Industrialized Construction for Affordable, Low-rise Housing using Cross Laminated Timber with Modular Bathrooms and Kitchens.

Part Three: Supply Chain & Vendor Selection

In this third installment of our series, we examine the development of key supplier relationships in the context of a Lean Supply Chain paradigm for real estate development and construction. This is then illustrated through our experience sourcing CLT panels and modular bathrooms for the Northwest Arkansas IC program.

CLT Panel Production, Sterling Structural, Phoenix, IL. Image courtesy of Sterling Structural.

Towards a Lean Supply Chain for Industrialized Construction

Industrialized Construction is an application of Lean principles from manufacturing to construction. Manufacturing concepts such as Kaizen (Continuous Improvement), Heijunka (Production Leveling), Pull Planning, Takt (cycle-time) are now fairly widely discussed within the construction context[1]. An equally important, but somewhat less appreciated, set of principles within Lean concern the development of the supply chain. Lean production places the supplier and assembler (or primary manufacturer) into a unique relationship that is distinct from both the mass production mindset in a 'classic' industrial plant and the supplier/ contractor relationship in a construction project.

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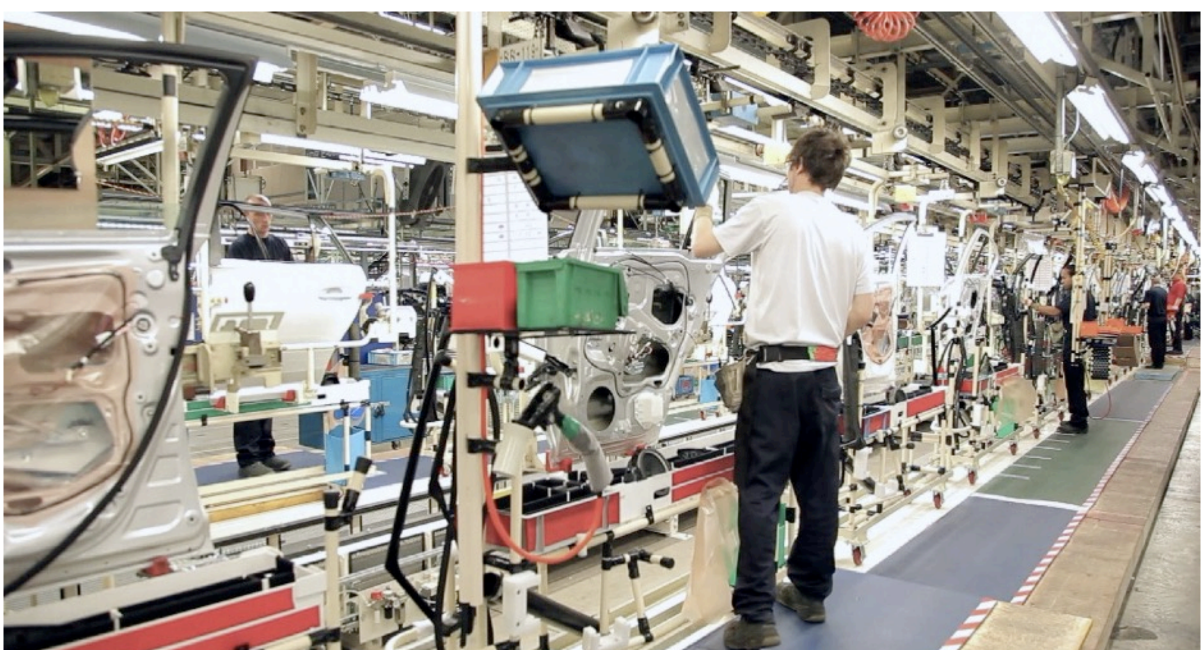
For a clear example, we can refer back to some of the classic literature on Lean. Writing in their seminal book on the Toyota Production System, "The Machine that Changed the World", Womack, Jones and Roos provide a good illustration of how Lean Supply Chain relationships are structured:

> *At the very outset of product development, the Lean producer selects all the necessary suppliers. The leading Japanese lean producers involve fewer than 300 suppliers in each project (compared with 1,000 to 2,500 at Western mass producers)…Significantly, they are not selected on the basis of bids, but rather on the basis of past relationships and a proven record of performance.*
>
> *The first-tier suppliers to a lean development program assign staff members- called resident design engineers- to the development team shortly after the planning process starts and* ***two to three years prior to production*** *[emphasis added]. As product planning is completed, with continuous input from the suppliers' engineers, different areas of the car- suspension, electrical system, lighting, climate control, seating, steering and so-forth- are turned over to that area's supplier specialist to engineer in detail…The suppliers development team with its own Shusa [Chief Engineer] and with the help of resident design engineers from the assembler company…then conducts detailed development and engineering.*
>
> *In 1988, for example. Nisshin Kogyo, a leading Japanese brake manufacturer, had a product-development team of seven engineers, two cost analysts, and a liaison person regularly positioned at Honda's research-and-development center. The team was working on a daily basis with Honda's development engineers on the design of a new Honda car.*[2]



