BRIDGE THE GAP

1st Edition
July, 2024

COLUMN & BEAM SYSTEMS

IMPLEMENTATION GUIDELINES

This guideline indicates critical considerations and common hurdles to support potential users in selecting a product but contains no advice on which product to choose.

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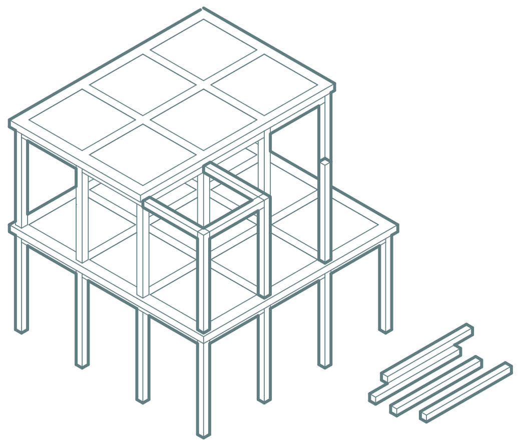
DEFINITIONS

Column and beam systems form the main parts of the structural frame of a building. Beams carry the loads from the slabs to the columns, and columns carry them to the foundation and provide stability to the structure.

The main Column and Beam systems and variations are as follows:



1 | Column and Beam system

1. LVL: Laminated Veneer Lumber (LVL) is an engineered wood product made by bonding thin layers of wood veneers together with adhesives under heat and pressure. The grain of each veneer is aligned in the same direction, resulting in a product that is strong, stable, and less prone to the defects found in solid lumber. LVL column and beam systems are structural components specifically designed to support loads in construction. These systems are widely used due to their high strength, dimensional stability, and uniformity compared to traditional solid wood.

2. Glulam Glulam (Glued Laminated Timber) column and beam systems are structural components made by glueing together multiple layers of dimensioned lumber, which are used to support loads in buildings. These systems offer high strength, design flexibility, and long spans while retaining the aesthetic appeal of natural wood. Widely used in residential and commercial construction, glulam beams and columns provide a durable and sustainable alternative to solid timber or steel.

3. Cold-rolled steel: Cold-rolled steel frames offer a much higher strength-to-weight ratio than Hot-rolled Steel, making it lightweight and, therefore, easier to handle, making it perfect for use in modern construction. Cold-rolled steel is particularly well suited for use in prefabricated buildings with spans of up to 24 metres. Foundations for Cold Rolled Steel Frame Buildings also tend to be shallower and, therefore, more cost-effective than for Hot Rolled Steel Frame Buildings. Both cold-rolled and hot-rolled steel have a higher environmental impact than the previous examples, but their bearing capacity makes it appropriate to replace concrete with a much higher environmental footprint. The steel industry is progressing toward green steel production to improve its environmental performance.

4. Hot-rolled steel: Hot-rolled steel frames tend to be used for larger clear spans or taller buildings, particularly where the frame is required to carry additional loads. As hot-rolled steel sections tend to be thicker than cold-rolled sections, they are better suited for this purpose. Hot Rolled Steel Frames are also better suited for potentially corrosive environments. As mentioned above, the environmental impact is higher than that of timber-based products, but the steel industry has a well-functioning recycling infrastructure.

5. Precast Concrete: Column and beam designs are suited to projects that require large open floor areas and carry heavy loads, such as multi-storey car parks. The frame can accommodate different floor designs, including non-concrete options. From a CO2 emissions point of view, precast concrete is the least favourable alternative for column and beam systems. Also, regarding circularity and waste production, there is little to no option to reuse concrete at a high value.

6. Reversible/non-reversible connections for column and beam systems: Reversible joints are connection mechanisms that allow columns and beams to be joined and later disassembled without damaging the structural elements. These joints are designed to facilitate assembly, disassembly, and potential reuse of the structural system. This creates the opportunity to make them circular but also provides flexibility over time for structures that require to be modified over time.

Timber, steel, and concrete column and beam systems each have unique characteristics, advantages, and applications in construction. The overview above is a summary of potential solutions. Each material offers unique benefits and challenges, making them suitable for different types of projects and applications based on factors such as structural requirements, aesthetics, environmental impact, and cost.

