Michael Kluck • Jin Ouk Choi

Modularization

The Fine Art of Offsite Preassembly for Capital Projects

WILEY

MODULARIZATION

MODULARIZATION

THE FINE ART OF OFFSITE PREASSEMBLY
FOR CAPITAL PROJECTS

MICHAEL KLUCK AND JIN OUK CHOI

WILEY

Published by John Wiley & Sons, Inc., Hoboken, New Jersey
Published simultaneously in Canada

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data is applied for
Hardback ISBN: 9781119824718

Cover Design: Wiley
Cover Images: © Photograph by Michael Kluck

Michael Kluck:

This book is dedicated to my patient and loving wife, Jeanette, who endured the invasion of her home office space during the business world's Covid-19 transition from the office to the home—not only my day-to-day business activity and annoying online meetings that totally disrupted her schedule, but also all the late night and weekend hours when an idea or thought hit me and I felt the need to incorporate it immediately (for fear I might lose it. . .).

Jin Ouk Choi:

I dedicate this book to my wife, So Hyun Bae, my new baby, who was just born in Feb. 2022, Sooho Choi, and my parents, Bok-Gil Choi and Se Young An. There is no doubt in my mind that without their continual support and love, I could not have completed this book. Also, a special thanks to Yoon Jeong Choi and Kyle Shackleton for all their support and love.

CONTENTS

PREFACE

We would like to begin with a couple of remarks about the title of this book: *Modularization: The Fine Art of Offsite Preassembly for Capital Projects*.

What is in a title? We probably spent more time going back and forth on the title for this book than what was necessary. But it was the first thing you saw when you picked up the book, so a short explanation is probably due, assuming you even read this Preface. We wanted something catchy but, more importantly, descriptive and indicative of what the book is about.

Modularization is not new, and it is not revolutionary. It has been applied to industrial plants both onshore and offshore for over 50 years and incorporated into many major construction efforts. However, the problem has been that, in many cases, it was not correctly incorporated or implemented. More often than not, the result was a less than desirable project solution and a subsequent conclusion by the project team something along the lines of: "modularization was wrong for the project" or "modularization was a bad idea." This (wrong) conclusion was then carried (along with the resulting bad reputation of the module concept) into the planning of the next several projects the team tackles.

This is where the "art" in the title comes in and a quick side note about the two authors. We are engineers by background and probably are blessed with maybe only one or two artistic bones in our collective bodies. But, we both recognize a great work of art, the timelessness of a piece of classical music, and anything else truly great for that matter. We cannot tell you what makes these works great because, at face value, the inputs are the same—oils, brushes, and canvas for the painting or notes and words on a piece of paper for the musical score. So obviously, it is the way the tools and materials are combined and used.

A successful module project is quite similar. The modular project uses the same inputs as the stick-built project, but they must be "mixed up" in a complex combination of slightly different approaches and then implemented in a certain sequence to be successful. Unfortunately, this sequence is different in many aspects than that of the traditional stick-built construction project.

Fortunately, we do know and understand what makes a module job "great," and we want all of you to also understand what it takes. That is the aim of this book and why it was written. We are not so pompous or ostentatious to think the module planning identified in this book will ever be compared to the likes of a great work of art or a piece of classical music. But, after reading this book, we believe that you will have a better understanding of what it takes to make a module job successful to the point where you can successfully implement it on such a project.

So, it is hoped that the title and this short Preface stimulate your curiosity enough regarding this age-old alternative to the standard stick-built process for plant design and construction to continue reading.

Thanks for indulging us.
MPK & JOC

ACKNOWLEDGEMENTS

Michael Kluck

First, to my co-author, who allowed me to continue my quirky way of writing, all the while patiently taking it in and then suggesting adjustments that made it sound so much better! For his writing and input into all the chapters (more than he will ever take credit for). For his attention to detail. And, just as importantly, for his help in the organization of this effort that very quickly got bigger than both of us ever imagined.

Finally, to all the folks associated with all the module projects I have ever been involved with. I know many of you forgot more than I ever was able to pick up, but I am thankful for the interactions, the trust placed in me, and the lessons learned, some very painfully. Without all of you collectively, this work would not have the depth it needed to really explain "the fine art of pre-assembly."