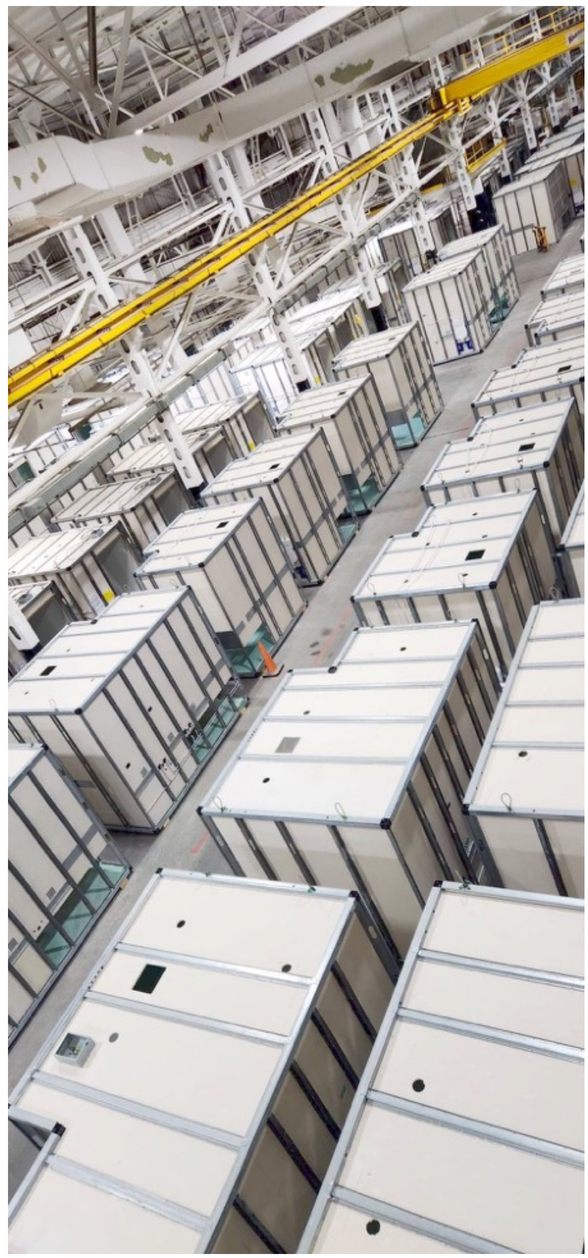
Toyota Auris Hybrid manufacturing, Burnaston UK. Image courtesy of Toyota Manufacturing, UK.

Producer-Supplier Relationships in Lean Product Development

The authors of "The Machine that Changed the World" go to great lengths to highlight the ways in the which the manufacturer-supplier relationship in Lean extends far beyond the spec and price-per-part metrics typically used to evaluate suppliers in North America prior to Lean adoption.[3]

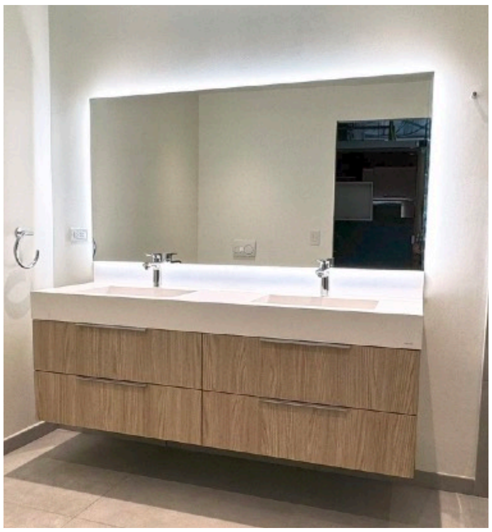
Most notable is the high level of integration and alignment with key suppliers during product development cycles. This deep and interdependent relationship is one of the keys that Lean uses to unlock value in production. The alignment of both parties on technical and financial goals during product development is a key differentiator of a Lean Supply Chain:

