NAC Executive Insights

Modularization Design

Key Points

- Modularization encompasses a wide range, from preassembly to full modularization of significant systems, structures, and components.
- The modularization design process begins with a client approval to utilize modularization for the procurement and delivery of a project.
- Prior to conducting any general arrangement of the facility, an expanded basis of design will be developed.
- Final decision on the portions of the project to be modularized will be made following a comprehensive cost and schedule analysis.
- Modules will incur specialized transport costs and module protection costs associated with transportation, especially in marine environments.
- Strong focus on interface definition between the various systems, structures, and components that are incorporated within the module is required.
- Strong interface definition and management are required of those systems and structures that interface with other modules or at site facilities.
- Shipping and lifting loads must be considered in the structural design of the module.
- During detailed design, pre-construction planning is initiated for the fabrication yard, any modifications required along the logistics path, and at the final construction site.

Introduction

This Executive Insight focuses on the design of modules. Modularization and preassembly are construction techniques in which all or part of sections or facilities are prefabricated or assembled in one location and then transported to the site. The term modularization as used in this Executive Insight is intended to encompass a wide range, from preassembly to full modularization of significant systems, structures, and components. This Executive Insight compliments the Executive Insight on Modularization.

Modularization
Modules are generally structures in excess of 1,000 tons (may be smaller) with physical dimensions outside conventional highway transportation envelopes. They incorporate significant high-value labor hours and are typically multi-trade. Later generation modules include all structural components, including integration/elimination of pipe racks. Piping is maximized, including small bore piping, required insulation, electrical tray runs and terminations, instrumentation and controls, and other equipment. Bracing to handle shipment related loads is often included as part of the final structural design.

Preassembly
Preassemblies are typically in a 50- to 600-ton range. Preassemblies are usually structural and generally exclude major electrical, mechanical, or process equipment. Pipe racks and cable trays may be included. Structural components included normally encompass all such components, including major structural members, plate, ducting, and decking (excluding site poured concrete). Handrails, ladders, and permanent platforms are included to enable site installations.

The Modularization Design Process

The modularization design process begins with a client approval to utilize modularization for the procurement and delivery of a project or significant, specific elements of a project. Typically this approval is based on the outcomes of a series of modularization studies, including:

- Logistical constraints study
- Module yard capability and capacity study
- Module readiness study
- Engineering organization requirements study

In engineering organizations or project teams new to the use of modularization, an initial kickoff orients the team to what modularization is, what is possible, and importantly the underlying engineer-procure-construct (EPC) philosophy for its use. This orientation session includes exposing the engineering team to photos and videos of prior module examples, highlighting fabrication in the mod yard, long haul transport by rail, barge or ship, transport by SPMT (self-propelled modular transporter) and final placement. The potential scope and extent of modularization on the project is outlined.

As the team becomes familiar with the challenges and opportunities that modularization represents, lessons from prior projects will be reviewed and discussions ensue on how the design process will be modified. These lessons learned must encompass all engineering disciplines as well as project management, project controls, procurement, fabrication, construction startup, commissioning, and operations & maintenance (O&M). Initial alignment on design roles, responsibilities, and work processes will be conducted, and will be based on a shared work process understanding. Table 1 lists some of the lessons learned from previous project experience by the author.

Table 1 Modularization Engineering Lessons Learned
Increases engineering effort by approximately 10-20 percent (support details; vibration analysis; emergency shutdown; electrical/control systems)
Drives engineering and deliverables to an earlier schedule.
Engineering must know the transportation details before the start of detail design (barges, transporters).
Need to organize by module rather than by discipline.
Finalizing of process datasheets is critical to support early vendor selection and involvement.
Vendor data (particularly with packaged units) to support the design critical path is required early on. Thus, the selection and involvement of key vendors is important early in the design.
The need for future expandability needs to be agreed upfront.
Interface management and configuration control are critical.
Design to maximize pre-commissioning/commissioning in the module yard.

Prior to conducting any general arrangement of the facility, an expanded basis of design (BOD^X) will be developed. This BOD^X will consider not only the owner's project requirements, but also the requirements of a construction basis of design and an O&M basis of design. The construction basis of design will be required to address means and methods type considerations at the final project site and also fabrication at the module yard. On projects where more than one module yard may be used, it is necessary to decide on the degree of yard flexibility desired as it will affect the construction (fabrication) basis of design for specific modules. Bringing O&M considerations forward is essential since any design changes in the module yard are quite simply disastrous.

