certifications controls) , applicable to this specific project?	I do not have visibility
To which extent is the Decreased plant quality due to the location of the offsite facility (cheap labour localities, recent opening) , applicable to this specific project?	Not applicable

To which extent is the Decreased plant quality due to second hand material adoption, applicable to this specific project?	I do not have visibility

CP Element questions	**Selected applicability**
To which extent is the Increased certainty and predictability of the completion time due to simultaneous work, applicable to this specific project?	Extremely applicable
To which extent is the Increased certainty and predictability of the expenditures due to higher visibility on the offsite facility costs (e.g. labour cost, supply, transport) , applicable to this specific project?	Somewhat applicable
To which extent is the Increased certainty and predictability of the expenditures and completion time due to early freeze of the design and anticipated decisions, applicable to this specific project?	Not applicable
To which extent is the Decreased certainty and predictability of the expenditures and completion time due to higher risk (e.g. during transportation and installation), applicable to this specific project?	Applicable
To which extent is the Decreased certainty and predictability of the expenditures and completion time due to higher necessity of coordination between the project phases and individuals, applicable to this specific project?	Applicable

S Element questions	**Selected applicability**
To which extent is the Increased sustainability due to less pollution (because of less vehicles movement onsite), applicable to this specific project?	Somewhat applicable
To which extent is the Increased sustainability due to more environmental friendly offsite working procedures, applicable to this specific project?	I do not have visibility
To which extent is the Increased sustainability due to less material usage, energy and water consumption, applicable to this specific project?	Applicable

To which extent is the Increased sustainability due to less material waste, applicable to this specific project?	Extremely applicable
To which extent is the Increased sustainability due to facilitated recycling process, applicable to this specific project?	Applicable
To which extent is the Decreased sustainability due to higher pollution during the transport of modules, applicable to this specific project?	Somewhat applicable

The D and RWE table are not provided due to the zero weight selected.

At this stage the algorithm executes the first level factors value calculation:

Factor calculation	Total value
C = (+9)*2+(+9)*0+(+3)*2+(+1)*2+(+1)*1+(+1)*0+(+1)*3+ (+1)*2 +(-9)*2+(-9)*1+(-3)*2+(-3)*1+(-1)*0+(-1)*0= 32 - 36	- 4
FE = (+3)*3+(+1)*0+(+1)*3+(+1)*0 = 12	12
T = (+9)*2+(+3)*1+(+3)*0+(-1)*2+(-1)*0 = 21-2	19
Q = (+3)*2+(+3)*2+(+3)*2+(+3)*0+(-3)*0+(-3)*0 = 18	18
CP = (+9)*3+(+9)*1+(+9)*0+(+3)*1+(-3)*2+(-3)*0 = 39-6	33
S = (+3)*1+(+1)*0+(+1)*2+(+1)*3+(+1)*2+(-1)*1 = 10-1	9

The M value is calculated, and the relative message box is displayed to the user.

$$M = (-4) * 0.4 + (+12) * 0.05 + (+19) * 0.2 + (+18) * 0.1 + (+33) * 0.2 + (+0) * 0 + (+9) * 0.05 + (0) * 0 = -1.6 + 0.6 + 3.8 + 1.8 + 6.6 + 0 + 0.45 + 0 = \mathbf{11.65}$$

The result of the information provided led to the following result:

Based on the information that you have provided, the project would gain benefits from the adoption of a modular approach. A considerable amount of modularisation is advised. For a further pre-feasibility study of the project tackle the second level analysis.

In order to understand and have visibility on the positive and negative factors and those that highly affected the final result look at the factors total value. The most incisive factors are (the positive values pushes the adoption of modularisation the negative inhibit it):

+6.6 certainty and predictability of expenditures and completion time

+3.8 time schedule of the project

+1.8 quality of the plant

-1.6 total project cost

<u>MasterMOD execution, pre-feasibility level</u>

Please answer the following questions on the applicability of the elements to your specific project.

Site conditions element questions	**Selected applicability**
To which extent is the restricted space for material storage (stock), applicable to this specific project?	Not applicable
To which extent is the brownfield site that hinders site living environment, applicable to this specific project?	Not applicable
To which extent is the not conductive working footprint onsite, applicable to this specific project?	Not applicable
To which extent is the restrictions on usage and placement of cranes, applicable to this specific project?	Somewhat applicable
To which extent is the reduced space for the movement of modules, applicable to this specific project?	Not applicable

Site location element questions	**Selected applicability**
To which extent is the lack of skilled workforce onsite, applicable to this specific project?	Not applicable
To which extent is the too expensive onsite workforce, applicable to this specific project?	Applicable
To which extent is the adverse onsite climatic conditions, applicable to this specific project?	Not applicable
To which extent is the problematic political situation in the site construction area (work not assured, supply hindered, lack of stable workers, energy and water provision not reliable), applicable to this specific project?	Not applicable
To which extent is the closeness to living accommodation of the	Applicable

construction site (necessity to reduce noise, dust, congestion of the site) , applicable to this specific project?	
To which extent is the long distance of the site from sea or rivers, applicable to this specific project?	Somewhat applicable
To which extent is the closeness to big cities of the construction site (good infrastructural systems, good network for supplier, workers own accommodation, energy and water providers) , applicable to this specific project?	Applicable

Transport infrastructure element questions	**Selected applicability**
To which extent is the lack of ship availability and port facility and/or roads and bridges availability and capacity, applicable to this specific project?	Not applicable
To which extent is the heavy lift cranes not assured, applicable to this specific project?	I do not have visibility
To which extent is the permits and legal legislation barriers on module movements, applicable to this specific project?	Not applicable

EPC (and contractor) propensity to go modular element questions	**Selected applicability**
To which extent is the EPC economic interest in advising a modular approach (e.g. design hours payment), applicable to this specific project?	Applicable
To which extent is the EPC relationship with network of subcontractors, applicable to this specific project?	Somewhat applicable
To which extent is the EPC economic interest in advising a stick build approach, applicable to this specific project?	Not applicable
To which extent is the EPC interest in not advising a modular approach due to lack of knowledge and experience, applicable to this specific project?	Not applicable

Experience of the contractors Element questions	**Selected applicability**
To which extent is the lack of consolidate methods and management procedures in facing modular projects, applicable to this specific project?	I do not have visibility
To which extent is the critical information management (during design, transportation and installation), applicable to this specific project?	Not applicable
To which extent is the lack of risk evaluation techniques (e.g. during transportation and installation), applicable to this specific project?	I do not have visibility
To which extent is the lack of coordination and communication methods, applicable to this specific project?	Not applicable

Project management, execution practices and systems element questions	**Selected applicability**
To which extent is the possibility to introduce standardisation for project replication, applicable to this specific project?	Applicable
To which extent is the opportunity for an early planning and mitigation of risks (e.g. during transportation) , applicable to this specific project?	Somewhat applicable
To which extent is the increased relationship with suppliers due to the increased contacts, applicable to this specific project?	Somewhat applicable
To which extent is the limited late changes due to early freeze of design and decisions, applicable to this specific project?	Somewhat applicable
To which extent is the high transportation risk (module damaged or lost), applicable to this specific project?	Somewhat applicable
To which extent is the increased engineering complexity, applicable to this specific project?	Extremely applicable
To which extent is the more effective communication and coordination required between project operators, applicable to this specific project?	Not applicable
To which extent is the early procurement might lead to higher logistic complications, applicable to this specific project?	Not applicable
To which extent is the risk allocation shift (e.g. from engineering	I do not have

design to engineering construction), applicable to this specific project?	visibility
To which extent is the higher requirements for suppliers, applicable to this specific project?	Applicable

According to the information inserted the elements are grouped in four main categories, among which the most important are the "strong constraints" and the "strong drivers".

