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# MORPHOLOGIC STUDY OF HYBRID TALL BUILDING TOWARDS AN INTERDISCIPLINARY DESIGN

**Sebastian Carcamo[1], Diego Valdivieso[2]**

**ABSTRACT:** Interdisciplinary design for tall wood buildings (TWBs) is a challenging task mainly due to the ongoing research on the behaviour of TWBs and to achieve cost-effective designs that allow the construction industry to improve the sustainability of the building inventory. Although more than 40 TWBs projects have been built, the lack of a guide regarding the distribution of structural elements increases the time that preliminary design requires, which commonly implies several iterations of different proposals. Based on the morphologic study of six TWBs, this paper analyses qualitatively timber buildings with reinforced concrete cores and study different parameters that should be taken into consideration in the early stage of the project, in order to achieve a healthy structure in a reduced time period. A comparative table with a range of values for each proposed parameter is presented. A range of values for the different studied parameters are presented as a guideline for the RC core typology.

**KEYWORDS:** Tallwood Buildings, Interdisciplinary Design, Morphological Parameters, CLT, RC, RC Core

## 1 INTRODUCTION

In recent years, the construction of tall wood buildings (TWBs) has become increasingly popular due to its sustainability, energy efficiency, and aesthetic appeal. However, designing such buildings is still a challenge, as there are few precedents to follow. As a result, designing the static dimensions of such buildings can be difficult. Even more challenging is the design of lateral bracing elements for seismic events, as most timber buildings in the world have been constructed in non-seismic areas.

To address this challenge, interdisciplinary collaboration between architects and engineers is encouraged. In order to have a successful design process, the evaluation in early stages of the structural performance is crucial for an efficient design process. The definition of a representative floor plan defines, through the analysis of geometrical or morphological parameters, relevant decisions that impact its performance.

Therefore, the objective of this study is to provide guidelines for designers to develop tall timber buildings that are structurally healthy and safe, using a collaborative approach that combines the expertise of architects and engineers. By doing so, reducing the time and resources invested in the design process.

## 2 METHODOLOGY

The aim of this study is to investigate morphological parameters that help in early stages of TWBs design. To approach this challenge, only hybrid timber buildings with concrete cores as lateral system were studied. The decision is based on the potential use of the proposed morphological parameters in seismic zones. Taking in consideration the results of the Tamango project [1], the use of CLT shear walls on highly seismic prone areas, such as Chile, implies the definition of restrictive architectural programs due to the amount of shear walls needed versus a similar program with reinforced concrete (RC) shear walls. The reason is the modification factor associated with the ductility of each material, where the seismic coefficient of a building with CLT shear walls is more than three times higher than a building with RC shear walls in the Chilean code. Different studies have analyzed these values, but according to the studies presented by FPinnovations [2], the modification factor for CLT shear walls used on these calculations seems to be representative.

To select the correct buildings to study, only built projects with concrete cores were taken into account. A literature review of these buildings was performed, were several publications of TWBs inventories were presented, among them are the work done by Wiegand[3], Huseyin Emre[4], Fryer[5], Green[6] Ražnjevi´c[7] and Foster [8]. From these sources, only six tall timber buildings with the mentioned conditions and with available information were found: the WoodCube Building (2013) in Germany, LCT One (2012) in Austria, Brock Commons (2017) in Canada, Hault (2020) in the Netherlands, HoHo (2020) in Austria, and Ascent (2022) in the USA. Further details of these last two buildings, the most recent ones, were taken in consideration from the investigation of Fernandez[9] and Verhaegh[10].

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[1] Sebastian Carcamo, Pontifical Catholic University of Chile, Chile, secarcamo@uc.cl

[2] Diego Valdivieso, Pontificia Universidad Católica de Chile, Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD) & Centro de Innovación en Madera (CIM UC-CORMA, Chile, dnvaldivieso@uc.cl

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For each building, a qualitative analysis of a representative structural floor plan was performed, which were redrawn approximately to study their morphological parameters. These parameters aim to quantify different structural properties regarding its performance. To define them a simplification of a typical floor plan is presented on Figure 1:

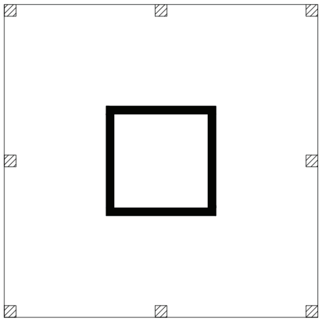


***Figure 1:*** *Simplification of a TWB with concrete core*

Here, the RC core is painted in black, the vertical timber elements are painted with a light hatch and the perimeter of the slab y represented by a continuous line. From these idealization of a building plan, the morphological parameters studied are described:

- Eccentricities by direction (Ecc): The distance in both the X and Y directions between the center of rigidity (CR) and the center of mass (CM) of each floor. The center of mass was calculated as the approximate geometric centroid of the floor, ignoring any openings. The center of rigidity was calculated based only on the reinforced concrete shear walls. To represent them graphically on the studied buildings, they are drawn with a circle and a square, respectably, and their perpendicular distances are represented by a discontinued line rectangle. See Figure 2. This parameter is crucial to understanding the symmetry of the project and the possible torsion that it may experiment.