Jin Ouk Choi

This book would not have been possible without the support from many individuals. I thank all the people involved in this book.

First, I really thank my co-author, Michael Kluck, who wrote this awesome book with me. Without Michael, this book really would not have been possible. I really enjoyed writing this book with him. With his great energy, passion, vision, and expertise on modularization, this book was possible.

Second, I appreciate the Project Management and Construction Engineering Lab (PMCEL) members' support. I would like to especially thank two PMCEL members: (1) Dr. Seungtaek Lee for supporting Chapter 3 Industry Status on Modularization, and (2) Dr. Binit Shrestha for supporting Chapter 13 Innovative Technologies for Modularization.

Finally, I would like to thank my loving and supportive wife, So Hyun Bae, and my sister, Yoon Jeong Choi, for their advice, encouragement, and support. In particular, Yoon's help and graphical advice on the figures were invaluable.

INTRODUCTION

Why is there an entire book devoted to the "art" of modularization? Simply stated, because the decision to modularize impacts every aspect of a project's planning and execution. Even from the very beginning of a project, in the Opportunity Framing (pre-FEL-1 or FEL-0) phase, some basic but important decisions must be made to avoid inadvertently limiting the modular opportunities.

So, the book has been written as a guide of sorts, walking through what is necessary to perform a modular project successfully, starting with some very basic "stuff." The path and sequencing of the book make perfect sense to us . . . to others, perhaps not so much. And while there may be a temptation to skip over these early parts to find answers needed in the later chapters, it is recommended that you ground yourself with the basics provided by these first few chapters. This will help set you up for the detailed module planning effort—just like a quick review of the rules of any game you plan to play is recommended prior to launching into it.

This book combines research findings from the analyses of real case modular projects with industry examples to help tie any theories presented to real-life scenarios. Thus, we expect that not all chapters will be of equal value to you. We also expect you may not even agree with some of the ideas and concepts stated. But we do hope that you can see past our methods on the approach and oversimplified examples to the reasoning and understand the conclusions from them.

So, consider this as a guide for your modular road trip. And, like a road trip, it's the journey, not just the destination. To be effective, such a guide needs to point one in the right direction/provide a preparation plan/suggest basic supplies/identify support along the way/and offer an emergency kit for when things don't go as planned. We hope the specific guidance in the format provided is helpful in implementing successful modular project planning, even if presented in a bit different format than you might have anticipated.

In order to help you better understand how the book has been written, the remainder of this introduction delves into a brief description of what each chapter is about, beginning with the basics of what modularization is.

Chapter 1: What Is Modularization?

Chapter 1 sets the basics in terms of what is needed from a ground-level or basic understanding of the concepts and terms. While this may seem too elementary, it is critical because everyone has their own definition of what a module is (or what it is not) and, as a result, a pre-conceived notion of what is involved in its development. It addresses the current state of industrial construction and why it continues to see productivity decline to the point where projects are becoming unsustainable with the traditional stick-built methodology. In addition, other sectors, such as manufacturing and shipbuilding, are examined in terms of how they have addressed their productivity issues and succeeded in a major turnaround in cost and schedule and how modularization offers a similar potential advance in both. Then, based on the foundation laid that "modularization is this industry's alternative," details are explored around the variability of the optimal modular answer and how a one size does not fit all. Finally, the chapter further grounds expectations by discussing "what modularization is not."

Chapter 2: Advantages and Challenges of Modularization

Chapter 2 follows the basics described in Chapter 1 with further details on the modularization concept, including a high-level look at why the module fabrication yard is such an ideal place for module assembly. More details are provided in terms of the advantages of selecting this project approach and some of the disadvantages (or challenges) of this project execution method.

Chapter 3: Industry Status on Modularization

Chapter 3 describes the industry status on modularization through a compilation of 25 actual case projects in terms of observed advantages, cost and schedule savings compared to the stick-built approach, difficulties, impediments, business case drivers for modularization, types of module units, module numbers, size, and weight, and characteristics of the job site and the modular fabrication shop, along with the subsequent editorial comments regarding some of the results themselves. This chapter validates the advantages and disadvantages which were initially identified in Chapter 2 via this set of actual project case histories and sets the stage for the following chapters, which address how to properly set up and execute a modular project in more detail.