STRONG DRIVERS

1. *too expensive onsite workforce*
2. *EPC economic interest in advising a modular approach*

WEAK DRIVERS

1. *closeness to living accommodation of the construction site (necessity to reduce noise, dust, congestion of the site)*
2. *EPC relationship with network of subcontractors*
3. *possibility to introduce standardisation for project replication*

WEAK CONSTRAINTS

1. *restrictions on usage and placement of cranes*
2. *long distance of the site from sea or rivers*
3. *closeness to big cities of the construction site (good infrastructural systems, good network for supplier, workers own accommodation, energy and water providers)*
4. *the limited late changes due to early freeze of design and decisions*
5. *high transportation risk (module damaged or lost)*
6. *increased engineering complexity*

STRONG CONSRAINTS

0

According to the information provided in this second case no strong constraints are related to the project execution, the following message comes out:

Based on the information provided the realisation of the project is not interested by strong constraints. However it is crucial to establish the applicability of the elements indicated *with "I do not have visibility", because they can result in a strong constraint for the feasibility of the project, the most important elements to pay attention on are the following:*

- *Heavy lift cranes not assured*
- *Contractor's lack of consolidate methods and management procedures in facing modular projects*
- *Contractor's lack of risk evaluation techniques (e.g. during transportation and installation)*

Comparing the result with the previous example, in this case the suggested level of modularisation is lower; in fact the "M" factor of the first example is twice the "M" factor of this one. However the second project has a higher "feasibility" level, since has less strong constraints that heavily hinders the adoption of modularisation. Furthermore, the balance of driver/constraint in the second case is more propending to drivers; this signals that the site conditions and project characteristics are more conductive to a modular approach. One factor to pay attention at is the level of experience of the contractor, in fact as it is widely reported in the dissertation a set of strong and consolidates competencies in managing modularisation projects is curial for the successful construction of the EC plants. Finally the attention has to be risen on the client understanding of modularisation; this tool promotes the acknowledgement of the client/owner of the project. Facing many different project characteristics, even though some of the answers are "I do not have visibility", focuses the attention on several critical factors, reducing the uncertainty and promoting risk assessment and mitigation. The overall picture of the complicated EC mega-projects, comprising objectives, project characteristics, site features, project management techniques and EPC propensity to go modular is clearer for the user of the tool after the completion; and where the visibility is lacking, focus can be dedicated during the feasibility study.

7 Conclusions

7.1 Research impacts and limitations

The initial part of the dissertation provides an overview of the literature on modularisation. After a brief description of the method, providing definitions, applicability and illustrating the advantages and disadvantages, the thesis delves in the EC sector explaining the characteristics features and specifying mutations. Then from the gap in the literature outlined emerges the uniqueness and scope of the research. According to the aim of the dissertation the main drivers and constraints of the adoption of modularisation in the EC sector was discovered. This process was long and complicated, interested by various data gathering processes. Each of the data collection processes was executed pursuing validity and reliability. In this respect triangulation of the data and consistency assuring techniques were used. For each of the characteristics individuated an explanation of the nature is provided. Moreover, an inter-relationship matrix was presented, showing the interdependencies between the discovered elements. As regard the factor findings many of the elements indicated in the literature occurred with the same impact in the research, while some of them appeared with higher or lower intensity; this is the case of the sustainability growing concern and hi-tech support systems. Moreover, few elements less treated in the investigated literature were introduced, for example the “development of the local content” (pressure exercised by the government when there is necessity to develop the local economy), and the “EPC/contractor propensity to go modular” (concerning economic interests and dynamics of the market (see 5.4.3). Subsequently findings and conclusions were drawn and compared between themselves and the literature. Each of the relevant characteristics was discussed, providing a temporal and sectorial comparison with the literature. A progressive and coherent path of the conclusions led in the final step to the generation of an early-phase decision support tool, tackling both the strategic and pre-feasibility stages. As evidenced the research phases were conducted in a structured manner giving consistency to the results. However, some limitations relative to the data gathering process can be considered, for example the sampling targeted might have been larger, including different sectors experts and roles. Moreover the narrowing process might have followed a wrong path and regarding the qualitative part of the research, important pieces of information might have been lost.

The tool was conceptualised in two levels, the first assists the client/owner of the project during the first crucial strategic phase of the decisional process. It does not aim at being specific and exhaustive; in fact the EC project world is continuously changing, but provides a basic strategically significant instrument to cope with the complexity and risks of modern mega-plants construction. The second level tackles the pre-feasibility phase, the aim is to provide a strong basis of knowledge and project understanding prior to the feasibility study. The tool promotes the understanding of modularisation by the industry; in the research this constraint was individuated as one of the most relevant together with the lack of contractors' experience. In order to promote the uptake of the industry this two aspects has to go parallel. Spreading the knowledge on modularisation will facilitate the selection of it, thus due to the higher number of modular projects the expertise of contractors will presumably increase. In this way the virtuous circle will both boost the comprehension of modularisation in the industry and qualify contractors and players on its adoption, fostering the managerial and technical competencies acquisition.

Regarding the results provided by the tool, it is possible to argue about the lack of specificity of the output messages, defining them general and only qualitative. Firstly the tool is conceptualized for a strategic initial evaluation, where the tactical and operative level information (cost, time and quality), due to the early stage are difficult to precisely forecast. Moreover, each project is characterized by extreme variability and interconnection of changing variables. For example, a holistic list of all the costs affecting the project seemed both unfeasible and pointless. Furthermore, the tool assists the owner and his team promoting discussions on the relevant topics and pointing the attention to hidden elements that without an early focus would result in a huge constraints during the execution of the project. For example, assuring the availability of cranes over the whole transportation and installation process of the modules helps to anticipated difficulties that lead to the increasing cost during the project execution.

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7.2 Further research

The main contribution of this dissertation is the development of a modern decision support tool for the EC sector. However, further research can improve the tool and continuously update it in order to cope with the market changes and industry innovations. Further research can test the tool in different scenarios, finding new impacting factors or modifying the existing one. A customisation of the tool, to precisely face different EC plant construction can be executed. Moreover, the initial drivers and constraints phase behind the tool can be strengthen, executing a deeper research on the factors affecting the modularisation decisional process, in fact the data gathering process misses the deeper level (case studies) of the data collection process (see Figure 9). Furthermore, a parallel study on the structural aspect of modularisation can be executed, in this way the comprehension of the impacts of the technical elements on the managerial aspect can be exploited to draw a more detailed cost, time and quality analysis, resulting in more detailed tool's results.

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9 Appendix

9.1 Appendix A – web-based questionnaire

Loughborough University

ECI Modularisation Task Force Survey

0% complete

Page 1: Page 1

Aim of the survey

This survey is part of the European Construction Institute and Loughborough University's on-going research into offsite and Modularisation, in particular in the Engineering Construction (EC) sector. This questionnaire (designed to be completed in 10-15 minutes), aims to confirm or challenge the benefits and drawbacks claimed in previous research, to explore the drivers and constraints to the use of Modularisation and identify the relevant factors that lead to the selection of a modular approach.