With an expanded basis of design developed, the results of previous studies are further informed by any data subsequently collected with respect to site and other location factors, both at the final project site and the selected module yard(s). Similarly, relevant logistical path information is updated. Factors that can influence the approach to modularization, the form that it takes, or its extent are enumerated.

A preliminary site plan showing major module battery limits is created and optimized using any of a number of modularization tools available. Correlation between cost and overall plant footprint are very strong as non-process infrastructure (NPI) costs come down with reducing plant footprints. Logical subdivisions of major modules are considered to confirm weight and transport initial feasibility. Through an iterative process, a module configuration table is built that details the boundaries of the individual modules, their physical dimensions and shipping and lifting weights, the location of major piping and equipment, and any pre-commissioning or testing that will occur in the module yard. The basis of design will be confirmed, especially those elements related to construction or fabrication.

A final decision on the portions of the project to be modularized will be made following a comprehensive cost and schedule analysis. This analysis will compare module costs and schedules to a "stick-built" (meaning all elements constructed at the project site) option. When one or more module fabrication yards are used, separate estimating databases and assumptions must be developed for each mod yard location. Work breakdown structures and work packages must ensure each estimate and schedule are complete for the selected execution approach and to ensure an apples-to-apples comparison. Modularization shifts not only direct work-hours offsite, but also shifts many indirect costs. These must be appropriately considered in the cost and schedule comparison, not just factored.

Modules will incur specialized transport and module protection costs, especially in marine environments. Lead times, availability, and costs associated with modularization will begin to be pinned down at this stage in order for any required transport booking or procurement lead times to be satisfied.

Labor cost, benefits, productivity, and work hours will vary between the site and module yard. Holiday periods may also vary. Modules provide an opportunity to move work-hours offsite, which can enhance productivity on what could be a congested site. Modularization also can help address labor shortages at the project site.

Module yards represent another construction work front facilitating parallel construction. Key metrics shift from tons of modules to work-hours removed from the site and schedule compression achievable. General labor availability at both the site and module yard need to be considered, with particular attention paid to skilled trades such as welders and electricians.

At the completion of this comparative cost and schedule analysis, a final module configuration table is issued. A final risk assessment also is conducted to identify module yard and logistical risks, management and mitigation measures to be implemented, and appropriate levels of cost and schedule contingencies to be provided.

With this modularization framework firmly in place, the preliminary site plan is refined and a final module layout developed. Module battery limits are further refined and the degree of modularization and pre-commissioning of each module established. Drivers of modularization for each module are clearly articulated (workforce/work-hours, cost, and schedule). An overall construction sequence is developed that identifies when modules are to arrive on site and be placed. Module schedules for design, fabrication, and shipping will be derived from these dates and confirmed as achievable.

The final module configurations will be confirmed for weight, dimensions, battery limits, and interfaces. Construction, logistics, heavy lifts, and other plans will be developed on this basis. Similarly, site engineering of any underground facilities, sub-grade structures, and utilities will be defined and designed to support the module layout. Foundation requirements are defined by module dimensions, weights, and loads and clear interface points for placing modules on foundations are determined.

Detailed design commences at this point, recognizing that the level of detail is more demanding to support efficient fabrication in the mod yard. Three major areas encompass detailed design:

1. Functional engineering
2. Discipline related assembly and transport specifications
3. Pre-construction planning

These are addressed later in this Executive Insight.

Module Generations

Module designs have continued to evolve over the years from so-called Generation 0 to today's Gen 3 modules.

- Generation 0 (Gen 0) – Stick-built plant
- Generation 1 (Gen 1) – Main pipe racks with major piping installed
- Generation 2 (Gen 2) – Piping and main equipment installed in modules; layout similar to stick-built project
    - Some footprint reduction
    - 40 percenet of labor is offsite
    - Site module yard constructed if not commercially available
    - Measurable savings in Net Present Value (NPV)
    - IRR improved by 0.2-0.3 percent
- Generation 3 (Gen 3) – Electrical and instrumentation included in modules; modularization drives layout; interconnecting pipe racks are not used; offshore design practices are utilized, where practical
    - Significant footprint reduction – up to 40 percent
    - 50-60 percent labor is offsite
    - Often requires water access to site
    - Significant savings in NPV
    - IRR improved by 0.9-1.3 percent

Functional Engineering

Functional engineering in module design in many ways mirrors traditional considerations in a stick-built design, but with added emphasis in a few key areas. One major difference is a strong focus on interface definition between the various systems, structures, and components that are incorporated within the module. This is essential for efficient fabrication at the module yard. A second area requiring strong interface definition and management involves those systems and structures that interface with other modules or site facilities. These interfaces will be reflected in BIM[i] (building information modeling) models and will be tightly controlled both in the fab yard as well as at the interfacing points at the site. Configuration management takes on new meaning in module design.

