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ZGF

# Design Solutions to Prefab Mass Timber Construction

Providing Design Guidance for Mid-Rise Mass Timber Buildings

September 2022

# Introduction

## Encapsulated Mass Timber Construction (EMTC) is a novel construction approach with great potential to advance building carbon performance and adds value to BC's forest products sector.

With that said, there are several barriers currently encumbering wider adoption of encapsulated mass timber construction within residential buildings, the biggest of these being the 12 storey (42m) maximum height limitation.

Mid-rise buildings of the 7-12 storey height are rarely built in BC for market and policy reasons. If a building is permitted to be taller than 6 storeys, it is almost invariably greater than 12, and typically much taller than that. The economics of 7-12 storey EMTC normally require a larger footprint than the dominantly accepted high-rise built in BC.* To effectively accommodate buildings of this form, Official Community Plan's (OCP's), Zoning Bylaws and Development Permit Area Design Guidelines require adaptation. Larger building footprints, 7-12 storey maximum building heights and densities of 3.5 FSR to 5.0 FSR will be required. These necessary OCP and Zoning standards to accommodate 7-12 storey mass timber buildings are provided elsewhere in this study. In addition, it is necessary to remove step backs traditionally expected for taller buildings and add provisions to ensure massings are appropriately articulated and the public urban realm interface at the street and neighbourhood scale are well considered.

This guidebook aims to identify and characterize the most significant barriers affecting mid-rise (7-12 storey) EMTC and presents a range of design guidance and high-level solutions. The design guidance provided herein are intended to supplement the proposed OCP and Zoning standards presented in this study. Together, these can be used to inform changes to OCP's, Zoning Bylaws and Development Permit Design Guidelines in support of mass timber construction.

**Source: Summary Report - Advancing Local Solutions To Mass Timber Barriers, Renewable Cities and SFU (May 2022)*

### Context

Despite somewhat recent building code revisions to the BC Building Codes (BCBC) & Vancouver Building By-law (VBBL) allowing 7-12 storey EMTC buildings, this building type and construction method for residential use has not had as much traction as anticipated with only 13 residential projects currently in the application stream.

In addition to other barriers found in the building code, construction logistics, Authority Having Jurisdiction (AHJ) approvals, etc., there are barriers implicit in municipal plans, bylaws and Design Guidelines which further reduce this building type competing as a viable alternative to existing types in non-combustible construction (defacto concrete). In part, this is because 7-12 storey buildings have not been a common building form in BC. As a result, multiple mass timber projects proposed in BC have reverted or switched to be in concrete or steel construction during their design and approvals process.

### Document Purpose and Use

The objective of this document is to highlight important considerations and provide design guidance to amend City OCP's, Zoning Bylaws and Design Guidelines as necessary to remove barriers and encourage mass timber development for 7-12 storey buildings with a residential focus.

The guidance provided in this document is intended to have flexibility to allow for interpretation and application based upon different municipal and site conditions. The terms "design principle" and "design intent" are used throughout this document but in all cases provide only guidance and are not to be read as prescriptive requirements.

### Figures and Illustrations

Several illustrative figures and diagrams have been used throughout the document as a means of conveying main design concepts and guidance. These visuals are not intended to be comprehensive, prescriptive, or definitive. It is expected that the detailed resolution and other qualified and quantified aspects of a proposed project will be addressed in full detail at the Development Permit Application stage.


### Funders

This project is funded by Forestry Innovation Investment, BC Hydro and the Office of Mass Timber Implementation in the BC Ministry of Jobs, Economic Recovery and Innovation.

### Contributors

This primer report was independently prepared by an interdisciplinary project team assembled by Renewable Cities with the MJ Wosk Centre for Dialogue, Simon Fraser University involving ZGF Architects, the Building Officials Association of BC, Ecosse Development Corp, Penway Consulting, John de Ruiter Consulting and Scius Advisory Services.

# Structure and Design

Mass timber has unique structural considerations implied in its details, but often evident in the form of the building. Designs for a structure will be determined by many factors during its conception. Once set, a project's exterior appearance will have a highly integrated and direct relationship to the underlying structure.

It is crucial for planners and urban designers to recognize the relative inflexibility of a mass timber project in later phases of design, as compared to cast-in-place concrete (CIPC) construction.

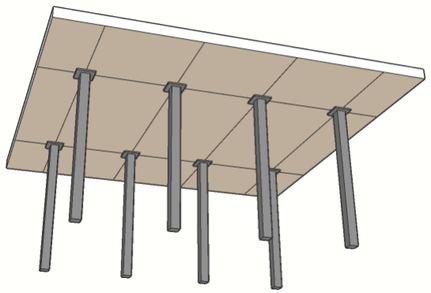
Authors of new guidelines should consider what aspects of existing ones have been originated and conditioned by long-established construction methods and materials for buildings. Design guidelines for mass timber buildings should recognize and reflect the patterns and principles unique to the construction.

The following summarizes three general patterns of structural strategy for a mass timber building, relating them to tendencies in the design of their outward appearance.

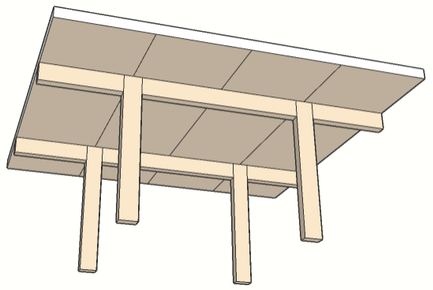
These are not exhaustive nor strictly bound, the appearance of any future mass timber buildings will rely on appropriate combinations of proven designs, and the ingenious invention of new ones.