In this context, Modularisation is used to describe the spectrum of applications (e.g. offsite construction, prefabrication, preassembly, etc.) where subassemblies, modules or whole structures are assembled away from their permanent position and then craned, jacked or otherwise installed into their final position. It is not just the consideration of very large modules.

Section 1: General questions

1 What is your role in your organisation? * *Required*

2 How many years' industrial experience do you have? * *Required*

- less than 5 years
- 6-10 years
- 11-19 years
- more than 20 years

3 Which of the following best characterize your main line of work? (click all that apply) * *Required*

- Oil & Gas
- Power & Energy : Nuclear
- Power & Energy : Thermal
- Power & Energy : Hydro-electric
- Chemical
- Pharmaceutical
- Metal processing
- Other

a If you selected Other, please specify:

4 Which of the following best describes your organization's role? * *Required*

- Client
- EPC
- Contractor
- Consultant
- Supplier

a If you selected Other, please specify:

Section 2: Benefits and Drawbacks

Add item

5 The benefits listed below are frequently suggested as applying to Modularisation. Please indicate, in your experience, how often that they have applied to your projects.

	Never	Sometimes	Often	Always
Shorter schedule				
Higher quality				
Reduction of (overall project) cost				
Enhanced sustainability				
Improved health and safety				
Economic benefits (from faster construction, e.g. earlier ROI)				
Improved predictability of the project outcomes				
Exploiting advances in information technology and automation				
Facilitating innovative design (e.g. implementing new hi-tech solutions)				
Higher workers productivity				
Project risks reduction (e.g. being over budget or late delivery)				
Opportunity to strengthen the relationship with suppliers				
Easier maintenance (through the whole life cycle of the plant)				
Easier and safer testing of the process equipment in the offsite facility				
Possibility to reuse/relocate the facility or part of it.				
Optimization of on site preliminaries				

6 The drawbacks listed below are frequently suggested as applying to Modularisation. Please indicate, in your experience, how often that they have applied to your projects.

	Never	Sometimes	Often	Always
Increased engineering/design effort (that leads to increased cost and complexity)	☐	☐	☐	☐
Increased logistic difficulties.	☐	☐	☐	☐
Increased overall project cost (e.g. due to longer initial planning and materials)	☐	☐	☐	☐
Increased complexity (higher complications in managing inter-relations within the project phases)	☐	☐	☐	☐
Inferior quality (e.g. due to the phase of assembly and separate production of modules)	☐	☐	☐	☐
Low flexibility (e.g. fewer design alternatives)	☐	☐	☐	☐
Transportation difficulties (e.g.in terms of cost, risks, scheduling and communication)	☐	☐	☐	☐
Site accessibility (e.g. for remote locations, distance from the sea)	☐	☐	☐	☐
Lack of experience (in terms of not wide spread usage of the method by companies)	☐	☐	☐	☐
Local regulation and context (e.g. local rules and polices)	☐	☐	☐	☐
Negative connotation of the method	☐	☐	☐	☐

Section 3: Factors affecting modularisation

Jump

Add item

Please indicate the relevance of the following factors (Client requirements, Site condition, Project managment) in terms of impact on the choice of selecting Modularisation as a construction method.

Add item

7 Please indicate the relevance of the following client requirement factors in terms of impact on the choice of selecting Modularisation as a construction method.

	Strong hindrance	Weak hindrance	Indifferent	Weak driver	Strong driver
Need to complete construction as soon as possible to realize economic benefits	☐	☐	☐	☐	☐
Need to maintain flexibility and opportunity of change (during both the design phase and erection of the process plant/facility)	☐	☐	☐	☐	☐
Need for predictability and certainty are crucial drivers for the client	☐	☐	☐	☐	☐
Need to replicate the process plant in the close future (e.g. repeat project)	☐	☐	☐	☐	☐
Need to relocate or reuse parts of the facility	☐	☐	☐	☐	☐
Need to maximize sustainability during the whole life cycle of the plant	☐	☐	☐	☐	☐
Need to maximize sustainability during construction (in terms of energy efficiency, environment protection, water consumption, reduced dust/noise etc.)	☐	☐	☐	☐	☐
Need to teduce the time that workers are exposed to onsite conditions (related to noxious chemical substances or pollution in the air)	☐	☐	☐	☐	☐
Need to minimize running costs and facilitate maintenance of the plant through the whole life cycle	☐	☐	☐	☐	☐
Need to use particular manufacturing procedures or materials	☐	☐	☐	☐	☐

a Please indicate the relevance of the following site constraint factors in terms of impact on the choice of selecting Modularization as a construction method.

	Strong hindrance	Weak hindrance	Indifferent	Weak driver	Strong driver
Type of the ground conditions	☐	☐	☐	☐	☐
Brown field site	☐	☐	☐	☐	☐
Adverse climatice conditions onsite	☐	☐	☐	☐	☐
Distance of the site from the sea or rivers	☐	☐	☐	☐	☐
Political reasons (like hire local workers)	☐	☐	☐	☐	☐
Availability of skilled people in the site location	☐	☐	☐	☐	☐
Restricted space available on site for storage	☐	☐	☐	☐	☐
Proximity of the site to living accommodation	☐	☐	☐	☐	☐
Distance of the site from offsite suppliers	☐	☐	☐	☐	☐
Necessity to not hinder the operation of the existing facility	☐	☐	☐	☐	☐
Strict regulation of the country in the onsite work	☐	☐	☐	☐	☐
Need of particular treatment of waste or scrap from the site (e.g. in nuclear or chemical plants)	☐	☐	☐	☐	☐
Need to reduce the noise or dust etc. of onsite work	☐	☐	☐	☐	☐
Hazard in testing the process of the facility onsite	☐	☐	☐	☐	☐
Availability and possibility to use large cranes not always certain	☐	☐	☐	☐	☐

b Please indicate the relevance of the following project management factors in terms of impact on the choice of selecting Modularisation as a construction method.

	Strong hindrance	Weak hindrance	Indifferent	Weak driver	Strong driver
Low experience of the contractor in dealing with modularisation	☐	☐	☐	☐	☐
Reluctance of the main players in the industry to adopt modularisation	☐	☐	☐	☐	☐
Wide geographical distribution of the offsite manufacturers	☐	☐	☐	☐	☐
Strict regulation of the country for the transportation of modules	☐	☐	☐	☐	☐
Willingness to establish an efficient communication and coordination process and culture	☐	☐	☐	☐	☐
Willingness to adopt a modern IT systems	☐	☐	☐	☐	☐
Time lag of new technologies being understood and implemented	☐	☐	☐	☐	☐
Time required training workers on site (in order to reach the required productivity with the modules compared to their traditional trades)	☐	☐	☐	☐	☐
Willingness to commit to single main supplier	☐	☐	☐	☐	☐
Critical mass of demand to create a sustainable manufacturing supply chain market	☐	☐	☐	☐	☐

8 Do you have any additional comments regarding the drivers and constraints listed above?

Section 4: Your contact details (Optional)

9 If you wish to receive feedback from this survey or you would like to share your opinions please contact me directly O.Gjepali@lboro.ac.uk or fill in your details below inserting Name and E-mail.

Loughborough University

ECI Modularisation Task Force Survey

100% complete

Thank you very much for your time

Your response to this questionnaire will be treated in strict confidence and anonymity. In accordance with the Data Protection Act (1998) any personal information will not be disclosed to third parties in any form. If you do not wish to disclose personal details you are not required to do so.