> *Even when it comes to parts where the assembler is only loosely acquainted with the technology and totally dependent on a single outside supplier, the lean **producer** takes care to learn an enormous amount about **the suppliers** production costs and quality [emphasis added].*
>
> *But what is it about this system that allows an interchange of such sensitive information to take place? The answer is simple. The system works only because a rational framework exists for determining costs, price and profits. This framework makes the two parties want to work together for mutual benefit, rather than look upon one another with mutual suspicion.*
>
> *Almost all of the relationships between supplier and assembler are conducted within the context of a so-called basic contract. The contract is, on the one hand, simply an expression of the assemblers' and suppliers' long-term commitment to work together. However, it also establishes ground rules for determining prices as well as quality assurance, ordering and delivery, proprietary rights, and materials supply…*
>
> *…For the Lean approach to work, the supplier must share a substantial part of its proprietary information about costs and production techniques. The assembler and supplier go over every detail of the*



Bathroom Modules under production at Bathsystem America, Houston TX.

supplier's production process, looking for ways to cut costs and improve quality. In return, the assembler must respect the suppliers need to make a reasonable profit. Agreements between the assembler and supplier on sharing profits gives suppliers the incentive to improve the production process, because it guarantees that the supplier keeps all the profit from its own cost-saving innovations and kaizen activities[4].



Double vanity mock-up at Bathsystem plant, Houston Tx. An example of IC program OEM sourcing working with first, second and third tier suppliers.

While this kind of relationship does increase the dependency between the supplier and manufacturer, it does not necessarily mean that key supply chain links are all sole source. In fact, as the authors point out, this is a common misassumption about Lean manufacturing. To the extent that sole source supplier relationships exist in Lean, they are usually limited to large, complex assemblies that require significant investments in tooling and training. These arrangements, as we have seen, are the product of extensive engineering efforts involving both companies. Sole source contracting is used much less for the remaining parts of the vehicle.[5]

Applications in Real Estate and Construction

In the context of Industrialized Construction programs, the supplier/ manufacturer relationship can be seen as analogous to the relationship between the contractor (or IC product fabricator) and the real estate developer, in the sense that the developer is ultimately responsible as the 'assembler' of the building portfolio. Note the similarity between the automotive example above and this excerpt from a recent industry report on Industrialized Construction:

A good starting point for developers is to identity the segments of a portfolio where volume and repeatability come into play. These can be designed as a 'product core' that remains consistent across developments. [This] will require more than merely asking suppliers for tender offers on existing designs; rather, they will need to work with the supply chain to optimize for manufacturability and make the right trade-offs among quality, cost savings and time savings.

[Suppliers] can ensure sufficiently large portfolios of projects to maintain the utilization of their factory if they integrate or partner with owners and developers to guarantee a pipeline. This will help sustain the productivity benefits provided by the manufacturing approach. In addition, developing design capabilities or partnering with designers can ensure the development of standardized products tailored for the manufacturing process. Integrating materials supply at the back-end of the value chain can help capture gains from standardization and internalize distributor and Original Equipment Manufacturer (OEM) mark-ups. This highlights the potential for…deeper structural changes in the industry.[6]

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Differences between Industrialized Construction and Lean Manufacturing are in degree and not kind

There are important differences between the automotive and construction industries that must be acknowledged. Among those:

- **Higher Variability/ Lower Volume :** 50 million 2019 Toyota Corollas were sold as of 2021[7]. There is simply no functional equivalent for buildings in terms of repetition and standardization. Buildings are unique and specific- even the ones that repeat must ultimately conform to the local soil, climate, regulations and costs.
- **Systems Availability and Maturity:** This reflects the decades of investment in car companies and their importance as elements of national security within their respective countries, whereas construction is often regarded as a laggard, fairly or not, in terms of technological and productive capacity. [8]
- **Production Batch Size:** An important difference when comparing Automotive manufacturing to Industrialized Construction has to do with the batch size of the production run of a given 'model'. Even in construction sectors where IC is fairly well entrenched, that longest production runs are orders of magnitude smaller than a typical mass market vehicle. Industrialized Construction should, therefore, be properly seen as a type of Small Batch Size Manufacturing (SBSM)[9].
- **Level of Uncertainty:** Virtually all of Industrialized Construction works on a Manufacture-to-Order (MTO) basis vs. a Manufacture-to-Stock (MTS) model typically found in automotive. This makes scheduling and forecasting more difficult and volatile, since the fabricators risk exposure for deliveries is inevitably tied to each individual real estate deal rather than to the broader automotive market.[10]