## Mass Timber Structural Systems

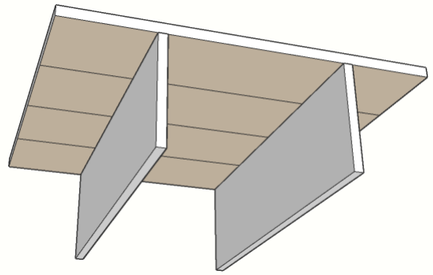
**Point Supported CLT (2-way Span)**



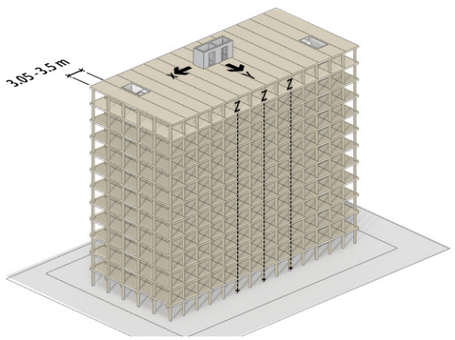
**CLT on Post and Beam (1-way Span)**
Note: beams add additional depth to overall assembly



**CLT Plate on CLT or Light-Steel Framed Shear-Walls (1-way Span)**



### 1. Typical Vertical Frame

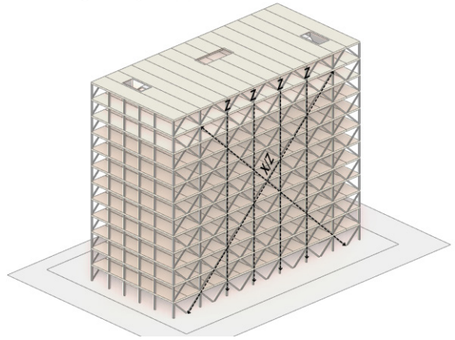



**Vertical Load Resistance:**
- Super imposed timber or steel columns,
- Point-supported 2-way spanning Cross Laminated Timber (CLT) floor structure
- Post and beam structure with 1 or 2-way mass timber floor

**Lateral Load Resistance:**
- CIPC cores
- Steel or mass timber braced frames

**Common Design Implications**
- Stacking
- Vertical alignment
- Expressed verticality
- "Classically" inspired, ordered compositions
- Expressed orthogonality
- Panelized construction

### 2. Diagonally Supported

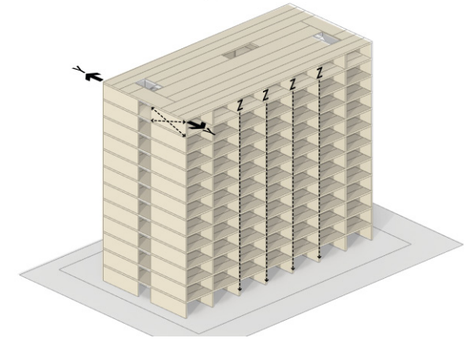


**Vertical Load Resistance:**
- Columns and perimeter frames
- Point-supported 2-way spanning CLT floor structure
- Post and beam structure with 1 or 2-way mass timber floor

**Lateral Load Resistance:**
- Perimeter frames/diagrid

**Common Design Implications**
- Anti-stacking or diagonal-stacking
- A-B modules
- Textile-like or "woven"
- Expressed diagonals
- Layered diagonal structured with orthogonal
- Panelized construction

### 3. Panel or Plate Type



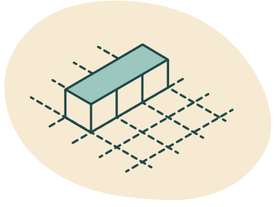
**Vertical Load Resistance:**
- Vertical panels/walls as load-bearing walls
- 1 or 2-way mass timber floor

**Lateral Load Resistance:**
- Vertical panels/walls as shear-walls

**Common Design Implications**
- Aspects of both
- More possibility of cantilevering if vertical CLT is used to form plate or box structure
- Horizontal massing
- Possibility of alternating/contrasting differences between floor plates
- Volumetric podular or panelized tilt-up construction

# Barriers and Design Guidance to Mass Timber Construction

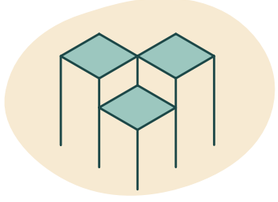
To effectively accommodate mid-rise EMTC buildings (7-12 storey), OCP's and Development Permit Area Design Guidelines require adaptation. The following aims to identify and characterize the most significant barriers affecting mid-rise EMTC buildings and presents a range of design guidance and high-level solutions.



## Mass Timber Structural Logic

The logic of a cost-competitive mass timber structure tends not to be as responsive as required by existing zoning bylaws.

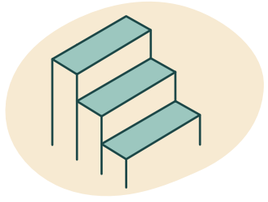
Pre-determined constraints or design expectations can erode the efficiency of structures conceived with repetitive, standard dimensions of engineered timber products.



## Building Height

Mass timber floor assemblies are thicker than concrete, translating to comparatively taller buildings to achieve the same interior clearances.