Functional engineering developed work breakdown structures and work packages are shaped by fabrication yard capabilities and crew and shift sizes. Module construction/fabrication involvement in work package definition is extremely important in fabrication efficiency.

In-module interfaces, such as those required for subsequent electrical and controls connections, must receive special attention to ensure ready access in the field. More recent trends in module design often include in-module power connections with required lengths of cable for "home runs" spooled on the shipped module. This plug and play feature aids in pre-commissioning select modules in the mod yard and may be used for low voltage cabling as well.

The content of P&IDs (piping and instrumentation diagrams) and specifications are expanded to consider not only final module configuration but also special features associated with the transport process (discussed below). Weight and dimension control is important in module design and these features must be tracked and reflected in specifications as well as in the BIM model. Modules incorporated into BIM must reflect not only the final installed condition, but also the as-shipped configuration, reflecting any special environmental or fire protection during this transitory phase. To the extent possible, these transit related installations should be incorporated into final plant design.

Shipping and lifting loads must be reflected in the structural design of the module. Where possible, bracing steel added to handle shipping loads can be incorporated in the final structural design. This allows reduction of loads in other structural members and eliminates the necessity to remove shipping bracing at the site. Similarly, lifting lugs can be incorporated into the permanent design and installed at the fab yard, eliminating the need to weld them to the structure at the site.

Table 2 **Best Practice Design Features to Consider**
Individual modules include MCCs (motor control centers) for their systems
Standardized electrical vault cable tray runs and preassemble (or include in modules as appropriate)
Preassemble any overhead cranes not incorporated in modules
Camp buildings fully modular, including mess hall
Conveyors completely preassembled, including cable trays, walks, ladders, and railings
Pre-cable modules and incorporate cable for home runs
Deflection control during all phases of transportation – adding outriggers (temporary stability framing), changing the configuration, or increasing trailer length
Checking the module for different boundary conditions as experienced during transportation

Assembly and Transport

Assembly and transport specifications are typically discipline driven. In industrial (energy, chemical, power, mining, and manufacturing) modules, the principal disciplines include:

- Structural
- Piping
- Equipment
- Electrical

Structural

In civil infrastructure modules (prefab bridge decks, towers, locks, and dams), structural is the predominant discipline. Building-related (commercial, institutional, residential) modules are not covered by this Executive Insight.

Structural engineering considerations are primarily driven by the added considerations created by shipping loads, recognizing that, depending on shipping methods, intermediate lifts may be required.

There needs to be signoff at this point from logistics so that the requirements for the selected/contracted shipping method and route are finalized for design to progress.

Added loads associated with shipping and transport include torsional loads associated with a shifting center of gravity during marine shipping in heavy seas and the need to distribute a load evenly across multiple SPMTs, either in roll on/roll off (RORO) transport or to or from the port. Weight distribution is also important in lift on/lift off (LOLO) operations and when smaller modules are being transported by truck. See Table 3 for shipping and transport loads by barge, RTVs, and SMPTs.

These various loads drive a need for added torsional and lifting bracing and reinforcement. The latter is associated with the placement of the lifting lugs.

Table 3
Module Shipping and Transport Loads

Barge Loads	Road Transport Vehicle/ Self-Propelled Modular Transporter Loads
Sea wave actions produce three acceleration components: pitch (longitudinal), roll (transverse), and heave (vertical)	Includes truck acceleration and deceleration loads (Impact loads)
Maritime accelerations vary with module height	Loads and truck-ability are dictated by road conditions
Temporary transportation beams connected to the stub columns are welded and tied down to the barge deck to restrain uplift	Axles are hydraulically connected to the ground, creating an equal pressure distribution that is applied as an upward vertical force on road transport vehicle girders
Hog and Sag due to barge deflection during shipment applied as support displacement loads at the geometric center of gravity of the module	Power pack load on both ends of road transport vehicle is added
	Length of road transport vehicle is dictated by module weight vs. allowable load per tire
	In the case of excessive deflection on road transport vehicle beams, outriggers can be added