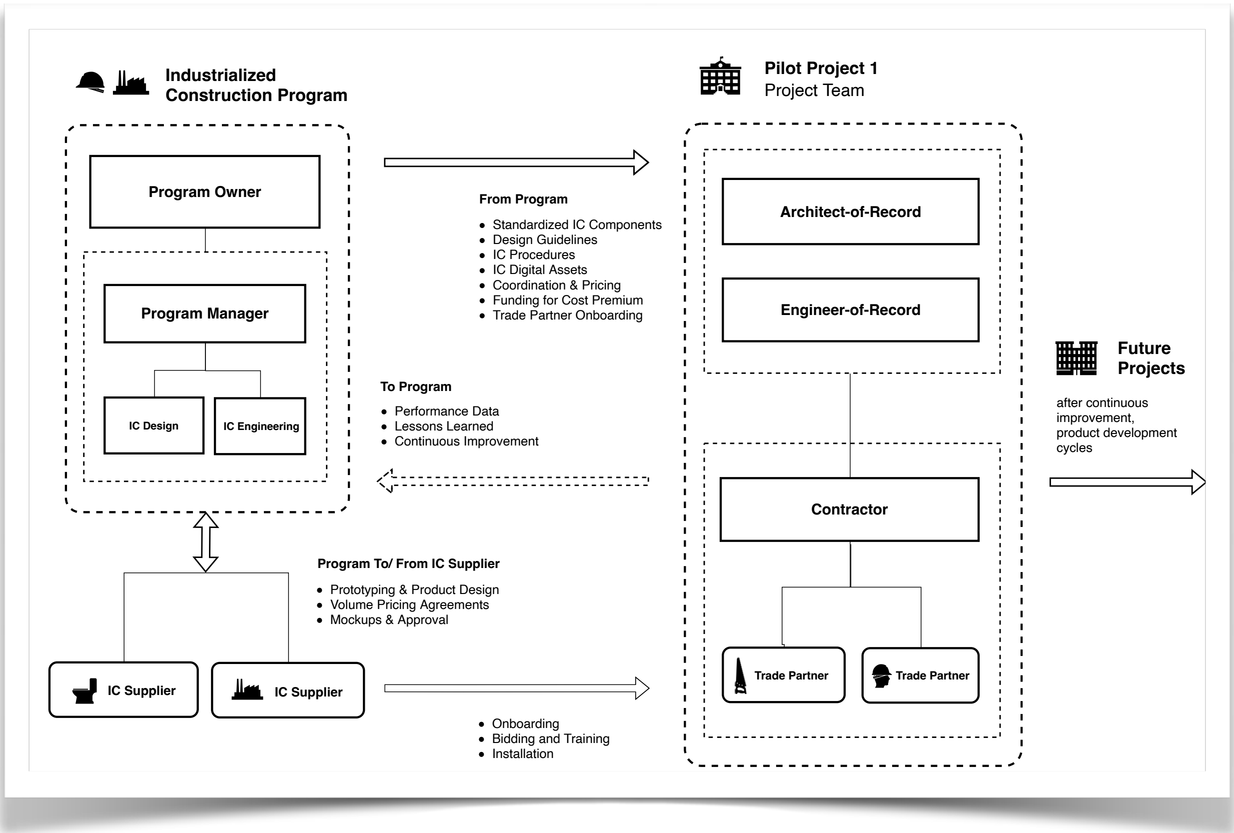
These are just some of the important parameters to consider when examining Lean for construction, but the differences, in of themselves, do not invalidate Lean methods. The same Lean principles that are applied to large scale auto manufacturing work for Industrialized Construction. Small Batch Size Manufacturing does, however, require more focus on particular aspects of the Lean production system, such as lead times, product development and customer alignment. [11]

Managing these differences in a way that maintains alignment with the owners goals is, therefore, one of the main functions of the Industrialized Construction Program.

Sequenced CLT panels, ready for shipment, Sterling Structural.

The Industrialized Construction Program drives the development of the Lean Supply Chain

We have discussed the role an Industrialized Construction Program can play in implementing Lean on behalf of the developer or owner-operator organization[12]. When it comes to setting up the supply chain network, the IC program acts as a bridge on the Lean journey, spanning the gaps between conventional construction methodology and classic Lean manufacturing.



Above: IC program Structure, Northwest Arkansas Industrialized Construction Program

During the initial set up phase, the IC program plays the role of the *Shusa* or Chief Engineer in Lean, establishing the performance parameters for the IC product, selecting the suppliers and developing the first-tier supplier relationship. In order to effectively work with suppliers over the long term to continuously improve cost and performance, the relationship of owner and supplier for the IC products must be primary- it can not be left to the project team to secure on their own. Just as the first tier supplier relationships span multiple models and makes in automotive, so too will the IC program span multiple building projects and teams. The continuity and primacy of the IC program function is what enables it to improve the performance of the component over time.