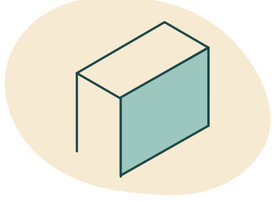
Thus, a Timber project may not fit under the same height restrictions as an equivalent building in concrete.



## Prescribed Articulation of Massing

Design guidelines and OCPs frequently request upper storey setbacks to provide massing relief and articulation of a base, middle and top of a building.

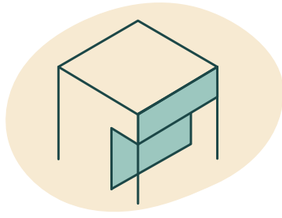
Such massing modulation can be difficult and costly to accommodate with a mass timber structure.



## Massive Bar

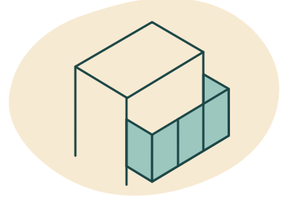
Bar-type buildings built on long lots with densities conducive to encapsulated mass timber construction often present an over-bearing, heavily shadowing building form.

These attributes may meet stiff public resistance.



## Public / Ground Interface

Consideration for varied ground plane responses which embrace the inherent vertical lines and material logic of timber towards creating activated street interfaces.



## Balconies / Private Outdoor Space

Multifamily residential buildings are often required to provide private outdoor space for family oriented units. Balconies can introduce significant complexity and cost on mass timber buildings.

# Mass Timber Structural Logic

## Barriers:

### Optimal Dimensions, Zoning Conflict and Design Recommendations

The logic of a cost-competitive mass timber structure tends not to be as responsive as required by existing zoning bylaws. Without due consideration, recommendations aimed at improving the “fit” of a building into an existing OCP framework may imply quite onerous/incompatible work to reconcile the overall form with the underlying structural system, which inherently follows different organizing principles to Cast-In-Place Concrete (CIPC) buildings.

The definition of building massing and spatial planning in a prefabricated mass timber building ought to be more “structure forward” than in a comparatively flexible concrete given the designer’s adherence to strict modules derived from the manufacturing process for Cross-Laminated Timber (CLT). In order to make mass timber housing as affordable as possible, the building floor plate ought to be developed using the most-common-denominator CLT panel widths (~3m wide) available among manufacturers to allow the CLT bidding to remain as competitive as possible.

## Suggested Guidance:

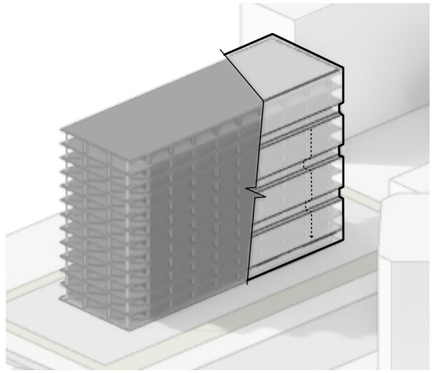
### Discretionary Variance

Given the overall lot dimensions of some sites, it may be necessary to provide discretionary variances to yards, setbacks, site coverage, and building depth and length to optimize for the latter.

### Attune Massing Guidance to Structure

Provide material or textural sub-scale design articulation for breaking up larger masses - this could be achieved through varied cladding colours, interplay of solid vs transparent, and exploration of multi-storey grouping of elements - *emphasize vertical expression over linear horizontality.* A repetitive massing break congruent with established structural module could be encouraged under broad massing moves.

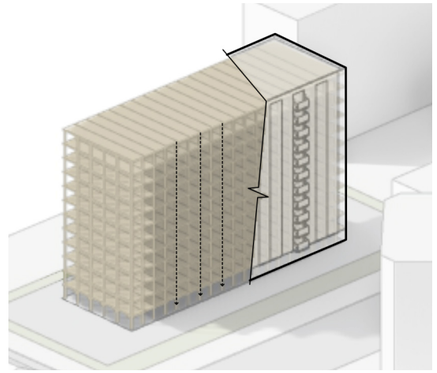
### Concrete Structure



**Concrete structure with horizontal massing**

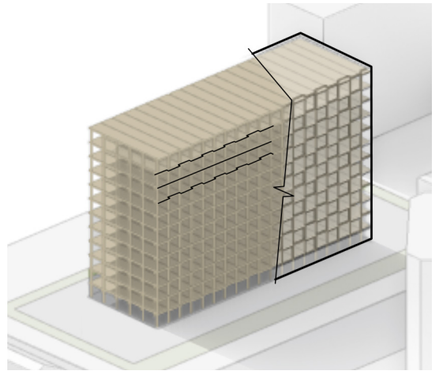
The need to cantilever concrete floors past supports and the formal freedom of the material lends itself to many horizontal breaks in the building.

### Attune Massing Guidance to Structure



**Timber structure with consistent vertical massing**

The direct transfer of vertical loads and the limitations on cantilevering timber floors, demands consistent vertical massing from top to bottom.



**Sub-scale massing modulation through repetition**

The modularity inherent to the prefabrication of mass timber structural elements and building envelopes can be used to coordinate repeated, gradual or subtle differences in massing.