Table 3
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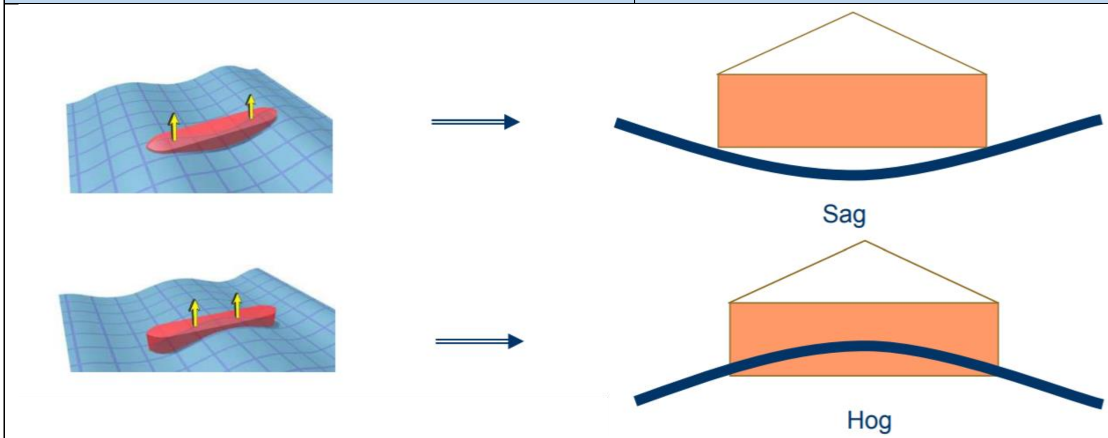
Barge Loads	Road Transport Vehicle/ Self-Propelled Modular Transporter Loads



Barge Transport Loads

Structural design must also consider the sequence of installation since certain modules may not be in their final stable positions until other modules or permanent, site-based works have been installed and normal, "complete" structural analysis may not yield correct sizing of members in a stand-alone mode.

Other structural engineering considerations include:

- Module-to-module structural connections.
- Module to foundation interface and installation method (RORO or LOLO).
- Incorporation of ladders, platforms, and other fit-outs as part of the fabricated module or as site add-ons.
- Handling of grating and walkways that span modules.

Piping

Piping on modules was one of the first industrial uses of large-scale modularization. Pipe racks readily lent themselves to fabrication in a module yard and shipment to the site. Originally, only large bore (30" or greater) piping was considered.

As modularization has taken hold, free standing pipe-rack-only modules have become less prevalent as site footprints continue to shrink. Increasingly, piping and equipment are integrated into larger modules than those first used in the industry.

Module to module pipe connections require careful configuration control. Pipe supports have an added load combination to consider, namely shipping related loads. Pipe supports must have springs installed for shipping loads with clear instruction for adjustment to the new settings required at final installation. This is a new quality control checklist item. The use of the correct support setting is essential to reduce the risk of damage during transport as well as subsequent safe operation.

Expansion joints incorporated into module piping systems must be braced for shipping and piping. Insulation for module-to-module connections are included with the shipped module and their location and tie-downs included in the module arrangement drawings.

Pre-commissioning requirements established at an earlier stage with appropriate plugs for protection during shipping are designed to allow leak testing of the piping or in some modules even more comprehensive sub-system testing and commissioning.

Equipment

Equipment can be thought of as consisting of major and minor equipment. Major equipment can be characterized as including those components shown on process diagrams and/or P&IDs. In most instances major equipment installation occurs in close coordination with module structural fabrication.

Engineering must carefully consider the sequence of construction in the mod yard with respect to the placement and timing of major equipment. A strong focus on O&M considerations at the outset of design development often strongly influences layout for equipment likely to have to be replaced or routinely undergo extensive maintenance.

Minor equipment may be field installed, but configuration control remains important to ensure no protrusions outside the shipping envelope or interferences for field run power, controls, or any field run, small-bore piping. Equipment installation and assembly instructions for the mod yard may differ from those normally associated with field installed equipment since certain manufacturing protections (such as those that lock a rotor during shipping) may want to be left in place during the journey from the fab yard to the final site.

Instructions to the field on the removal of these protective measures is essential. On modules where pre-commissioning may necessitate normal operation of the installed equipment, it may be necessary to reinstall some of the manufacturer’s shipping features.