POINTS OF INTEREST

STRATEGIC CONSIDERATIONS

GUIDANCE	DESCRIPTION
Geography	In the case of a pipeline of potential projects in different regions, starting with a single region simplifies the development activities. Regional requirements, codes, building norms, and other regulations will influence the design variations required. In general, the National Building Code should be considered, but most municipalities have specific wishes and zoning requirements next to that. During the design process, keeping an eye on the future target markets is beneficial in avoiding potential conflicts later on and lowering the variation level.
Production location	The distance of the production location to the building site or market region plays a role when selecting off-site manufacturers. A short distance is often preferable, but other considerations may outweigh this. For instance, the supplier's quality, local staff wages, material costs, or the experience level in the target region all play a role when deciding on a supplier. Critical factors with longer transportation lines are the traffic regulations that impact the dimensions of the load and an increased risk of damage. Longer distances do not necessarily mean higher costs, which depend more on topics like market circumstances, the type of transportation and the nationality of the transporter. They will, however, have a negative impact on the CO2 footprint.
Training and communication	Using off-site construction requires changing the traditional design and construction process. This means that staff will need to be trained and upskilled. The manufacturer should also provide contractor-facing materials to educate them on the new product.

CONTRACTING, WARRANTIES, AND PROJECT FINANCE

GUIDANCE	DESCRIPTION
Securing financing	Project financing of off-site construction projects will require additional information to be provided to financiers. Primarily, banks will want to have a guarantee that the off-site manufactured goods will be delivered and installed on-site. Until the off-site products are installed on-site, several banks view off-site construction more as financing goods than real estate. Depending on the percentage of equity in the project, this could complicate the debt financing in some cases.
Typical contract provisions with off-site providers	Before proceeding to product reservations, clients should negotiate their contracts with the off-site system providers. Essential items to include: · Quantity and scope of delivery · Delivery schedule · Acceptance process and handovers · Price, including margins and contingencies · Payment schedule · A sharing mechanism for the proceeds of collective product improvement in case of multiple projects · Warranties · After-sales services and maintenance

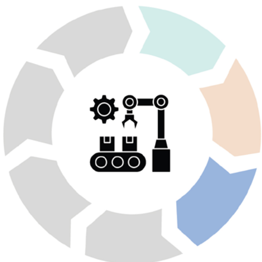
GUIDANCE	DESCRIPTION
Scope of work definition	The division of work between on-site and off-site contractors should be clearly defined in a schedule that divides the work and responsibilities between the factory and the contractors on-site. This should be included in the contracts with all parties involved to ensure the scope of work is clear to all. Grey areas should be avoided in a schedule that divides the work and responsibilities between the factory and the contractors on-site. Grey areas should be avoided and included in the contract to ensure the scope of work is clear to all parties.
Product warranties	Several key provisions should be included in the off-site manufacturer warranties, including: · Extended warranties: The warranty should cover everything after production, including storage, transportation, delivery, and installation of the modules on-site. The warranty should explicitly say that the product should be in the same condition when going into operation as it was when it left the production line. · Completion guarantee: This warranty stipulates that the manufacturer will manufacture and deliver their products themselves or via third parties in case the company must cease operations. In those cases, the client should also obtain full ownership of the production data as collateral and compensation for any delays caused by the manufacturer.
Production capacity reservation	Parties must agree on a clear schedule for the delivery of design documentation to the factory and the lead times for production engineering. The manufacturer has to share the availability of the production line, the production lead-in time, and the due date for the reservation of manufacturing capacity. Based on this, the client can schedule its project and submit the production reservation to the manufacturer.
Production reservation payment	The client must usually submit a payment alongside the production reservation. This payment is according to the schedule agreed upon earlier. This payment could precede the production by up to six months. In the event that the customer cancels the order, this payment is usually not refunded.
Plan for early payments	Typically, a high percentage of the product payments to the manufacturer must be made before the panelised systems are installed on-site. The client must know this and map out this payment schedule for external financiers alongside the on-site assembly schedule. Typical payments for off-site construction that precede the on-site construction are the Production reservation, Procurement of materials, and Production batches.