### Examples

Image: UBC Lot 11 (ZGF Architects)
Geoff Lister, Photographer

Image: Brock Commons (Acton Ostry Architects)
Michael Elkan, Photographer

Image: M5 Concept (Henriquez Partners Architects)

# Building Height

## Barriers:

### Required floor-to-floor heights

Mass timber floor assemblies are thicker than concrete which inherently translates to an increase in required floor-to-floor heights, creating comparatively taller buildings. In conventional concrete residential construction, building services such as electrical conduit and exhaust duct work can be buried within the slab without significantly impacting structural strength. In Cross-Laminated Timber (CLT) construction, such services must be suspended below the wood slab and then concealed with ceiling construction. This also effectively increases the thickness of the floor-ceiling assembly.

## Suggested Guidance:

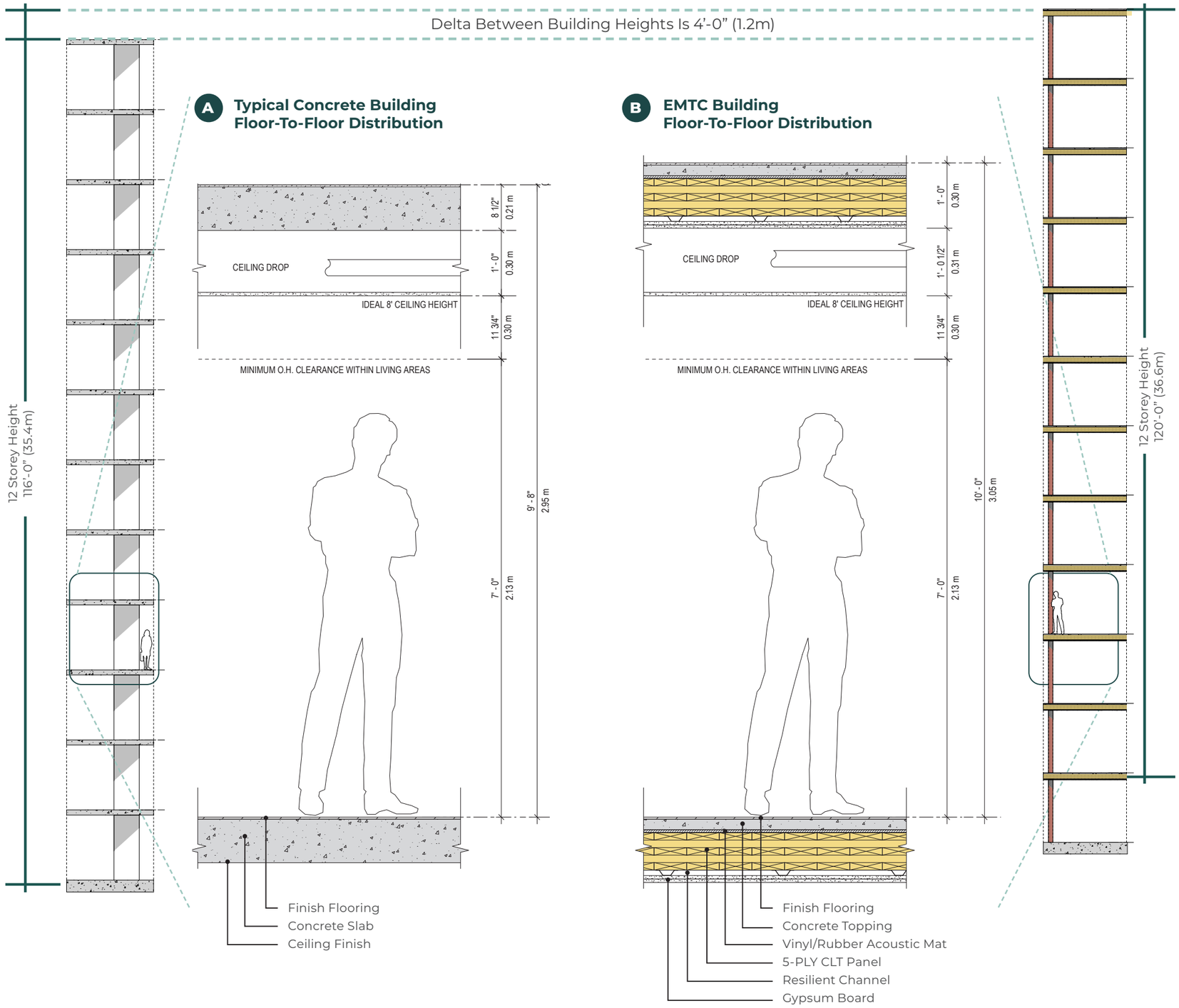
### Discretionary Height Variance

Allow for a discretionary height variance (Per Storey) for buildings meeting the zoning definition of a mass timber building above 7 storeys, where height provisions are stipulated in certain district schedules.

Additional height requirements will vary by the particular structural system selected. In the example illustrated, where a flat, two-way CLT floor plate can be point supported on steel or engineered timber columns, the increase in thickness between a typical EMTC floor assembly and equivalent concrete assembly is 4".

So, to achieve the same interior clearance in a point supported EMTC building, a variance of 4'-0" (1.2m) for a 12 storey building is required, at minimum.

This differential would be even greater if a post and beam structure were used.



# Prescribed Articulation of Massing

## Barriers:

### Set-Backs and Proscriptive Massing

OCP's frequently request upper storey setbacks to provide massing relief and building articulation towards defining a base, middle and top of a building .