9.2 Appendix B – Structured part of the interviews

0. Initial set of questions on the compiled questionnaire
1. Which are the three most important drivers for the adoption of modularisation? Please provide examples and personal experience.
2. Which are the three most important drivers for the adoption of modularisation? Please provide examples and personal experience.
3. Does this drivers and constraints changed over time? If yes why and in how?
4. Does the rate of innovation and development of new hi-tech system to support the construction projects increase over the years?
5. Do you perceive an increasing concern on sustainability in the construction industry? Is it a strong concern for the client?
6. Do you think that the adoption of modularisation will increase in the coming years? And why?

9.3 Appendix C – Plenary section questionnaire

Demographic information

1. Which of the following best describes your main sector of work?

A	B	C	D	E	F	G
Oil and Gas	Power	Pharma ceutical	Heavy industrial	Civil/infra structure	Buildin g	Other

2. Number of years working in the industry?

A	B	C	D	E	F
0-5	6-10	11-15	16-20	21-25	Over 25

The following questions aim to understand the drivers and the constraints that are involved in the selection of the construction method.

1. How familiar are you with Modularisation (related terms: Offsite construction, Prefabrication, Preassembly etc.)?

A	B	C	D	E
I have never heard about it	I know what is it	I am familiar with it	I regularly deal with it	I often deal with it

- These are 'RANKING' questions – please aim to rank from 1st to last, avoiding equal 1st etc. if at all possible.

2. **<u>Rank</u>** the following **drivers** according to their importance in choosing Modularisation with respect to conventional stick build construction

complete construction as soon as possible to realize economic benefits	
Need of predictability and certainty	
Need to maximize sustainability	
Reduction of workers exposition to onsite conditions	
Adverse climatic conditions onsite	
Political and socio-economic difficulties onsite	
Lack of availability of skilled people onsite	
Restricted space available onsite for storage	

3. **<u>Rank</u>** the following **constraints** according to their importance in <u>NOT</u> choosing Modularisation, with respect to conventional stick build construction

Need of flexibility	
Long distance of site from sea or rivers	
Low experience of the contractor	
Reluctance of the industry to adopt Modularisation	
Strict regulations in transporting modules	
Time lag of new technologies	