Chapter 4: What Is a Module?

Previous chapters defined modularization and module terms, mentioned the advantages and challenges, and spoke about WHY the industry needs to really embrace this alternative to stick-built execution, but they did not provide details on the modules themselves. Chapter 4 explains the length and breadth (and height, no pun intended) of module variability. Modules are identified and described in terms of their more common types with the goal of providing a basis for understanding the magnitude and variability of options available when the term "modularization" is mentioned. Further, this chapter dives into the "module considerations" necessary to develop a successful module project concentrating on those that are slightly different and unique to the module philosophy, such as:

- Plot Plan development
- Differences between the stick-built and module layout
- Optimal module size
- Typical module contents and those that might require special considerations
- Guidance on division of responsibility in terms of material procurement.

Chapter 5: The Business Case for Modularization

Chapter 5 begins the discussion of the modularization business case, as a logical extension of the information provided by the previous four chapters that identified the basis of understanding what a module is, why modularization is important, why implementation will be a challenge, and the potential options in terms of module configuration. In addition, it explains what makes a project a good candidate for modularization, the factors to consider, the importance of timing in modularization considerations, the modular project execution planning steps by project phases, and describes how to conduct a business case analysis using the tool provided. It also provides guidance on how to approach the project module option in terms of developing the project-specific details necessary to identify the optimal module case for your specific project in terms of size, number, cost, schedule, etc. The three key contents addressed in this chapter are as follows:

- Important **Business Case Considerations** are identified and explained.
- **The 13-step Business Case Model** is explained in detail.
- A usable **Business Case Financial Analysis Model** is provided.

Chapter 6: The Module Team and Execution Plan Differences

This chapter presents how to manage the project philosophy shift to the modular approach via the Module Team, identifying key team members and their qualifications. The dynamics of the team are explained and contrasted against the typical stick-built project team. Examples are provided on team organization as well as how the team should be incorporated into the overall project management. Also, a deep dive is taken into explaining how the execution of the modular project differs from the stick-built project. These major execution plan differences are identified in terms of what they are, when they should first be incorporated into the project execution, and their priority for implementation within each project phase. This detailed listing is visually summarized in an activity table showing the various execution plan differences by project phase and the priority of execution within each project phase.

Chapter 7: Key Critical Success Factors for Modular Project Success

Chapter 7 complements Chapter 6 because, when considered together, the two chapters provide the foundational basis for why the modular job is so different and why understanding these differences and success factors are so important to the success of a modular job. Chapter 7 explains the concept of critical success factors (CSFs), how they were developed, and their importance to the success or failure of a modular project. The 21 CSFs are equated to a listing of common mistakes identified on modular projects that failed or were only marginally successful. Later, the chapter examines the CSFs in terms of difficulty of accomplishment, and identifies an ideal time for initial implementation and who has primary responsibility. Furthermore, it demonstrates the relationship between the CSFs and project performance. Finally, a somewhat whimsical exercise involving the Module "Perfect Storm" is provided, a hypothetical scenario of a module job where almost everything aligns in terms of the worst possible outcomes, and where we comment on the subsequent conclusions reached.

Chapter 8: The Fabrication Yard

Chapter 8 continues the explanation, initiated in Chapter 2, of the benefits a fabrication yard can provide in terms of the overall modular project execution. Specifics are explained in terms of location, physical size, and layout, and operational philosophy. Project guidelines for yard selection are suggested in terms of size, location, complexity, and number utilized. In addition, contracting strategies are discussed in terms of pros and cons as well as what seems to work best. Options on the division of responsibility regarding who provides what are addressed and suggestions provided.