DESIGN

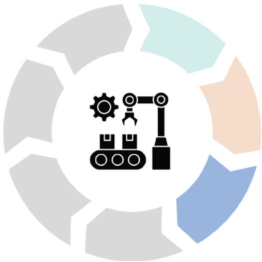
GUIDANCE	DESCRIPTION
Choose off-site technology for the project early	Each building system will come with specific requirements, which should be established from the onset of each project. These requirements are the design constraints that the team must adhere to. Environmental and construction approaches should be defined and agreed upon at the project onset.
Involve the manufacturer in the design process	To realise the full potential of each system, the manufacturers should be involved during the design stages through a consulting agreement or other short-term contract. The manufacturer must be consulted before the building concept is drafted.
Aim for repetition	The success of off-site construction is strongly related to repeatability and production volume. When using a column and beam system, achieving a high level of repetition is beneficial to limit the amount of variation in the manufacturing process.
Determine transportation limitations	The manufacturer should determine the maximum dimensions and packing configurations for transportation based on legislative constraints. This should be communicated to the project team, particularly to whichever party is coordinating transportation to the site.
Design for Circularity	Design for disassembly, reuse, recycling, and replacement to minimise material waste at the end of life. This is easily achievable with columns and beams by making their connections reversible. Column and beam systems should ideally incorporate reused or recycled materials instead of virgin materials to support circular material use. More information on the circular economy can be found in the Knowledge Bank.
Agree to the required level of detail	Agree on what level of detail the manufacturer needs to translate the design into fabrication. Without a clear understanding of what is required on the manufacturing side, the design documents might be inadequate and delay the manufacturing schedule due to additional coordination between the architect and the manufacturer.
Plan for tolerance management	Prefabricated column and beam projects require strict tolerance management and a common strategy before the architectural design is detailed. Manufacturing tolerances are below 5mm, while traditional construction tolerances are up to 50mm. The interface points where traditional construction (e.g., foundations or cores) and off-site products come together must be detailed precisely. The design team must provide ways to bridge the difference. Typically, architects leave this to the contractor, but when using off-site construction, that is too late, and the contractor might be unprepared for it. Avoid “Field verify” in shop drawings.
Stick to manufacturing conditions	The design conditions for using the building system must be agreed upon by the architect and the manufacturer at the start of the project. The benefit of using prefabricated systems could go lost if the starting principles are not followed.
Codify design rules	Interfaces between components, placements, dimensions, and other factors detailing the limitations of design variance should be codified. This is especially important if the building is comprised of building systems from several manufacturers. This codification leads to a coordinated set of standard details.

GUIDANCE	DESCRIPTION
Develop a product library	Once developed, column and beam systems can be designed and stored in a product library or catalogue. With this library, standardised and repeatable components and systems can be used by designers to quickly design new projects without recreating those components and systems from scratch. This library will save time and money in the design and manufacturing phases.
Implement unique design scenarios	If a unique design scenario falls outside the agreed system restrictions, the team must seek advice from the manufacturer to avoid unexpected costs.
Test ideas	Testing the processes and products before manufacturing at scale is advisable. Depending on the desired result, this could be through virtual sample projects or physical prototypes. Validation testing can start as early as the first data becomes available.

MANUFACTURE



GUIDANCE	DESCRIPTION
Production ramp-up schedule	The client must consider the time needed to set up production and synchronise with on-site preparation work in the project timeline. The manufacturer should coordinate this with the on-site contractor to establish efficient site logistics.
Prototyping	The manufacturer should provide a product prototype that the client can use as the baseline for quality control and sign-off. In the case of a client-specific design, this prototype is usually one of the last components installed in the building. The client should work with the manufacturer to determine the prototyping timing and agree on quality control procedures based on the prototype.
Quality control	A quality control protocol between the client and manufacturer should be established, which could sometimes include inspectors from the building authority.
Acceptance process	The client and manufacturer must agree on how the client will accept the column and beam systems before being shipped to the building site. Acceptance can go hand in hand with the transfer of ownership to lower risk for the client in case the factory experiences financial challenges. This should be done in combination with extended warranties.
Order delays	Construction projects often face delays caused by permit issuance and legal procedures. Discuss this early on and produce a contingency plan between the client and the manufacturer. This plan could include provisions for storing products or delaying production and the costs associated with each option.
Post-production storage	Depending on the materials used, column and beam systems should be stored in a controlled environment to avoid the risk of product deterioration. The duration of outdoor storage should be minimal. Large fluctuations in temperature and humid conditions can lead to moisture-related issues in uncontrolled surroundings.