9.4 Appendix D – Plenary section questionnaire data analysis

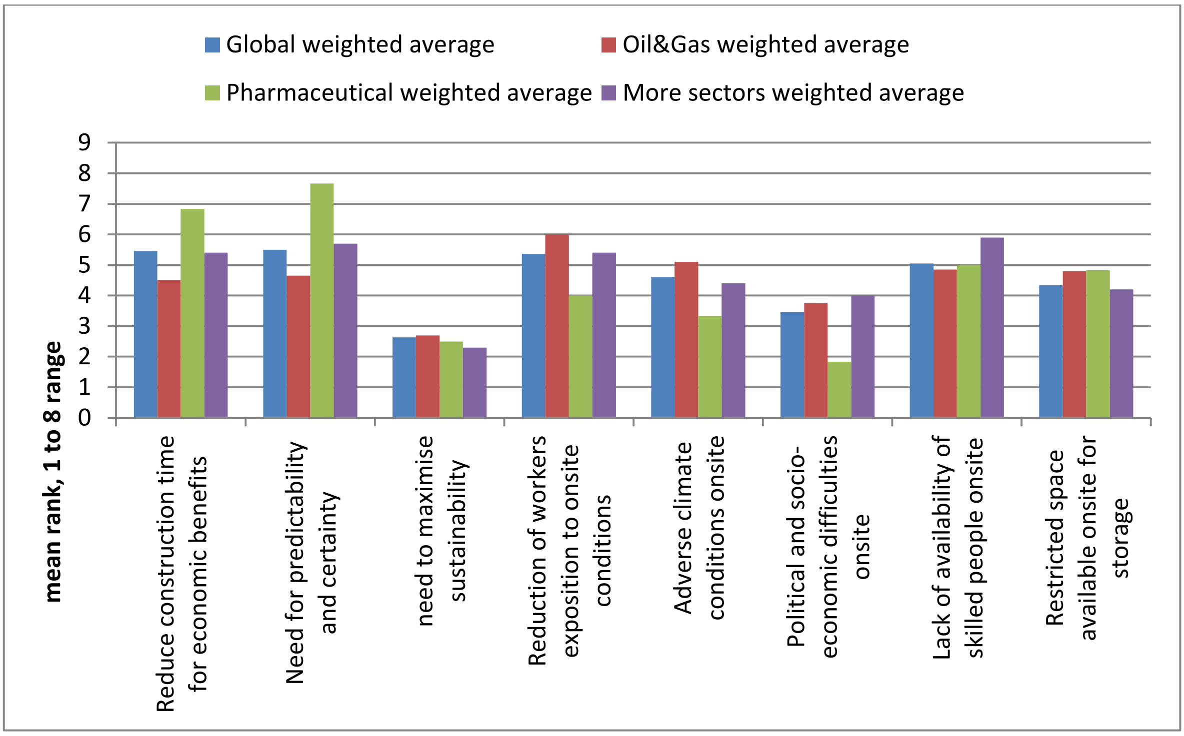

Figure 35 - sector drivers average comparison

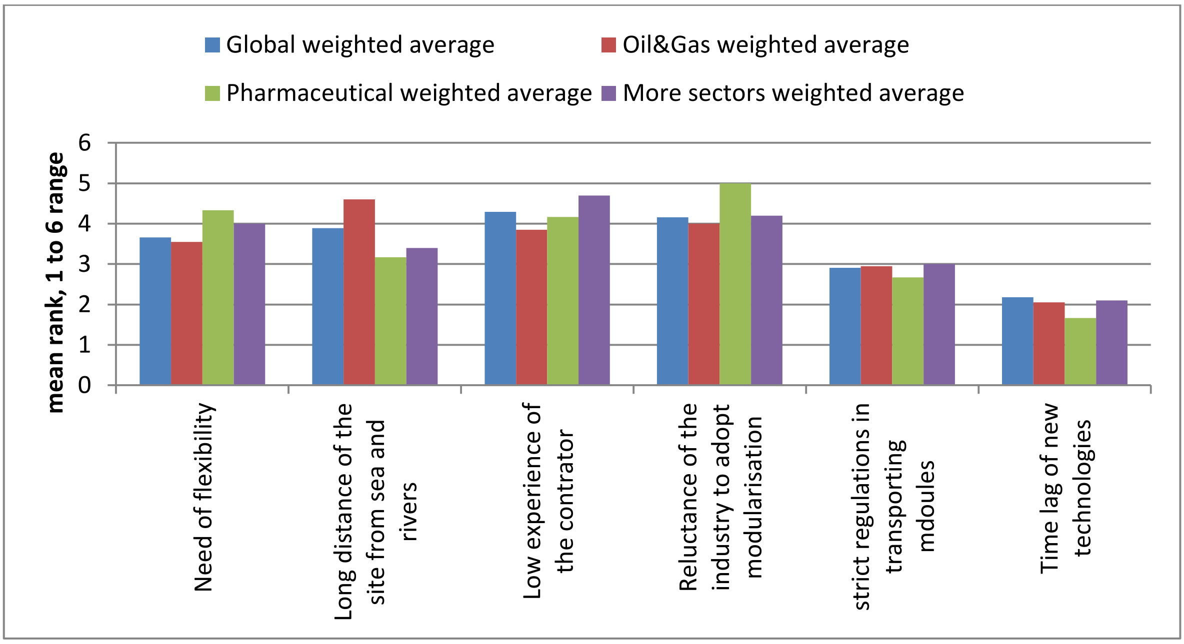

Figure 36 - sector constraints average comparison

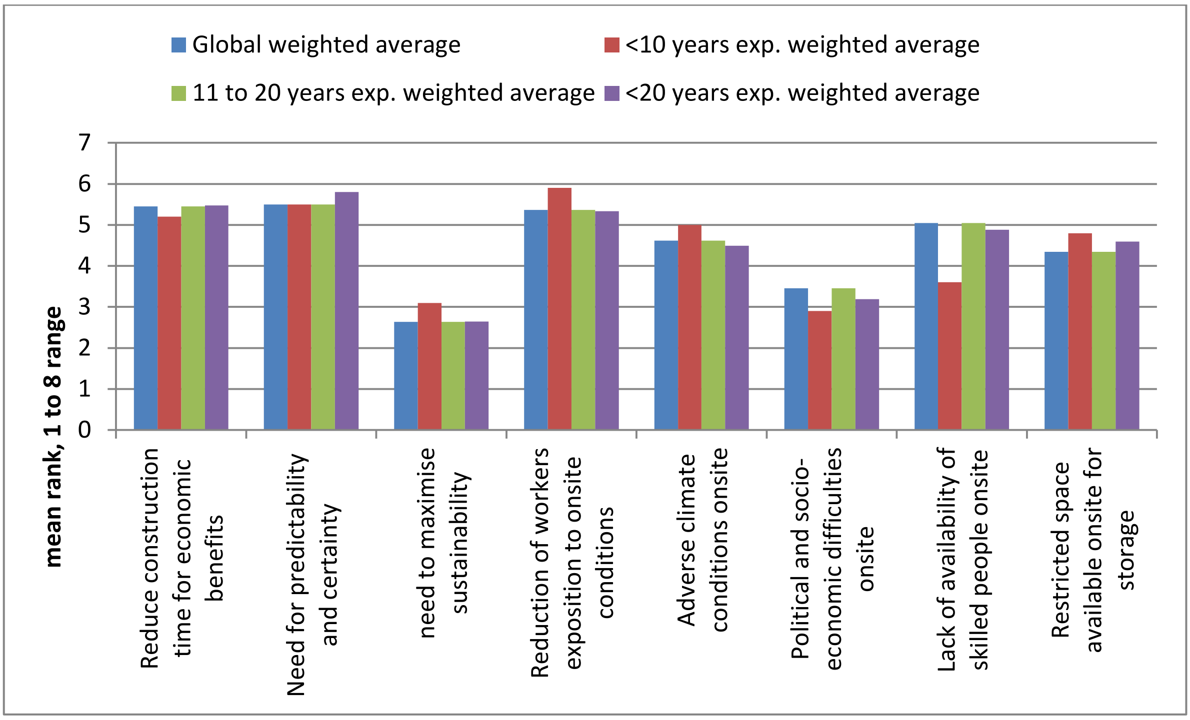

Figure 37 - years of experience drivers average

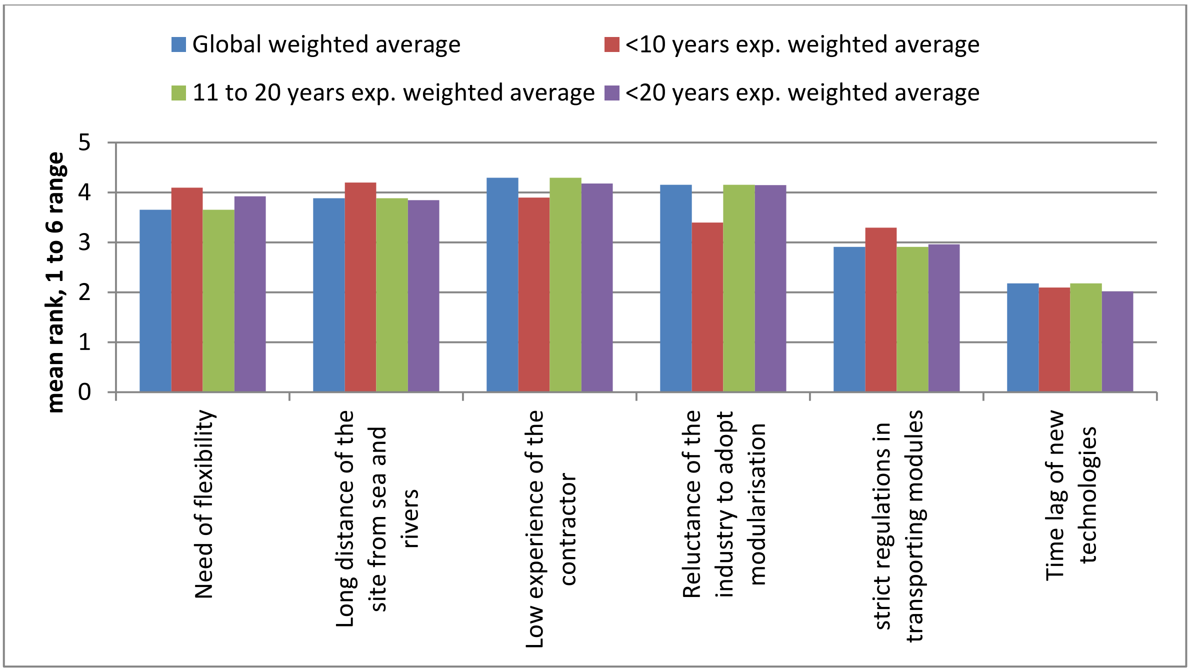