Embedding the IC program within the owners organization allows it to mitigate the specific risk profile of SBSM. Visibility into the owners pipeline of projects, and the ability to forecast productions runs accordingly, gives the supplier some assurance against the volatility of the real estate market. Locating the component design within the owners organization also ensures that product development efforts can be ongoing and

An example of a Lean 5-S implementation at Sterling Structural, Phoenix IL

well calibrated to the owners needs, providing a valuable level of control within the SBSM context to better manage batch size and design variability.

Another important benefit of such an arrangement for the owner is that many suppliers in the IC space have spent years developing their own Lean production systems. Unlike the example of Toyota, where the production system at the assembler level is more advanced than the supplier, the IC program is likely to be less advanced in implementing Lean than some of its suppliers.

Selecting suppliers, such as Sterling Structural, who were well along in implementing Lean production within their facilities and understood the mindset, was an invaluable asset during the startup phase of the Northwest Arkansas program. Not only did this provide an added level of assurance in terms of cost and quality, the suppliers became a resource to the program itself. There is no need to have to explain why extensive and continued collaboration on the design, logistics, execution and planning of the effort was important, or to 'sell' the value of a long term relationship. This was already well understood by the suppliers.

Supplier Selection during Pilot Phase and the impact of COVID-19 pandemic

There were a number of unique circumstances related to the COVID-19 pandemic that proved especially challenging during the initial pilot phase of the NWA IC program.

Access to manufacturing plants was limited, which hampered the program teams ability to physically evaluate the production environment. Pandemic restrictions on operations and potential outbreaks at plants meant that production capacity would also be constrained or potentially unavailable, so the delivery timeline was a key concern.

It was also important that the two primary Industrialized Components needed, CLT floor panels and modular bathroom units, were technically compatible, particularly at the floor interface where service penetrations and threshold conditions had to precisely align.

Candidate Selection Criteria for Supplier Partnerships, NWA IC Program

- Performance track record
- First cost falls within acceptable premium
- Availability of production capacity
- Compatibility of systems with design intent
- Suppliers experience and facility with Lean Production Systems
- Willingness to work collaboratively to improve product cost and quality
- Willingness to engage on a program basis
- Availability of technical resources during prototyping
- Facility with BIM; ability to coordinate and clash detect
- Availability of plant for tours during selection process

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The development team also understood that the price of the IC products would come at a premium over conventional, given the nature of a pilot project. The task for the program was to bring the cost of the components to a level that was in line with the premium cost threshold set by the developer. This proved to be especially challenging in the immediate aftermath of the Covid pandemic as the price of lumber escalated dramatically[13]. The volatility of raw material prices, however, cuts both ways. While Industrialized Construction purchases are exposed to rapid rises in commodity prices, IC Programs can also provide a hedge against escalating costs by locking in prices early during an inflationary run-up.

Wall Street Journal, Dec. 19, 2021

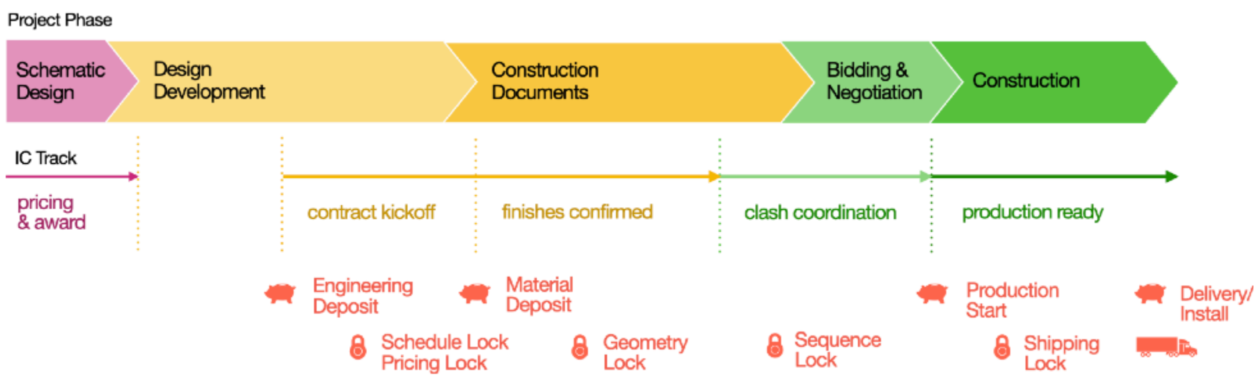
From a technical standpoint, the NWA IC program needed to find suppliers with relatively mature systems that could be validated. In both cases, the selected suppliers came with a long history of performance and well established product delivery systems. In the case of Sterling Structural, the selected partner for CLT panels, the program was able to take advantage of an over 30 year history of high volume CLT panel production, and a highly developed logistics support capability for their industrial matting business. The standardized panel sizes offered also helped define design parameters quickly when evaluating the system. The selected bathroom module supplier, Bathsystem America, also had an over 30 year track record of global project delivery through its Italian parent company, and a well engineered system that complimented CLT floor deck assemblies.