Chapter 9: Module Considerations by Project Group

Chapter 9 takes everything provided in terms of basic "learning" in the first eight chapters and starts using this modular basis of understanding to look at and make decisions on how to approach some of the different day-to-day aspects of the typical module project in terms of the various groups involved. This chapter gets down to the "nuts and bolts" or, as some suggest, "gets into the weeds" of the modular analysis. It is where "the devil in the details" of the previous general modular statements is exposed. The chapter is filled with personal experiences—both good and not so good. But the content of these module-supporting details is universal and provides an idea of the types of decisions one will face. Subjects include:

- Engineering considerations: module evolution, timing, discipline leads, fab yard coordination
- Fabrication considerations: structural members, welding vs. bolting, sub-assemblies, weight control
- Completion/testing/pre-commissioning: what is "complete," pre-commissioning, tradeoffs
- Shipping considerations: basic logistics, motion analyses, grillage and sea-fastening
- Load-out: methods, design considerations
- Movement to site and hook-up: design considerations and the single weld hook-up (SWHU).

Chapter 10: A Practical Module Development Process

Chapter 10 is our "second most favorite chapter" (*sic*) of the book in terms of its development and the culmination of the previous nine chapters. Chapter 9 took all the basics from the previous chapters and used this information as a basis to help identify and resolve issues that typically come up when planning and implementing a module project from the technical standpoint. Chapter 10 takes a slightly different approach, still going all the way back to the left on the project timeline (to Opportunity Framing) but walking through potential interactions required during the early stages of project development. It also provides a detailed 5-step method for early module screening analysis that builds on the 13-step business case discussed in Chapter 5. Other specific items covered include:

- Module tenets: common misunderstandings in terms of the modular philosophy
- Initial project analysis requirements and timing of required discussions and decisions
- Recovery options should the module decision be made late in the project life.

Chapter 11: Modularization Application Case Study Exercise

Chapter 11 is the development of a composite "made for this book" modular project case study exercise. The hypothetical case study exercise walks the reader through a modular project development, beginning with a summary of the project and proposed facilities. Each phase of the project is developed with information typically available at that time in the project development. The reader must take the information available and, based on what is known, make assumptions and develop a plan forward, answering the questions at the end of the project phase. This effort is reiterated through each phase of the project—Opportunity Framing/Assessment/Selection/Basic Design/Engineering, Procurement, and Construction (EPC). To keep the exercise on a consistent path, a primary solution has been developed that is used for "re-setting" the exercise for all, so there is a consistent approach at the beginning of each of the subsequent project phases. As a textbook, this solution is not part of the printed version but available for instructors (not for students) as a separate supplement. Contact Dr. Choi for the solution file: choi.jinouk@gmail.com

Chapter 12: Standardization: The Holy Grail of Pre-Assembly

Chapter 12 is the next step in the evolution of an effective implementation plan for the industrial capital project: Standardization. It starts with a brief explanation of the potential in cost and schedule savings, referencing both the historical gains of the shipbuilding industry as well as the more recent CII UMM-01 research on standardization. It starts by describing the two different paths to integrating standardization with modularization and the benefits, tradeoffs, and basic economics of each. Later, it provides a road map in terms of identifying what makes a good candidate, when to start the evaluation process, how to approach the evaluation effort, and some critical success factors associated with the standardization concept.

Chapter 13: Innovative Technologies for Modularization

Modularization techniques have recently evolved thanks to the advances in and incorporation of certain innovative technologies. Chapter 13 examines the part that technology plays in modularization in terms of a few key emerging innovative technologies that can help the industry implement the modular technique more successfully on more complex and sophisticated projects. Those technologies of interest are:

- visualization, information modeling, and simulation
- sensing and data analytics for construction
- robotics and automation.

Chapter 14: Moving Forward

Chapter 14 is dedicated to a semi-formal wrap-up of the book along with some "thought-provoking ideas" on what the future of our industry might be. It reiterates the authors' goals and provides seven specific industry "Accelerators" that will make the future a more module-friendly world, if implemented. Those "Accelerators" are:

1. Applied Knowledge
2. Different Academic Teaching Approach
3. Identify, Acknowledge, and Incorporate Required Paradigm Shifts
4. Friendly Contracting
5. Industry Re-branding
6. More Alliances and Research
7. Planning Techniques and Their Combinations.

Chapter 15: Key Literature and Resources on Modularization

Chapter 15 provides a resource guide that can be used for further follow-up on the future actions suggested for our industry in Chapter 14. It lists reports, tools, and academic papers on modularization and standardization that may be considered beneficial in terms of a follow-up study or research—many of which were referenced at one time or the other in the preceding chapters.

chapter 1 What Is Modularization?