Figure 38 - years of experience constraints average

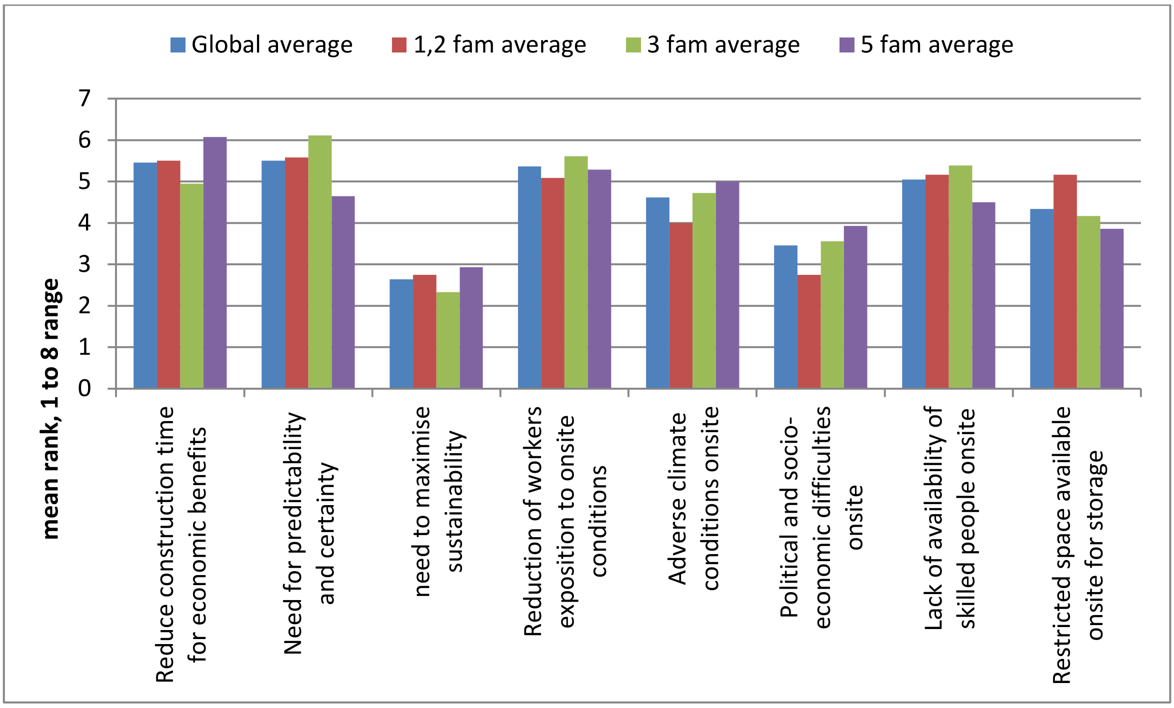

Figure 39 - familiarity with modularisation drivers average

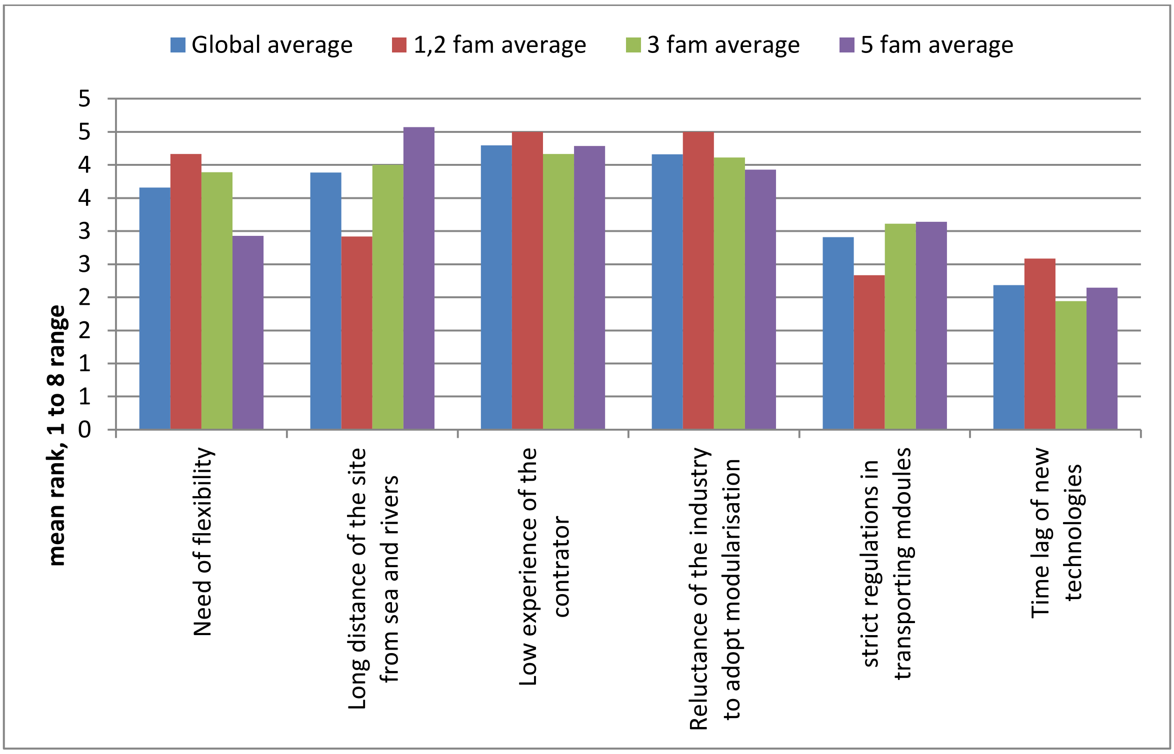

Figure 40 - familiarity with modularisation constraints average

9.5 Appendix E – ECI workshop

Clickers' results

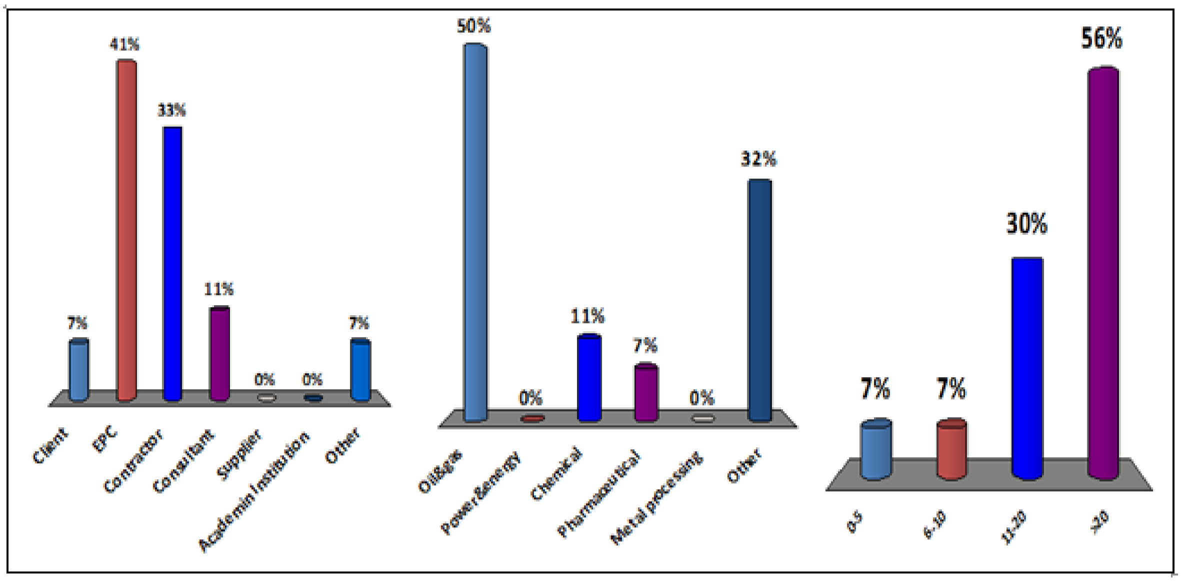