Sterling CLT industrial matting, image courtesy of Sterling Structural.

Typical Procurement Process and Milestones

A short list of candidate supplier partners consisting of three potential suppliers for each of the systems was developed, prior to pilot project start. Phone interviews and, when possible, plant visits were scheduled. A pricing package consisting of prototypical designs for the bathroom and schematic documents for the building layout was prepared, and a basic Request For Proposals was sent to each of the candidates.

An approximate timeline of activity from that point forward is shown below:



These milestones are staged to provide needed information for the suppliers at the earliest point possible to allow for meaningful value engineering during the Design Development phase. Production scheduling requirements at the manufacturing plant also means that **engineering and material deposits for the IC products are often due prior to the release of construction documents,** an important requirement for developers to keep in mind. This is the only to ensure that the products are available when needed, since the manufacturing plant is under constant pressure to maintain steady production volumes. By locking in the schedule, sequence, geometry and logistics in the phase-gate process above, the development team and supplier are able to ensure that the production tempo remains aligned with the overall project schedule.

Changes are still possible after 'locks' are in place, but become more costly and difficult. For example, storage fees will usually apply if the project schedule is delayed after the production schedule is set, since the backlog of other projects at the plant makes rescheduling prohibitive for the manufacturer.

The process is subdivided into the following steps:

- **Pricing and Award:** RFP responses are received and evaluated against a detailed schematic pricing package. Supplier selection is made based on qualifications and provisional pricing from each supplier submittal. Final pricing will not be locked in until later, once the Design Development phase has reached a sufficient level of resolution.
- **Contract Kickoff/ Schedule Lock:** Preliminary engineering work begins with each suppliers technical team. An engineering deposit is typically assessed as a percentage of the total value of the suppliers estimated contract amount. Once preliminary engineering has been approved, the supplier and developer can then lock in schedules and pricing. If the developer decides to forego using the IC products, the supplier retains the deposits in order to defray the cost of preliminary engineering.