Such step-backs and massing modulation can be difficult and costly to accommodate with a mass timber structure that relies on repetitive stacking of its structural elements.

Similarly, step-backs designed to continue consistent building lines and street walls, while reducing the shading and massing effects of tower elements, may demand multiple step-back locations, starting at a relatively low point in a 7-12 storey building. These proscriptions are difficult to reconcile with a consistent tower foot-print conducive to mass timber construction.

## Suggested Guidance:

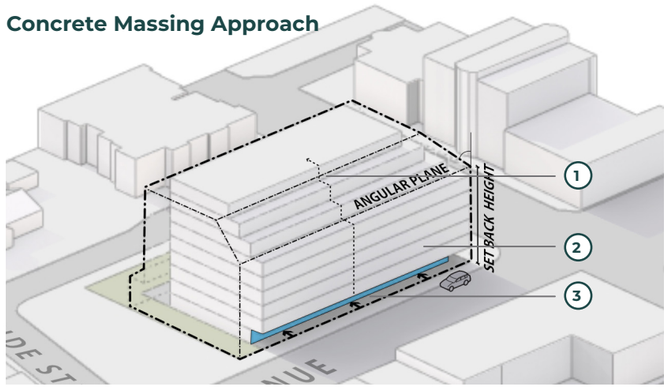
### Reformulate Massing Guidance

Allow for discretionary design flexibility for mass timber buildings 7 storeys and higher to relax massing articulation requirements, as well as yards, set-backs, site coverage, building depth, and external design. Creating flexibility to reduce or remove building step-backs (where appropriate), will simplify mass timber construction and make the typology more cost competitive.

### Podium Massing

Where the scales are appropriately balanced, consider allowing for a "podium" massing which fits into the existing street wall and scale of an urban location at a lower elevation than the maximum proscribed, and a tower foot-print set-back which continues up with a step-back.

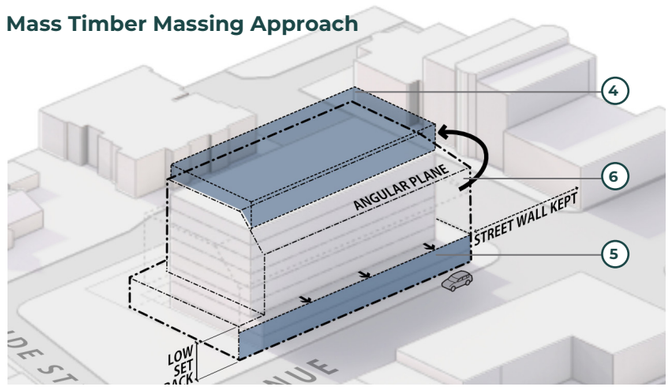
### Concrete Massing Approach




**Typical mid-rise concrete framed building approach to zoning envelope.**

1. Terracing/step-backs beginning at angular plane are easily accommodated by varying suspended slabs/transferring of CIPC.
2. Building maxed out to zoning envelope.
3. Possible inset at grade for pedestrian ROW can be accommodated with simple canti-lever/transfer logic of suspended concrete floors.

### Mass Timber Massing Approach




**A comparable approach made feasible in mass timber.**

4. Discretionary allowance for viable "single" tower massing (no multiple "set-backs") can approach intent of angular planes and street-facing height limits. In this case, a feasible timber system may encroach on a maximum developable volume.
5. A lower, initial set-back can maintain street-wall/integrate with existing low rise context, while providing some relief and street level solar access from "tower massing" above.
6. A slimmer tower with a larger site footprint may represent "un-used" allowable volume in a zoning envelope, compensated by exceeding the height limitations of the envelope, with a consistent floor plate. This could allow for a compromise between development goals and urban design/ planning goals.

### Examples

Image: Duke Condos (BDPQuadrangle Architects)
Thomas Noussis, Photographer
Duke Condos is a 7-Storey, concrete-framed residential building with retail along avenue at grade. The structure allows for distinct, horizontal massing transitions with a variety of terraces, step-backs, and over-hangs breaking up the form and adhering to neighbourhood zoning and planning requirements.

Image: Arbora Apartments (LeMay, CHA, Provencher-Roi Architects)
Adrien Williams, Photographer
Arbora Apartments combines a 3-storey concrete podium with 5 storeys of CLT/Glulam Framed apartments above. Note the distinct, sheltered transition between pedestrian level uses provided by concrete frame below, and the regularity of the timber-framed floor plate of the apartments above.

# Prescribed Articulation of Massing (cont.)

## Barriers:

### Finishing the Tower

Certain design language and elements at the crown of a building may be prescribed by neighbourhood character guidelines to avoid the “harsh” and continuous break at the roof-line of a modern parapet or flat roof along a bar-type.

These design elements may or may not work well with practicalities of the construction method.