Figure 41 - voting section, general questions

Characteristic 1: LEVEL OF PREDICTABILITY AND CERTAINTY ACHIEVABLE

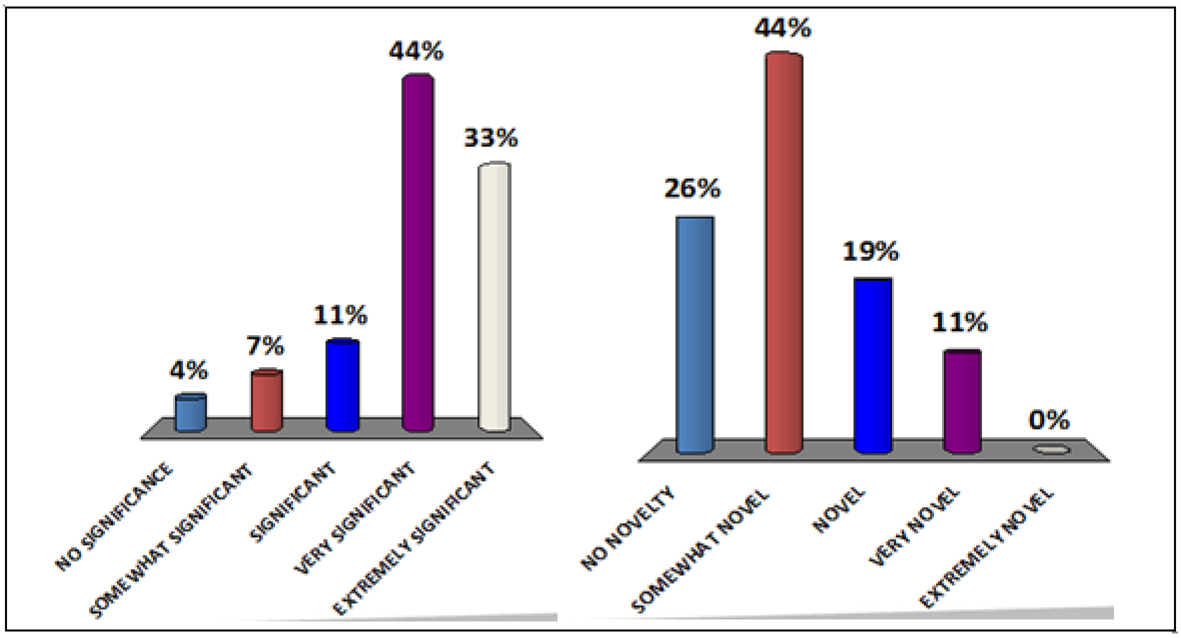

Figure 42 - significance and novelty of the first characteristic

Characteristic 2: LOCATION/POSITION OF THE SITE (weather conditions, distance from the sea/rivers, closeness to big cities)