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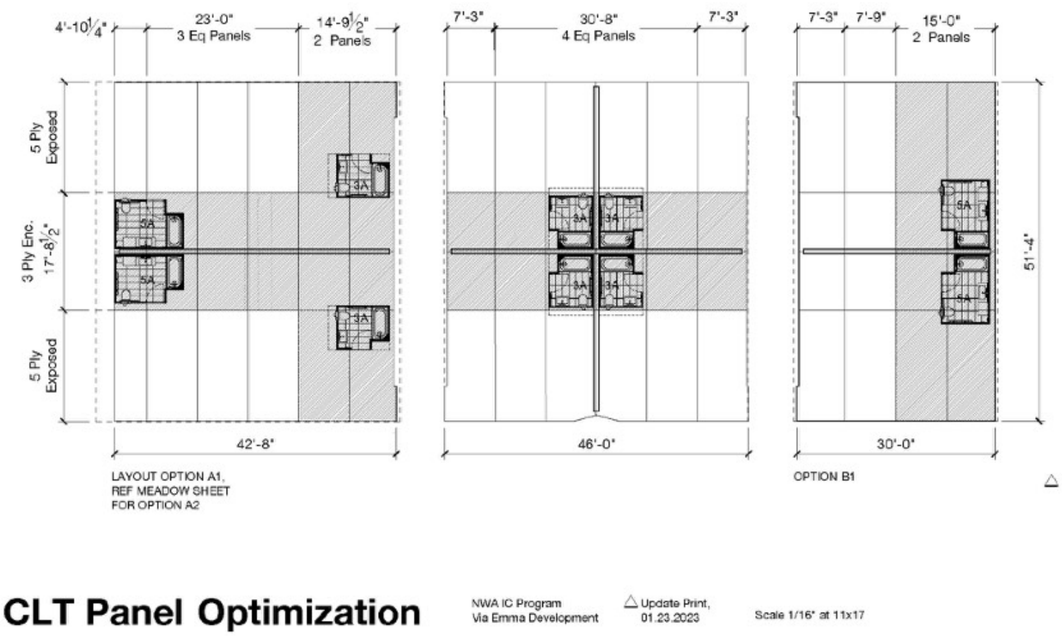
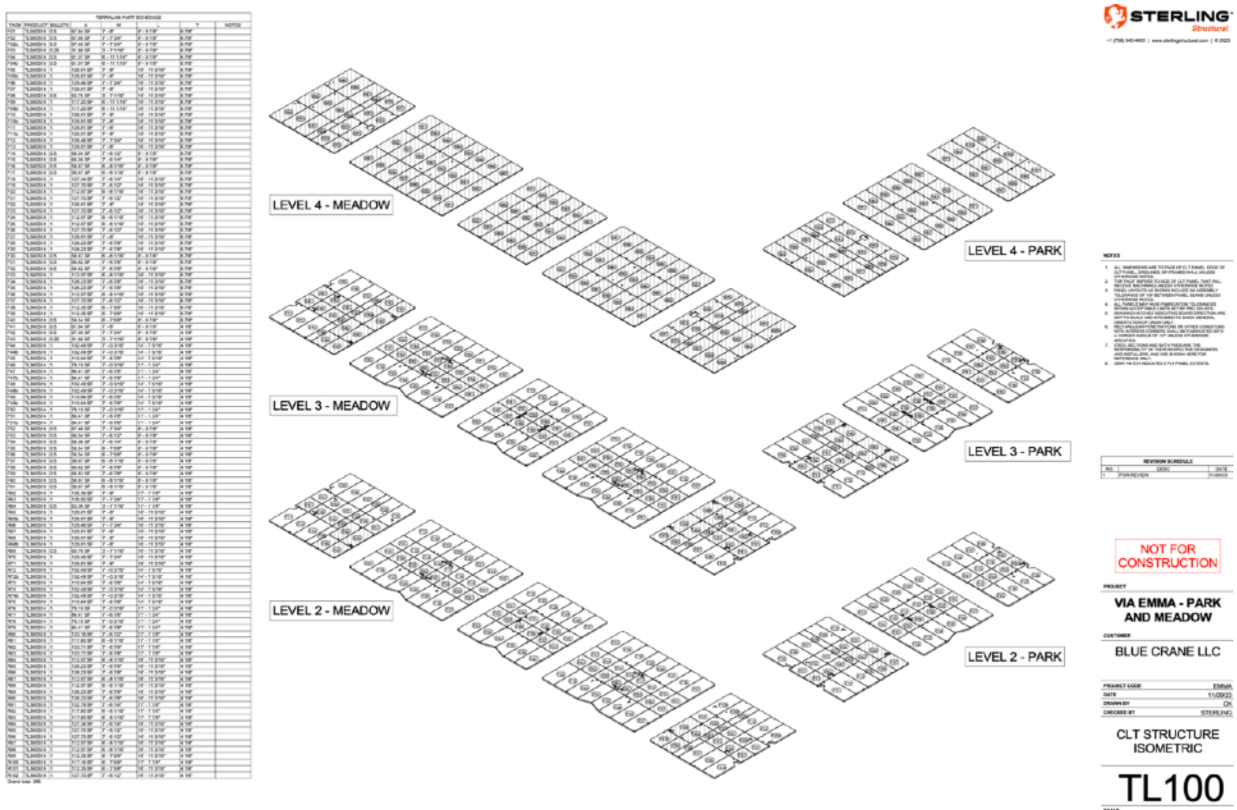


Above: CLT panel optimization and coordination, early Design Development phase. An example of program level documents showing disposition of CLT panels, demising walls and modular bathroom units. These were prepared by the program for use by the project design team to assist in early phase evaluation.

- **Material Deposit/ Geometry Lock:** A deposit for material orders is due at this milestone. This deposit typically runs between 25-45% of total order. Materials for the production run are typically purchased no later than 6-8 weeks prior to production, but any long lead time items will ultimately dictate order-by dates. In general, purchased materials should be clearly labeled for the project and available for review at the manufacturing plant. If bridge financing was needed in order to make the early purchase, labelling and storage requirements at the plant may be a part of the financing terms. The Geometry lock milestone means that no further geometric changes to the IC product (panels and bathrooms) will be undertaken by the design team and the preparation of the final production documents for manufacturer may begin. In the event that the project does not move forward, the materials can be recouped and sold or re-allocated to a different project. The geometry lock milestone then allows final BIM coordination and clash detection to take place.
- **Sequence Lock/ Production Start:** A production deposit is due prior to the start of manufacturing. In order to ensure that the components are produced in the order that they will be consumed on site, the manufacturing sequence is set prior to the start of production. If the units have to be stored or staged prior to assembly on site, the manufacturing sequence may flow in reverse order of construction.
- **Shipping Lock/ Delivery & Installation:** Depending on the extent of work done on site, the developer or contractor may chose to hold a certain amount for retainage to cover punch list items or any defective or incomplete work. Additionally, the program should also ensure that a clear chain of custody is established for receipt of the manufactured goods, particularly if a third party storage