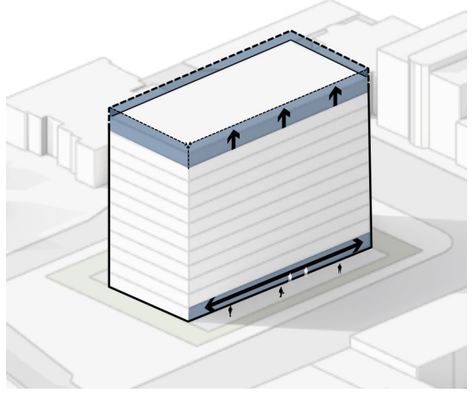
## Suggested Guidance:

### Massing of Crown/Softening Bar Massing

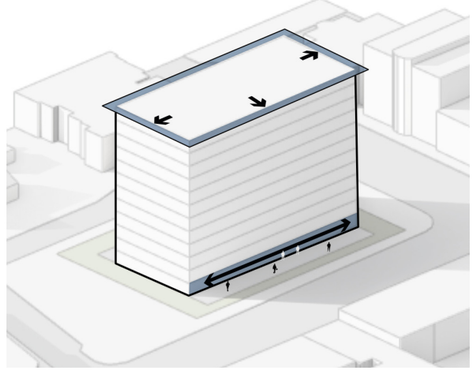
There are several other design approaches that can be explored to achieve similar desired outcomes that do not include a step-back:

1. Switch the scale of the building expression at the upper stories. Can also create a well defined building “top”.
2. Provide a protruding architectural element or unique expression at the parapet, like a cornice or “crowning element”.
3. Where practical (likely in lower 7-8 storey building, a gabled roof framed in heavy-timber construction may bring more positive formal associations in keeping with a BC municipality’s general design guidelines and more acceptable in character than a modern flat roof.

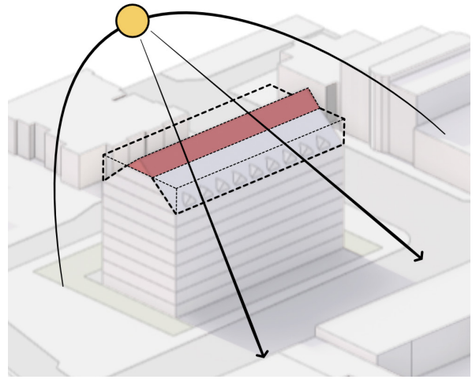
**1** **Grow Upper**



**2** **Cornice Parapet**



**3** **Gabled Roof**



**Examples**

Image: Sandy Pine Proposal (Lever Architects)

Image: Brock Commons (Acton Ostry Architects)
Michael Elkan, Photographer

Image: Strandparken Hus B, Sweden
(Windgardhs Architects)
Tord-Rickard Söderström, Photographer

# Massive Bar

## Barriers:

### Overbearing/Shadowing Form

As identified in FAR studies, bar-type buildings built on long lots with densities conducive to mass timber present an over-bearing, heavily shadowing building form. Long, slab-type building forms identified as workable in the pre-study tend to evoke unsuccessful examples of urbanism, forming oppressive street walls. Such proposals may meet public resistance for their impact on existing neighbourhoods.

Addressing issues of solar-access is highly site-specific, but the details of a building's design can anywhere influence the sense of scale.

## Suggested Guidance:

### 1 Inflect Mass with Grid

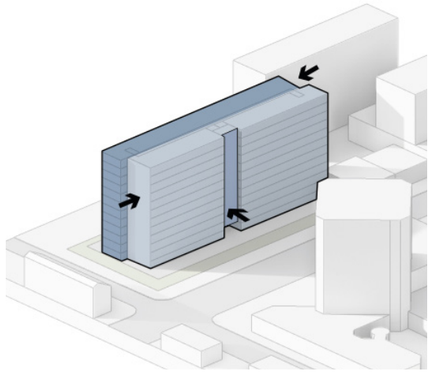
Guidelines should allow designers to confine massing articulation to large scale, singular or rational moves that fall along the logic of timber structural grids. This may still result in large faces, but there are simple "tricks" to start breaking up a timber mass which are conducive to structural alignment.

### 2 Bent Bar

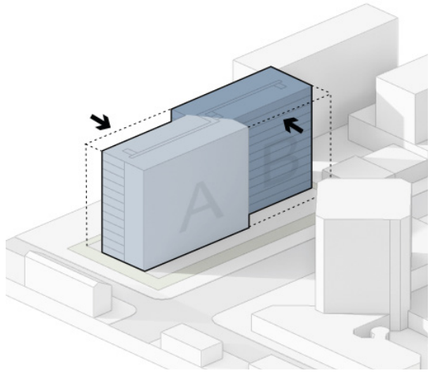
Without sacrificing the efficiencies of the "bar" when executed in mass timber construction, one possible variation may be a "bendy", "trapezoidal" or "knuckled" bar which features an inflection point to articulate the bar into sections. Allowing for more oblique approaches to lot-boundaries, angled forms will present a dynamic form in the urban context. Context-depending, they may offer some advantage in terms of over-shadowing and self shading.

This strategy may work best in places where development is occurring on large, unencumbered green or brownfield sites, rather than as infill projects on constrained urban sites.

### 1 Inflect Mass with Structural Grid

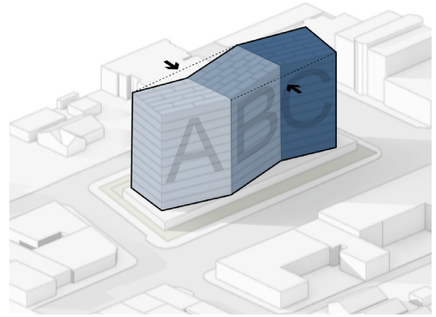


Shifted bar along major axis.




Slipped or pinwheeled bars hinging on central cores.

### 2 Bent Bar




Inflection points to articulate the bar into sections.