This chapter starts by answering the question, "What is modularization?" and setting the basics in terms of what is needed from a ground-level/basic understanding of the concepts and terms. Starting with a definition of terms, including modularization, module, and percentage modularization, it then introduces an industry best practice, "Planning for Modularization," and some basic modularization/pre-assembly philosophy. Next, it goes into the current state of industrial construction and discovers why it continues to see productivity decline to the point where projects are becoming unsustainable with the traditional stick-built methodology. A description is given of how other industries, including manufacturing and shipbuilding, have addressed their productivity issues and succeeded in a major turnaround in cost and schedule and how modularization offers a similar potential advance in both. Then, based on the foundation laid that "modularization is an alternative," details about the variability of the potential optimal modular projects and how one size does not fit all are explained. Depending on the project type and configuration, the analysis result can range from no reason to consider modularization to modularizing as much as possible. Finally, what is needed to get started with considering modularization as an option as well as "what modularization is not" are presented.

1.1 Definitions

1.1.1 Modularization

The authors define modularization as follows:

Modularization is the project business/execution strategy that involves the transfer of stick-build construction effort from the jobsite to one or more local or distant fabrication shops/yards, to exploit specific strategic advantages.

Very simply put, it is the fabrication, assembly, and testing of a portion of a plant or manufacturing facility away from its final site placement. The key is a conscious shift in project execution strategy.

Our definition is aligned with (Tatum, Vanegas and Williams, 1987) and (Construction Industry Institute, 2013; O'Connor, O'Brien, and Choi, 2013).

- Modularization is used to describe a process in which the principal construction method is the use of off-site prefabricated, totally preassembled and pre-finished modules (Tatum et al. 1987).

- Modularization entails the large-scale transfer of stick-build construction effort from the job site to one or more local or distant fabrication shops/yards, to exploit any strategic advantages. Thus, modularization may be considered a form of project business/execution strategy (Construction Industry Institute, 2013; O'Connor, O'Brien, and Choi, 2013).

Note that for the purposes of future reference and proper understanding, all pre-assembly efforts should be considered as part of the term modularization. This is a simplifying assumption on the part of the authors in order to eliminate the typical discussion that ensues regarding how to define and separate the two terms or differentiate between them. ANYTHING done to move work off site will fall under the term modularization.

Unfortunately, not all modularization (or pre-assembly) solutions end up being beneficial. The very fact that this book is being written is due to numerous examples of how a modularization effort was not properly implemented and ended up not adding value to a project. Since these efforts also fell under the term "modularization," the last clarifying phrase was included in the definition, ". . . *to exploit specific strategic advantages*." Another way we sometimes clarified this caveat was ". . . that, when properly executed, provide best value for the project."

So, what makes a project a modular project? Is it any amount of pre-assembly being performed or having at least one bona fide module in the mix? Is it exceeding a specific minimum percentage or a specific minimum ratio of modules to stick-build? Probably none of the above. As mentioned in the definition of modularization, it is a conscious shift in project execution strategy. So, a project becomes a modular project when the project team makes the specific conscious changes in job planning and execution in order to facilitate a modular outcome.

It would be nice if a magic wand could be waved over all the modularization projects, and those which were not implemented properly could be magically called something else. This would eliminate all the bad press, wrong conclusions, and in general erroneous implementation efforts that resulted in giving this term and this concept the bad rap that it currently carries. We have no such magic wand, so education in the proper approach to modularization and its planning is the next best solution.

1.1.2 Module

So, what is a module?

A module is a "portion of plant fully fabricated, assembled, and tested away from the final site placement, in so far as is practical."

(Construction Industry Institute, 2013*; O'Connor, O'Brien, and Choi, 2013)*

Again, the authors have taken some liberties in terms of this definition with some simplifying assumptions. The module can be very large or as small as a simple sub-assembly of a skid. It can be fabricated and assembled halfway around the world in a sophisticated fabrication yard, or it can be put together on a plot of land immediately adjacent to the actual project site. There are benefits with both scenarios, and we do not want to limit what can be considered in terms of options for the alternative to stick-building by unintentionally limiting the definition of these terms.