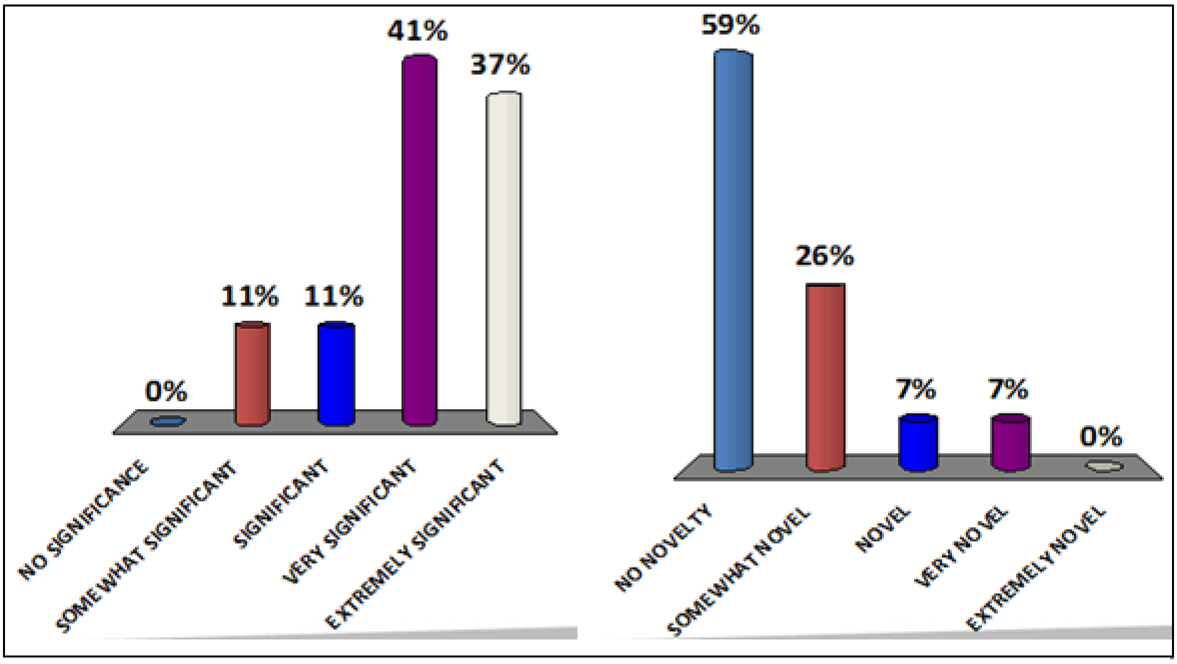

Figure 43 - significance and novelty of the second characteristic

Characteristic 3: REDUCTION OF WORKERS' EXPOSURE TO ONSITE CONDITIONS

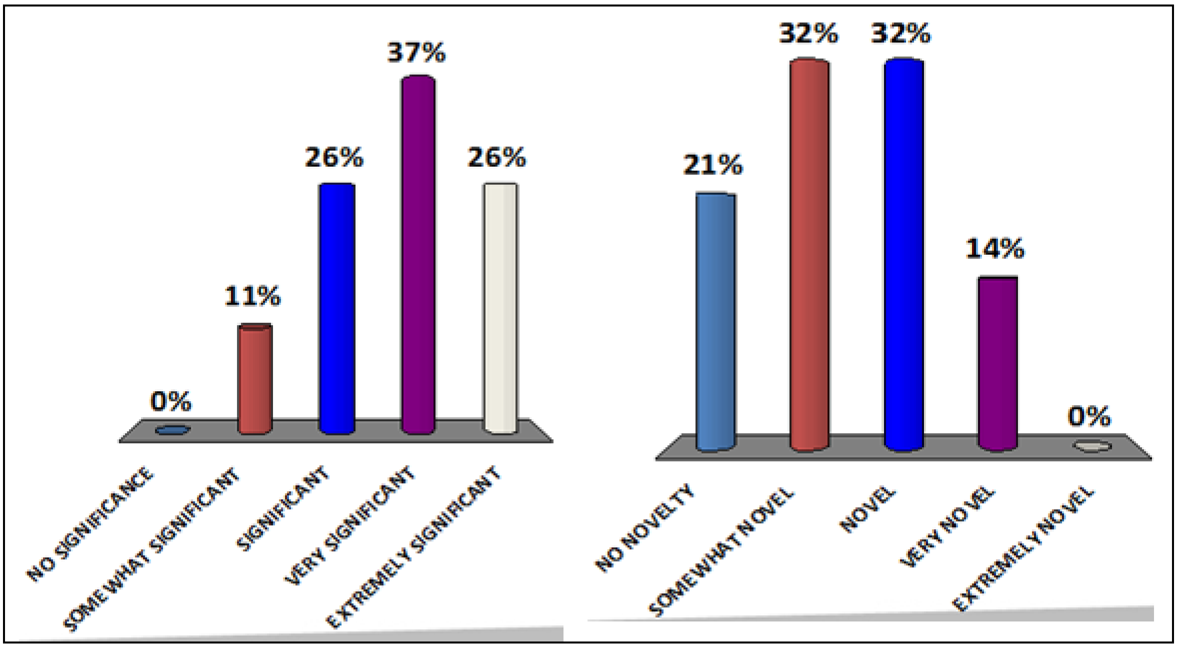

Figure 44 - significance and novelty of the third characteristic

Characteristic 4: POLITICAL AND SOCIO-ECONOMIC SITUATION

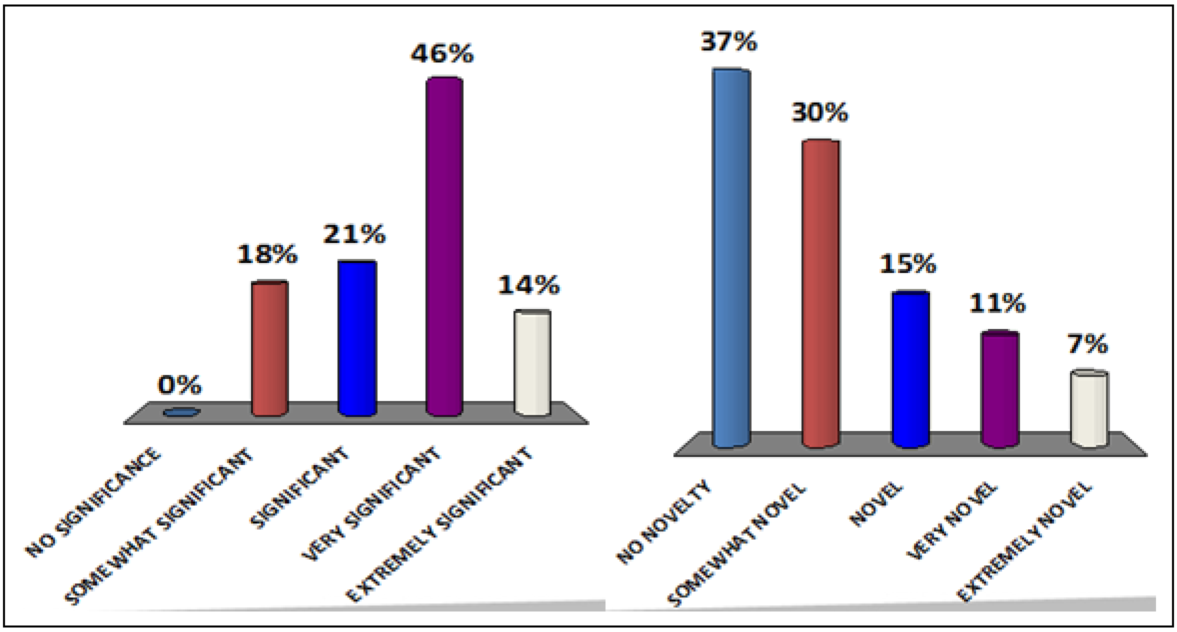

Figure 45 - significance and novelty of the fourth characteristic

Characteristic 5: CONDITION OF THE SITE (type of ground, brownfield and living environment, space availability)

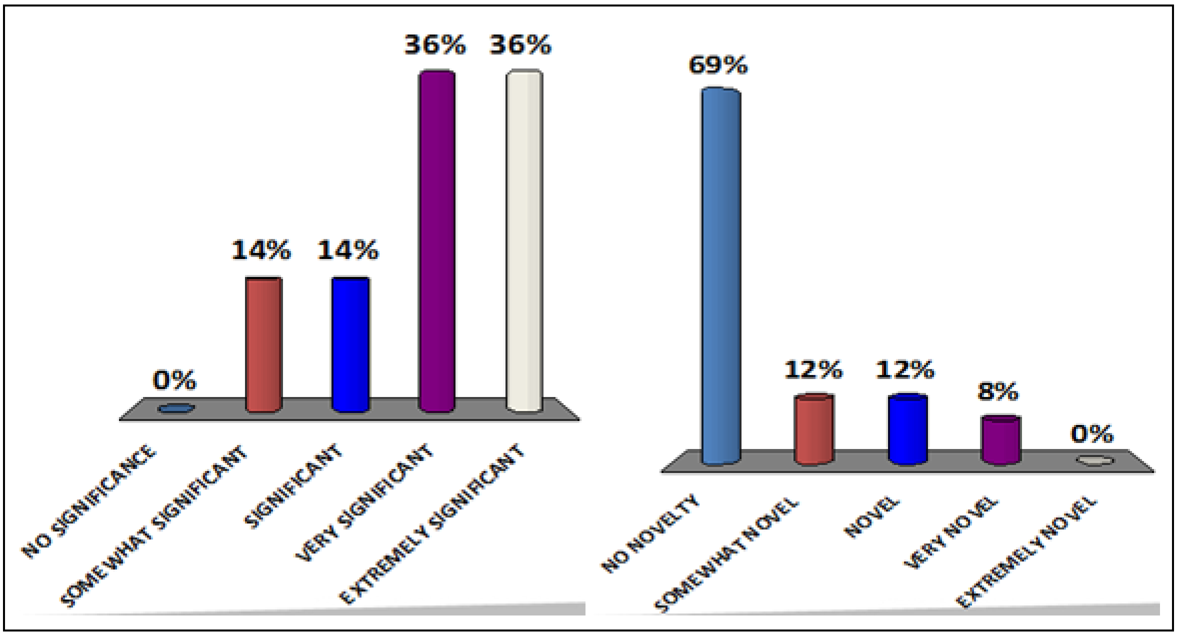

Figure 46 - significance and novelty of the fifth characteristic

Characteristic 6: MAXIMISE SUSTAINABILITY (both in the construction phase and during the whole life cycle of the plant)

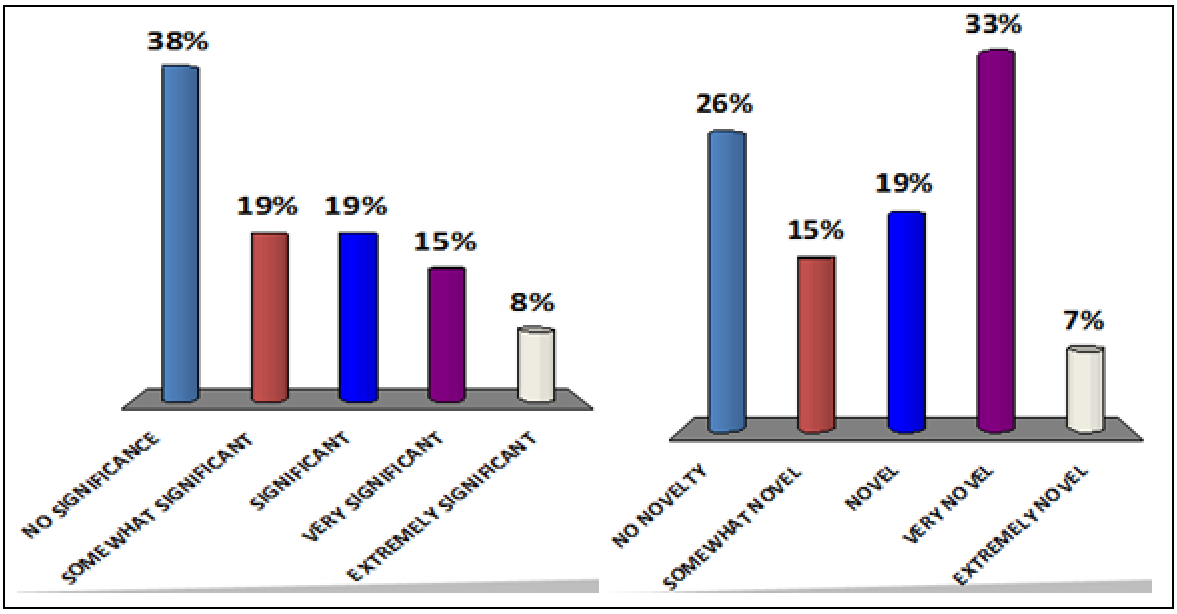

Figure 47 - significance and novelty of the sixth characteristic

Figure 48 – focus group, picture one

Figure 49 – focus group, picture two