### Examples

Image: Ascent by Architects Korb and Associates
Naim Olker, Photographer

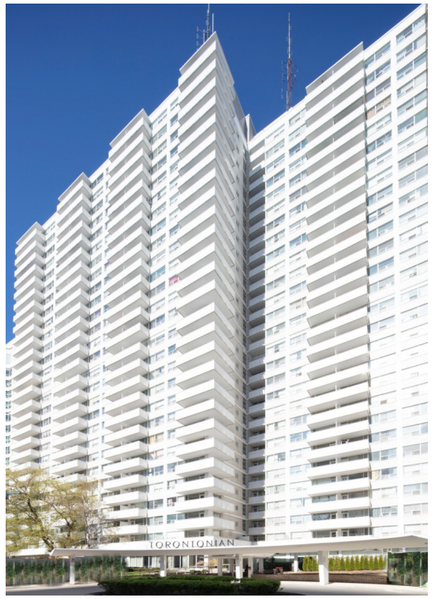



Image: Torontonian Apartments (Northgrave Architect) Photo Courtesy of Shiplake Properties
The form of this very long building is attenuated by conjoining two smaller bars with a central core at their corners. The highly regular grid of the building would also lend itself to a contemporary mass timber building.

Image: Pukkoka Housing Block (OOPEAA)
Mikko Auerniitty, Photographer
Pukkoka Housing complex is a trio of gabled bar buildings responding to an irregular site. The design inflects rectangular CLT 'wings' at a central atrium, resulting in a dynamic form with a plan much like a conventional bar.

# Massive Bar (cont.)

## Suggested Guidance:

### 3 Materials and Colour

Where residential typology permits only limited glazed area, and limited exposed timber due to stricter code provisions of use type, encourage façade treatment with natural, or colourful materials.

Lighter, reflective materials will also have a positive impact in reflecting more indirect sunlight where the building would other wise block direct exposure.

Where timber elements have been used as structural members of balconies, encourage visibility of soffit with its direct line-of-sight to public realm. (With appropriate provisions against moisture and fire)

### 3 Materials and Colour Examples

Image: Mac (MA+HG Architects | EDR)

Colour and panel modulation can animate another highly regular, flat façade.

Image: Forte Building, Melbourne
(Nielsen/Lend Lease)
Emma Cross, Photographer

White cladding provides large area to reflect direct sunlight indirectly, exposed CLT structure at balcony soffit, creates a direct visual connection to wood from pedestrian at street level.

Image: VAHA Burrard (ZGF Architects)

Modulation of window elements, addition of bright colour adds vibrancy to an otherwise flat façade designed to contain a regular CLT floor plate in an energy efficient envelope.

# Public / Ground Interface

## Barriers:

### Massing & Urban Design

Consistent vertical lines/massing required by structural logic of timber may not sit well with requirements for more dynamic/activated street interface required in urban design guidelines, nor with ground-level right of way set-backs.

## Suggested Guidance:

### 1 Hybrid Structural Solution

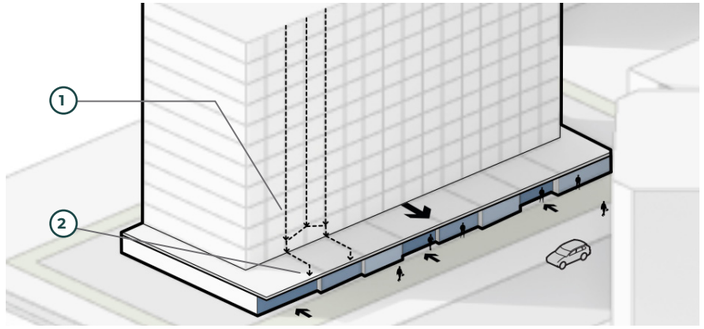
Concrete podia constructed up to level 2 are likely required in any case as part of transfer structures to below grade structures and foundations. These can serve to modulate an over-bearing massing above, by providing relief in the form of canopy projections, overhangs, façade-insets, breaks in pattern, greater transparency, etc., relying on the greater flexibility of concrete structure for these breaks.

### 2 Timber Structural Solution

Where it is desirable to continue a timber structure to grade, complex urban interfaces may be encouraged by more subtle means, less formally intensive and more material or texturally driven, or by better integrating landscaping elements.

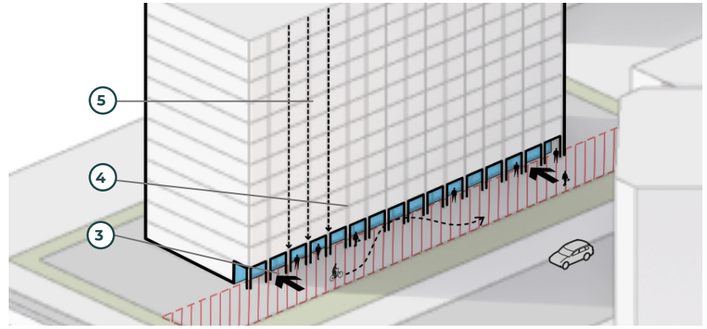
Partially exposed timber is intrinsic to the building, encouraging the use of exposed timber elements at grade for canopy supports/enclosed or exposed arcades, can provide both formal interest and add material vibrancy to the urban experience at grade.

### 1 Hybrid Structural Solution




1. A concrete transfer structure can reconcile differences in dimensions of structure and program above with mixed-used program below.
2. Highly variable/cantilevering structure can accommodate many detailed requests/multiple competing demands for resolution of building where it meets the ground.