GUIDANCE	DESCRIPTION
Track and manage waste	Clients should verify that their manufacturers track the amount of waste generated and investigate ways to reduce this waste or monetise it through various reuse streams. This will help lower the environmental impact of the manufacturing process and minimise excess material costs.
Provide final documentation of product composition	Clients should verify that manufacturers provide clear documentation of the final products regarding the reversibility of connections, material type, material amount, and reuse potential. This can then be used to document the circularity of the building products and can guide actions in later lifecycle stages.

TRANSPORTATION TO SITE

GUIDANCE	DESCRIPTION
Weather protection and product packaging	Minimise materials needed to package and protect products as much as possible to reduce transportation costs and environmental impacts. Consider reusable weather protection.
Optimize transportation routes	Utilise planning software to select the most efficient routes and means of transportation to the project site, thereby minimising fuel usage, travel time, and costs.
Plan for just-in-time delivery	Column and beam systems are installed directly from the trailer and are delivered to the project site on their day of use. Manufacturers and contractors must coordinate their manufacturing and transportation timeline and delivery order. Not doing so will cause delays and cost overruns.
Quality control during transportation and on-site	Manufacturers must ensure that their products remain undamaged from when they leave the factory until they are installed onsite. Damages usually come from mishandling during transportation (penetration of the waterproof membrane, sloppy placement, deformation due to hoisting, collision, etc.) and from uneducated installation onsite (lack of temporary waterproofing, unauthorised tampering with membranes, the connection of services, etc). The QA and QC must prevent these issues.
Site preparation in time for building system arrival on-site	A detailed traffic plan must be developed to coordinate the stream of delivery trucks in line with the crane operation. Access routes should be kept free to avoid traffic jams and onsite congestion.

ON-SITE ASSEMBLY

GUIDANCE	DESCRIPTION
On-site assembly of prefabricated systems	Assemble the column and beam systems as quickly as possible to avoid weather-related difficulties. Plan on-site construction process to "practice" and reduce construction time on-site.
Temporary weather protection during construction	Depending on the material used, there is a risk of moisture issues from the weather when assembly on-site is in progress. If necessary, temporary weatherproofing should be provided until the building is wind and weatherproof.
Avoidance of scaffolding	Offsite construction brings the opportunity to avoid scaffolding. Most prefab column and beam manufacturers have solutions to prevent scaffolding, which results in significant cost savings.
Tolerance control on-site	During construction and the installation of columns and beams, someone must monitor tolerance fields to avoid mismatches between in-situ works and off-site works.

MAINTENANCE

GUIDANCE	DESCRIPTION
Data management	Clients will have full access to the digital manufacturing data. This will help to identify used products, components, and materials and ease maintenance and replacement.

END-OF-LIFE

GUIDANCE	DESCRIPTION
Establish end-of-life scenarios for circularity	With off-site construction, one can design buildings that can be disassembled and reused. The project team should investigate end-of-life scenarios that can reduce the environmental impact. Some ideas for this could include but are not limited to: · Repair and reuse components and systems: If a component or system is still functional after disassembly, repair it if needed and reuse it in future building projects. · Returning materials to suppliers: If a manufacturer or supplier has a “take-back” program, disassemble the products to the necessary level and return those products or materials so that they can be reused or recycled properly by their supplier. · Establish reimbursement arrangements: Some manufacturers have begun using a deposit-type system that reimburses clients for returning critical high-value materials to them. · Sell materials with high residual value: Some materials have a high residual value in secondary marketplaces and should be salvaged by the deconstruction team. More information on circularity can be found in the Knowledge Bank.