Alignment instructions must be provided to the module yard for fabrication and then reconfirmed and if necessary readjusted at the project site. These instructions together with any uninstalled parts and spares should be shipped with the module they serve and their location and shipping bracing reflected in the module shipping arrangement.

Equipment that will be exposed to a marine or other harsh environments requires necessary protections during shipping. Protection and any “packaging” used in a module should preferably be minimized through incorporation in the final design or made from a single recyclable material to reduce site waste streams associated with mixed waste.

Electrical

Electrical engineering considerations in module design should reflect the module pre-commissioning plan, the philosophy with respect to on module motor control centers (MCC), and a decision of whether instrumentation and control tubing only or tubing and wire will be installed.

Consideration should also be given to the robustness under shipping loads of any installed instrumentation. Connection points should incorporate any required environmental protections during the shipping process.

Electrical plans must reflect any temporary electrical connections or provisions associated with pre-commissioning. Final site-based installation instructions should be included with the shipped modules.

Across all disciplines, all fabrication yard and final site instructions and documentation should be accessible through BIM. A final point: modularization does not handle changes well. This is now a manufacturing process and any changes are best left to post-delivery at the final project site. Modularization underscores the importance of strong scope and configuration control.

Pre-Construction Planning

During the detailed design stage, pre-construction planning is initiated for the fabrication yard as well as any modifications required along the logistics path and at the final construction site. Module configurations, construction requirements, and any special tools and equipment should now be identified and fabrication yard laydown and assembly areas defined.

Rigging studies are conducted for the module yard, temporary facilities identified, and staffing requirements defined. An initial assembly plan is created and sequence of assembly confirmed with engineering, procurement, and construction.

Engineering and inspection resources, together with project management, procurement, safety, and quality assurance/quality control (QA/QC) resources to be located at the module yard, are identified.

Heavy haul requirements along the logistics path are identified and any modifications to the logistics path identified and necessary approval and modifications obtained. Examples of logistical path modifications include:

- Removal and replacement of street light, telephone poles, or electrical power lines
- Reinforcement of bridges along the path of travel
- Widening of right-of-ways
- Removal of obstructions along path of travel
- Creation of turn-outs and bed down areas for limits on travel corridor access

Pre-construction planning related to the final site should include ensuring that necessary paths for module transport and placement are clear and that any temporary roads have the necessary load capacities. Cranage required for any final placement of modules needs to be considered.

In some situations, modules will be barge mounted and the entire barge incorporated into the final plant. Any dredging or other marine considerations should be identified and planned for at this stage.

Procurement and Construction

With detailed engineering well under way, the focus shifts to procurement, which is now procuring equipment for delivery to two or more intermediate and final sites. Depending on the nature of the module yard fabrication contract, materials for the fabrication yard also may now be undergoing procurement.

Coordination of equipment and material deliveries to the module yard is critical in order to not delay the module fabricator. Timely design is an essential first step. Expediting must be present at the module yard as well as with the central project team. Coordination of delivery of materials to individual modules and construction sites increases the importance of the material management function. Material management should be set up by module. A clear procedure is required to transfer ownership of spares from the fab yard to the site.

Logistical contracting processes are initiated, vessels and other logistics equipment reserved, and shipping windows confirmed with both the module yard and final site.

Similarly, construction planning and engineering oversight of construction must deal with both initial fabrication and final site installation, recognizing that the as-built condition of each may be different.

Summary

Modularization is an effective component of an overall program delivery strategy. Under modularization, the sequence, control of, and basis of design change when compared to a stick-built project. While the primary focus in this Insight is for industrial facilities, the information provided is applicable to many different types of projects that will utilize modularization in some areas, such as project utility systems, distributions centers, and others.

References

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For Further Reading

Executive Insight, Business Basis of Design
Executive Insight, Constructability Reviews before Design Commences
Executive Insight, Location Factors in Large Complex Projects
Executive Insight, Indirect Field Costs
Executive Insight, Configuration Management
Executive Insight, Procurement Management in Large Complex Projects

About the Author

Bob Prieto was elected to the National Academy of Construction in 2011. He is a senior executive who is effective in shaping and executing business strategy and a recognized leader within the infrastructure, engineering, and construction industries.

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[i] BIM – Building Information Models are data-rich virtual models of a building or other constructed asset through its life cycle.