### 2 Timber Structural Solution




3. Pedestrian ROW requirements may limit the most direct use of mass timber structures in maximizing an urban zoning envelope above.
4. Residential grid dimensions and typical commercial or parking grid dimension do not match-up well for most building programmes.
5. Permitting some flexibility in how a mass timber structure can carry directly to ground level while still allowing pedestrian passage, and permitting some flexibility in mixed-use programing allows for one continuous, tight grid.

### Examples

Image: The Emery (ZGF Architects )
Pete Eckert, Photographer

**Wood-Construction Above a Concrete Base**

The above is a 6-storey light-framed wood apartment over a mixed-used concrete base. The building cantilevers an inflected floor plate over a commercial street frontage. Its successful integration with the street relies on a well articulated ground level, without complicating the design of the apartments above. Similar principles can be applied to a taller structure in mass timber construction.

Image: Catalyst Building, WA (Michael Green Architects)
Benjamin Benschneider, Photographer

**Timber Structure to Grade Forming a Covered Arcade**

Permitting the extension of a timber structure above to ground level can provide a human scaled covered area while allowing for the functional requirements of passage along a pedestrian right-of-way.

Image: Brock Commons (Acton Ostry Architects)
Michael Elkan, Photographer

**CLT Entrance Canopy**

Mass timber elements itself can be used to form an appealing, sheltered, and distinct interface between the building and the street without the need to inflect the building envelope.

# Private Outdoor Space

## Barriers:

### Private outdoor space requirements

Multifamily residential buildings are often required to provide private outdoor space for at minimum 2 and 3 bedroom units. Balconies introduce significant complexity and cost on mass timber buildings.

## Suggested Guidance:

### 1 Combined Outdoor Spaces

Allow for discretionary design flexibility for mass timber buildings 7 storeys and higher to relax design requirements for individual private outdoor patio/balcony spaces, and instead provide for more meaningful shared indoor/outdoor building amenities.

Giving freedom for designers to imagine alternatives ways of connecting apartment spaces to the outside can result in as much amenity or more than private, projected balconies, while supporting the design of an envelope in keeping with practicalities of mass timber construction.

With a particular focus on affordable housing solutions, this flexibility could dramatically simplify mass timber construction and drive down project cost.

### 2 Reduced Balcony Requirements

If balconies must be included, attenuate their size requirements or reduce the number and types of units required to be served by a balcony. Consider also alternatives to projected balconies which can reclaim usable indoor-space while providing a good connection to the exterior through appropriate design.

### 1 Combined Outdoor Spaces

Image: 1190 Burrard Proposal (ZGF Architects)

**Shared Spaces on a Roof**
Gathering outdoor spaces in central rooftop locations- allows greater possibility of activities, better solar access, and fosters community within a building. As a substitute for balconies, this can focus design efforts on a part of the building where tricky problems of envelope and structure are addressed as a matter of course, while simplifying the overall form of the building.

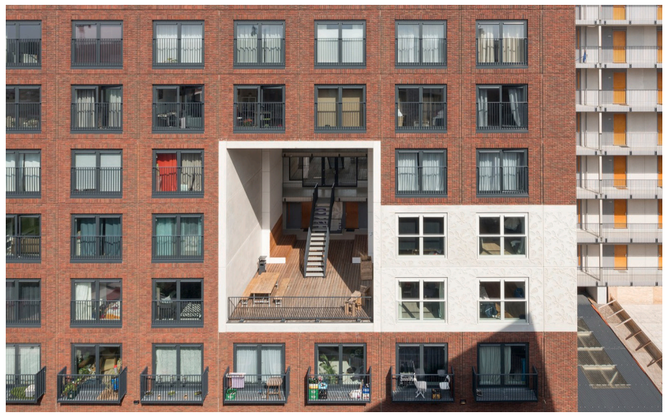


Image: Villa Mokum (Kampfman Architecten)
Ossip van Duivenbode, Photographer.

**Various Alternatives to Balconies**
The above is an 8 storey, concrete-framed apartment building with a pre-fabricated envelope. In-lieu of singular projected balconies, the complex integrates expansive juliette balconies in most suites, and incorporates several large covered loggias as communal outdoor spaces.

### 2 Reduced Balcony Requirements

Image: Pukkoka Housing Complex (OPPEA) Mikko Auerniitty, Photographer

**Semi-Enclosed Balconies**
The above is a semi-enclosed balcony in the world's first 8 storey, volumetric mass timber housing project. Allowing for partial sheltering and finishing within a pre-fabricated unit could improve the viability of balconies in timber buildings by mitigating risk of moisture-related issues inherent to projected balconies, and by simplifying structural integration.

Image: 355 Branan (David Baker Architect) Bruce Damonte, Photographer

**Modest Balconies**
Simply reducing expected sizes for balconies can diminish the size and complexity of their connections to the buildings' structure and envelope. The above example shows partly prefabricated balcony units, feasibly hung onto a hybrid-light-wood frame.

Renewable Cities | Morris J. Wosk Centre for Dialogue
Simon Fraser University
3300-515 West Hastings Street
Vancouver, BC V6B 5K3
778.652.4077
www.renewablecities.ca

355 Burrard Street, Suite 350
Vancouver, BC V6C 2G8
604.558.8390
www.zgf.com