ONGOING IMPROVEMENT

GUIDANCE	DESCRIPTION
Set long-term goals	Goals that span multiple projects can help create a mindset for continuous improvement. Quantifiable and tracible goals are best for the entire team to track progress.
Think releases	Traditional design and construction treat every project as unique and, therefore, implement every potential idea or improvement during the cause of a single project, even when it is reasonably too late. Using off-site construction supports product releases, which means that a potential idea or improvement can be scheduled for implementation during one of the following projects when time is an issue.
Log lessons learned	Establish a quality control system where stakeholders can register every fault, issue, or suggestion for improvement during the building’s design, manufacturing, construction, and operation. These data will form valuable input for product improvement and can feed into product development for the subsequent releases of the off-site product.
Product improvement	Consider tracking two main categories for product improvement: · Quality improvements (coming from logging the lessons learned as mentioned above). · Innovation opportunities (leveraging new technical insight to improve product design, construction, use, and end-of-life).
Create a product roadmap	Parties must agree upon how releases of the building systems are implemented and documented. A product roadmap helps to keep a clear overview of which projects use which building system release. How this is handled will depend on the complexity of the design and the level of change between versions.

COMMON PITFALLS

The following list represents common and avoidable pitfalls of implementing Volumetric Building Systems:

1. Project Development Pitfalls:

a. Unpreparedness to embark on a new way of construction and disregarding the impact on the process, like not involving manufacturers at an early stage of a project.

b. Not reaching the required scale to offset the related engineering costs for manufactured products.

c. Keeping options open to modify the design after completing the technical design.

d. Underestimating the impact of fluctuating prices in the timber and steel markets.

2. Design and Engineering Pitfalls:

a. Starting to design a building without the involvement of the supplier of the column and beam systems or knowing the constraints of a preferred system. Even an experienced architect will need the input of a potential supplier to realise the full potential of the construction method and avoid unnecessary costs.

b. Disregarding the interfaces and tolerance differences between manufactured products and in-situ works.

c. Lack of detail, late changes, and unresolved topics in the design package when starting production. “Field verify” has no place in off-site construction shop drawings.

d. Ensuring watertight and structurally sound joints can be challenging, and in the case of timber-based products, this requires much attention to avoid moist-related deterioration.

e. Differential thermal expansion between prefabricated elements and other materials can cause issues. Steel expands and contracts with temperature changes, and timber-based products may react differently to temperature and humidity than other materials.

3. Manufacturing Pitfalls:

a. Lack of QA and QC procedures or the execution thereof.

b. Insufficient weatherproofing for storage outside, transportation, and assembly on-site

c. LVL and Glulam:

i. Variability in wood quality and imperfections in lamination can lead to weaknesses in the overall strength and performance when using

ii. Long-term durability of adhesives can be a concern, particularly in humid environments.

d. Steel: Poor welding practices can lead to weak joints and structural failures.

e. Precast Concrete:

i. Inclusions, air pockets, and improper curing can weaken the concrete and

ii. Maintaining tight mould tolerances is crucial to ensure proper on-site fit.

4. Transportation Pitfalls:

a. Transportation comes in different classes depending on the dimensions of the load. A few centimetres extra could lead to additional permits or mandatory escorts. Manufacturers are aware of these restrictions and can inform the design team accordingly.

Susceptible to damage from moisture and physical impacts during transportation.

5. Onsite assembly pitfalls:

a. Improper coordination between the on-site contractor and the off-site supplier leads to logistic inefficiencies and delays.

b. Lack of proper instruction and quality control by the off-site supplier during assembly of the column and beam systems onsite. Ensuring columns are perfectly vertical and beams are level can be challenging, impacting the aesthetics and functionality of the structure. Improper joining or inadequate fastening can weaken connections.

c. Uncertainty about the ownership of the volumetric panelised systems once assembled onto the building.

d. Lack of weatherproofing during construction to prevent moisture-related problems.

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