1.1.3 Percentage Modularization

As one starts using modularization on projects, one of the first questions management has is: "What percentage of your project is being modularized?" In many cases, the answer received is incorrectly used by management. In some cases, the assumption is that the higher the percentage of modularization, the more significant the schedule or cost savings a project has. In other cases, it may even be used to compare completely different projects by a similarly incorrect metric—the higher the percentage modularized, the more efficient the project execution.

While the above simplifications can occasionally be true, they frequently are not and instead become a slippery slope to start down. As we will explain in future chapters, there are just too many factors that influence what determines the "optimal" percentage modularization for a specific project, many of which have nothing to do with the actual module itself but depend on the site location, type of equipment, labor, and material costs, etc.

So, we will just simplify and say it straight up: To simply make a direct relationship between percentage modularization and project efficiency is wrong! There are just too many other factors that will impact the optimal solution. With the above preface, here is the definition:

Percentage modularization is the portion of original site-based work hours (excluding site preparation and demolition) exported to fabrication shops.

(Construction Industry Institute, 2013; O'Connor, O'Brien, and Choi, 2013)

We have attempted to qualify the definition to pertain to the actual erected plant or facility by removing variables associated with the differences in site location, these being the potential demolition of existing facilities or naturally occurring geographical impediments as well as the surface preparation required to make a site ready to physically support the proposed construction effort for the project. These efforts and costs are not to be ignored for the overall project economics, but it is important that such costs are not included in any metrics developed on modularization comparison as they could be so vastly different from one site to the next. With this basic understanding of a few of the terms that will be used throughout this book, we can now move forward on why modularization is important to our industry.

1.2 "Planning for Modularization" as a Best Practice

The Construction Industry Institute (CII) has identified 17 construction best practices (Construction Industry Institute (CII), 2021). By definition,

Best practices improve performance not only in terms of cost, schedule, and safety, but they also increase the consistency and predictability of project performance. By improving the consistency of project delivery, a company will have a better chance of improving project performance over the long term. This combined benefit of best practice use will likely give companies a distinct competitive advantage.

(Construction Industry Institute (CII), 2017)

Basically, to simplify this, **a best practice is a methodology that is critical to the success of a project.**

Below is a quote from the CII article publicizing the promotion of Planning for Modularization as CII's newest best practice back in 2015.

Planning for Modularization is not necessarily focused on promoting or marketing the concept of modularization, but rather on helping project teams better understand whether modularization is the right strategy for the project and, if so, how they can successfully implement the strategy to achieve improved outcomes in cost, schedule, safety, and quality while mitigating issues such as a lack of skilled craft labor or extreme weather.

(Construction Industry Institute, 2015)

Not only CII but many renowned agencies and institutes also highlighted the potential of modularization. Below are some quotes from them:

New trend, the reemergence of prefab & modularization tied to current influential construction trends, such as the increasing interest in lean construction, the rising use of BIM technologies and the growing influence of green construction.

(McGraw Hill Construction, 2011)

Modularization technology has evolved – more sophisticated and complex facilities are subject to its implementation.

(Modular Building Institute, 2010)

Over the next 20 years, its growing prevalence could significantly advance the productivity and competitiveness of the capital facilities sector of the U.S. construction industry.

(National Research Council, 2009)

Why do we bring up this best practice reference and other renowned institutes' quotes here in our introductory remarks in Chapter 1? CII and many others have identified (Planning for) Modularization as having the potential to dramatically improve project outcomes. But, this planning needs to be simple and straightforward enough so it can be implemented. The problem is that this implementation path is not often very clear and oftentimes is neglected or badly carried out—hence the basis for the book.

1.3 Current State of the Construction Industry

The construction industry is in trouble. Current productivity rates are unacceptable, and the industry now as a whole is unsustainable. Labor costs have increased while actual skilled workers' "time on tools" has decreased. Regulations (of all types) have further restricted how the average worker can function on the job.