Panel layout drawings, Sterling Structural. Early selection and technical partnership allows for detailed coordination of the timber elements within a Building Information Model. In this case, penetrations for the plumbing risers servicing the Bathroom modules have been pre-routed within the panels and no on-site drilling will be required.

site is used. When utilizing large numbers of complex assemblies, such as modular bathroom units, IC program should be familiar with the manufacturers quality assurance measures and understand the procedure to handle any non-conforming or incomplete work. Arrangements for inspection of units during and after the production phase can be incorporated into the Program terms.

- **Onboarding of Installation Sub-Contractors:** In many cases, erection, installation and final connections of the IC elements on site will be executed by a different sub-contractor than the supplier. In these cases, particularly if the sub-contractor has not had extensive prior experience with Industrialized Construction products, an onboarding process including both pre-bid and pre-construction conferences should be undertaken by the program in order to ensure that scope and costs have been

CNC Routed panels, Sterling Structural

accurately allocated by the sub. Here, the suppliers' internal technical support teams and third party consultants with field experience in IC can play an invaluable role in introducing partners to IC cost effectively.

Installation subcontractor onboarding, NWA IC program, 2023 with Blue Crane, ICG and Kimbel Mechanical Systems.

Other Considerations

- **Authorities Having Jurisdiction:** In jurisdictions with less experience with Industrialized Construction products or methods, it will be important to onboard local officials well in advance of execution. Inspection, certificate and code requirements vary and the local officials have the authority on code interpretations for each jurisdiction. The IC Program once again acts as a bridge between the manufacturing systems used and local ordinances. In some cases, a review of local regulations may be a due diligence activity prior to site selection. Differences in requirements from locality to locality have direct impacts on costs and ought to be well understood prior to finalizing contracts.

- **Early Financing and Procurement:** In many cases, the supplier will require deposits far in advance of conventional construction timelines. Deposits may be due prior to the full capitalization of the project and before a contractor has been retained. Developers should carefully analyze these requirements and determine how these early commitments can be met. It will be more advantageous for developers to stand up a procurement function internally should the program prove viable in the long run.

The supplier-developer relationship in a Lean model is much more about reliability and performance over the long term than the value of a single transaction. Developers can take advantage of this kind of relationship using Industrialized Construction programs to unlock the full value of cost and productivity gains through ongoing investment and close collaboration.

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Notes

[1] For a recent example see: Phillips, Zachary. "What is a Gemba Walk?" Constructiondive.com, 10 September 2024. https://www.constructiondive.com/news/gemba-walk-guide-lean-construction-how-to/726442/

2 Womack, James P, et al. *The Machine That Changed The World,* 2007 ed., Free Press, 1990, pp. 149-150.

[3] For a full discussion see Chapter 7,"Coordinating the Supply Chain" in Womack et al.

[4] Womack, James P, et al., 149-152.

[5] Womack, James P, et al., 157.

[6] "Modular Construction: From Projects to Products", McKinsey & Company, 18 June 2019. https://www.mckinsey.com/capabilities/operations/our-insights/modular-construction-from-projects-to-products

[7] "A Quick Look Back on the Corolla's 55-Year History with Over 50 Million Customers", Toyota Times, 13 August 2021. https://toyotatimes.jp/en/report/corolla_50million/164.html

[8] For a typical example see "The Construction Industry's Productivity Problem", The Economist, 17 August 2017. https://www.economist.com/leaders/2017/08/17/the-construction-industrys-productivity-problem

[9] This would include categories such as Engineer to Order, Manufacture to Order, and High Variety Low Volume.

[10] For an excellent discussion of Lean applied to a Small Batch Size Manufacturing paradigm within high-cost countries see N. Adine et. al "Lean Indicators for Small Batch Size Manufacturers in High Cost Countries", 30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021) 15-18 June 2021, Athens, Greece.

[11] N. Adine et. al

[12] See Parts one and Two of this series of articles, available at https://www.modly.design/journal

[13] Dezember, Ryan, "Sky High Lumber Prices are Back", The Wall Street Journal, 19 December 2021, retrieved https://www.wsj.com/articles/sky-high-lumber-prices-are-back-11639842879

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