Furthermore, the construction industry is losing its skilled workers. They are getting older, retiring, or with the increasingly cyclic nature of the business, getting weary of the uncertainty of employment and moving to other professions. Making it worse, the industry is also not attracting many new younger recruits. Part of the reason is that the construction industry, as currently viewed by many, is not considered "glamorous" or appealing to these new younger people coming of work age. With computer and tech jobs in the forefront and the over-emphasis on a "college degree" as the only path to success, the typical construction industry job is often seen as a bit dirty, low-paid, difficult, and possibly even beneath their dignity. Trades, such as welding, pipe fitting, and instrumentation, which still pay handsomely and offer increased mobility and salary, are no longer considered as noble a profession as they historically have been. So, some of the potential students of these trades shy away from considering these trades as acceptable alternatives to college. As a result, the construction industry continues to suffer in terms of recruiting and maintaining an adequate skilled workforce necessary to support these project construction efforts.

With the recent trend of more large-scale mega capital projects (see Figure 1.1), not only in the number of projects but also in the greater share of investments in terms of dollars, these new megaprojects come with increased emphasis on holding both cost and schedule goals. However, unfortunately, "98 percent of megaprojects suffer cost overruns of more than 30 percent; 77 percent are at least 40 percent late" (see Figure 1.2).

Owners continue to enforce these cost and schedule goals by shifting more and more of the cost and schedule risk to the Engineering, Procurement, and Construction (EPC) contractors, who in turn push it down to their sub-contractors. With increased competition for the

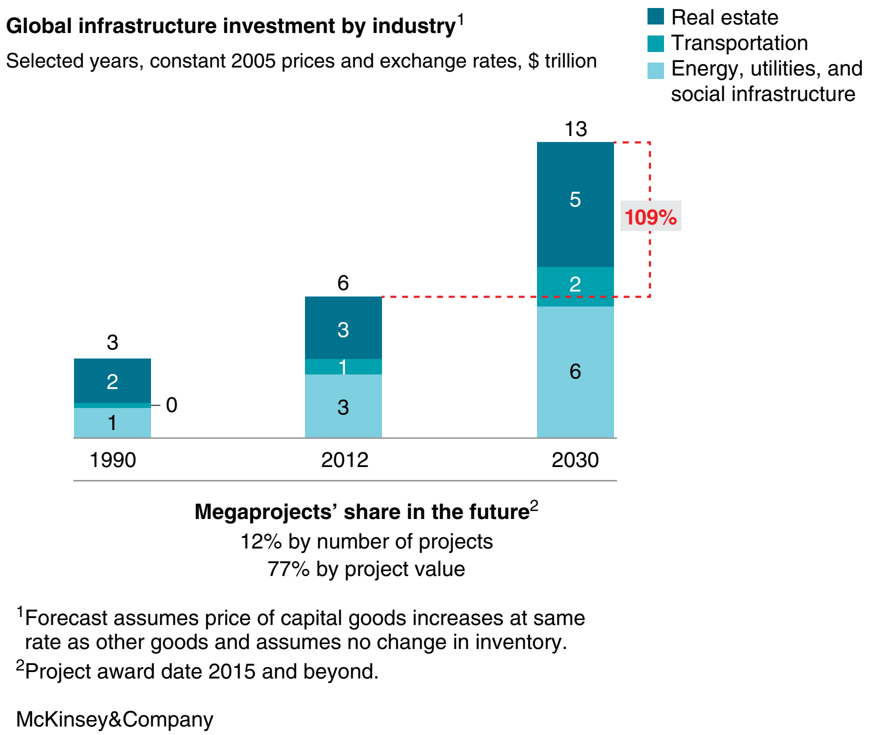

Figure 1.1 Global infrastructure investment by industry. Source: McKinsey Productivity Sciences Center (2015). Reproduced with permission of McKinsey & Company.

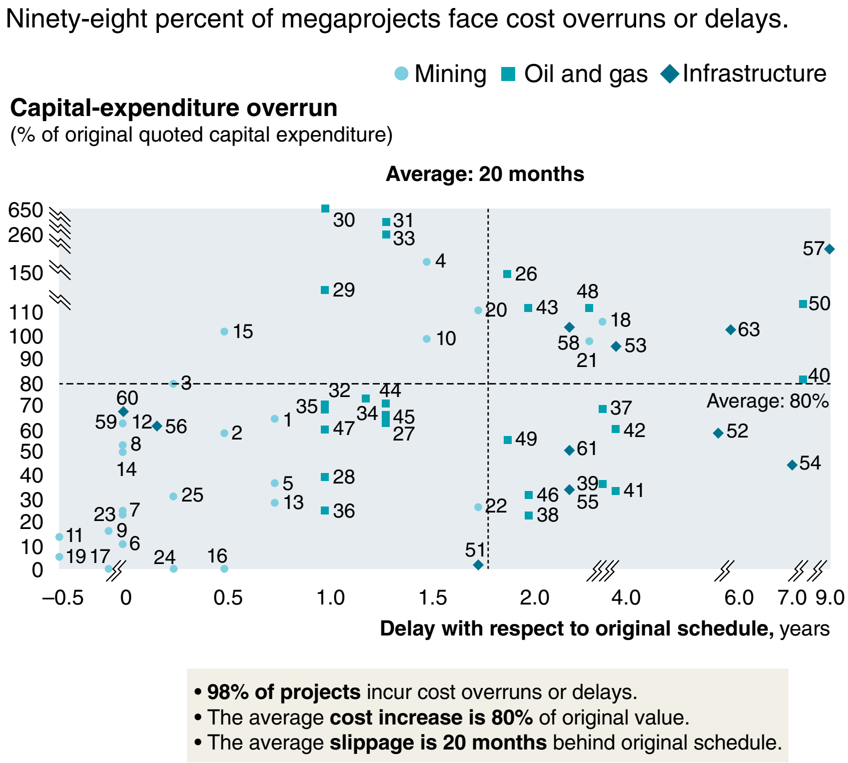

Figure 1.2 Megaprojects' capital-expenditure cost and schedule overrun. Source: McKinsey Productivity Sciences Center (2015). Reproduced with permission of McKinsey & Company.

fewer projects currently available in the market, the few successful EPC contractors must execute projects with razor-thin profit margins. Any deviation in labor pricing, material escalation, or schedule delays can spell financial disaster.

Modularization offers an alternative where the outcome is more predictable in terms of both cost and schedule, provided the required engineering and material inputs are provided in time. This is because the module fabrication yard operates more like a manufacturing facility

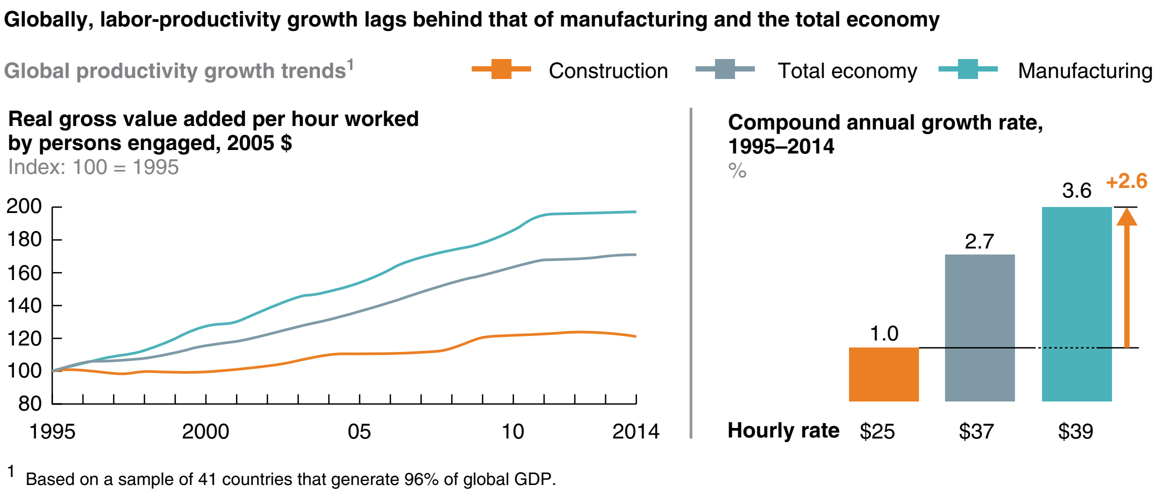

Figure 1.3 Global productivity growth trends. Source: McKinsey Global Institute (2017). Reproduced with permission of McKinsey & Company.