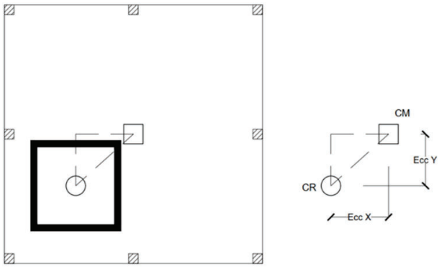
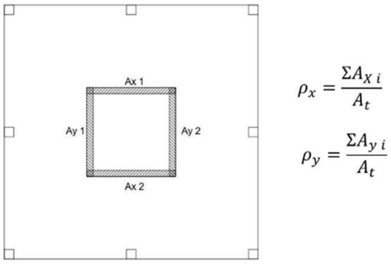


***Figure 2:*** *•Eccentricities by direction (Ecc)*

- Density of shear walls by direction (ρ): The total area of reinforced concrete shear walls per floor in both the X and Y directions divided by the total floor area. Is possible to relate the overall stiffness per direction with the total area of the RC walls, which are graphically represented on Figure 3.

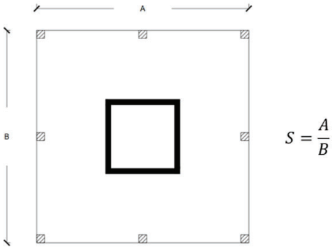


$$\rho_x = \frac{\Sigma A_{X\,i}}{A_t}$$

$$\rho_y = \frac{\Sigma A_{y\,i}}{A_t}$$

***Figure 3:*** *• Density of shear walls by direction (ρ)*

- Slenderness ratio (S): This involved calculating the ratio of the longer length to the shorter length of each floor. This parameter is related to the deformation modes that the building may incur, and also quantifies symmetry. (Figure 4).



$$S = \frac{A}{B}$$

***Figure 4:*** *• Slenderness ratio (S)*

- Maximum distance between the concrete core and the edge of the building (D): The distance between the concrete core and the farthest point of the slab. This parameter quantifies the amount of stresses on the slab, and in consequence, the level of deformation demand that the building may experience (Figure 5)

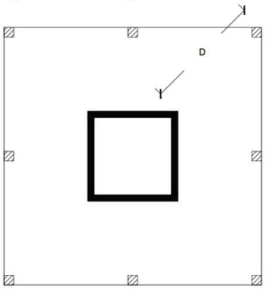


***Figure 5:*** *• Maximum distance between the concrete core and the edge of the building (D)*

In Figure 06, all the representative floor plans of the studied buildings are presented in the same scale to demonstrate the proportion of each building relative to the others. The reinforced concrete shear walls are depicted in black, while the timber elements are shown with a light hatch. In addition, the maximum distance between the concrete core and the edge of the building is measured and annotated, and the center of mass (represented as a square) and the center of rigidity (represented as a circle) are graphically shown, both connected by a dashed rectangle to illustrate the eccentricity of each building. These visual representations provide a comprehensive understanding of the morphological parameters studied, and how each building's design differs.

## 3 RESULTS

The parameters studied for each building are summarized in Table 1. The country of origin is included to represent the seismic hazard that each building may face. Additionally, the material composition of the floor slab has been included as a relevant parameter, as it should directly relate to the capacity to increase the distance to the edge of the building from the RC core. These parameters provide insight into the morphological characteristics of each building, and how they are influenced by their respective loads' sources and location.

It is crucial to understand that the parameters presented in Table 1 should be considered only as rough approximations, and thus, they define a range of values rather than a statistically valid value. The purpose of the analysis was to identify morphological parameters that can provide guidance for designing TWBs with RC cores based on existing constructions, rather than conducting specific calculations for verifying the proposed design. Therefore, the parameters presented in Table 1 provides a general idea of the characteristics of the analysed buildings and should be used as reference values for similar design projects. It is important to keep in mind that specific designs may require further analysis and consideration of additional parameters to ensure the safety and stability of the building.

Table 1: Summary of Proposed Parameters

| **Case** | **Stories** | **Height [m]** | **Year** | **Country** | **Ecc $_X$ [m]** | **Ecc $_Y$ [m]** | **$\rho_X$** | **$\rho_Y$** | **S** | **D [m]** | **Slab** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ascent** | 25 | 87 | 2022 | USA | 1,0 | 2,3 | 0,7% | 0,6% | 0,52 | 20 | CLT |
| **HoHo** | 24 | 84 | 2020 | Austria | 0,8 | 2,0 | 1,7% | 4,0% | 0,87 | 7 | CLT RC |
| **Hault** | 22 | 73 | 2020 | Netherlands | 1,4 | 0,2 | 1,4% | 0,7% | 0,42 | 13 | CLT-RC |
| **BC** | 18 | 58 | 2017 | Canada | 0,8 | 4,6 | 1,8% | 0,6% | 0,27 | 15 | CLT |
| **LCT One** | 8 | 27 | 2012 | Austria | 6,3 | 6,7 | 2,6% | 2,0% | 0,54 | 16 | CLT-RC |
| **Wood Cube** | 5 | 25 | 2013 | Germany | 0,2 | 0,2 | 1,4% | 0,8% | 0,89 | 10 | DLT |

The eccentricities in both X and Y directions (see Figure 7) show that the center of rigidity and the center of mass do not necessarily coincide, which can affect the building's response to lateral loads. The shear wall density by direction (see Figure 8) indicates the amount of reinforced concrete shear walls needed to resist horizontal forces, which is influenced by the type of loads the building is subjected to. The slenderness ratio (see Figure 9) measures the elongation of the building in one direction and is an important factor in determining the building's lateral stability. The maximum distance between the concrete core and the edge of the building (see Figure 10) can give an indication of the distance lateral forces have to travel to be transferred to the core. Finally, the material of the slab is a relevant parameter to consider, as it affects the building's weight and stiffness.

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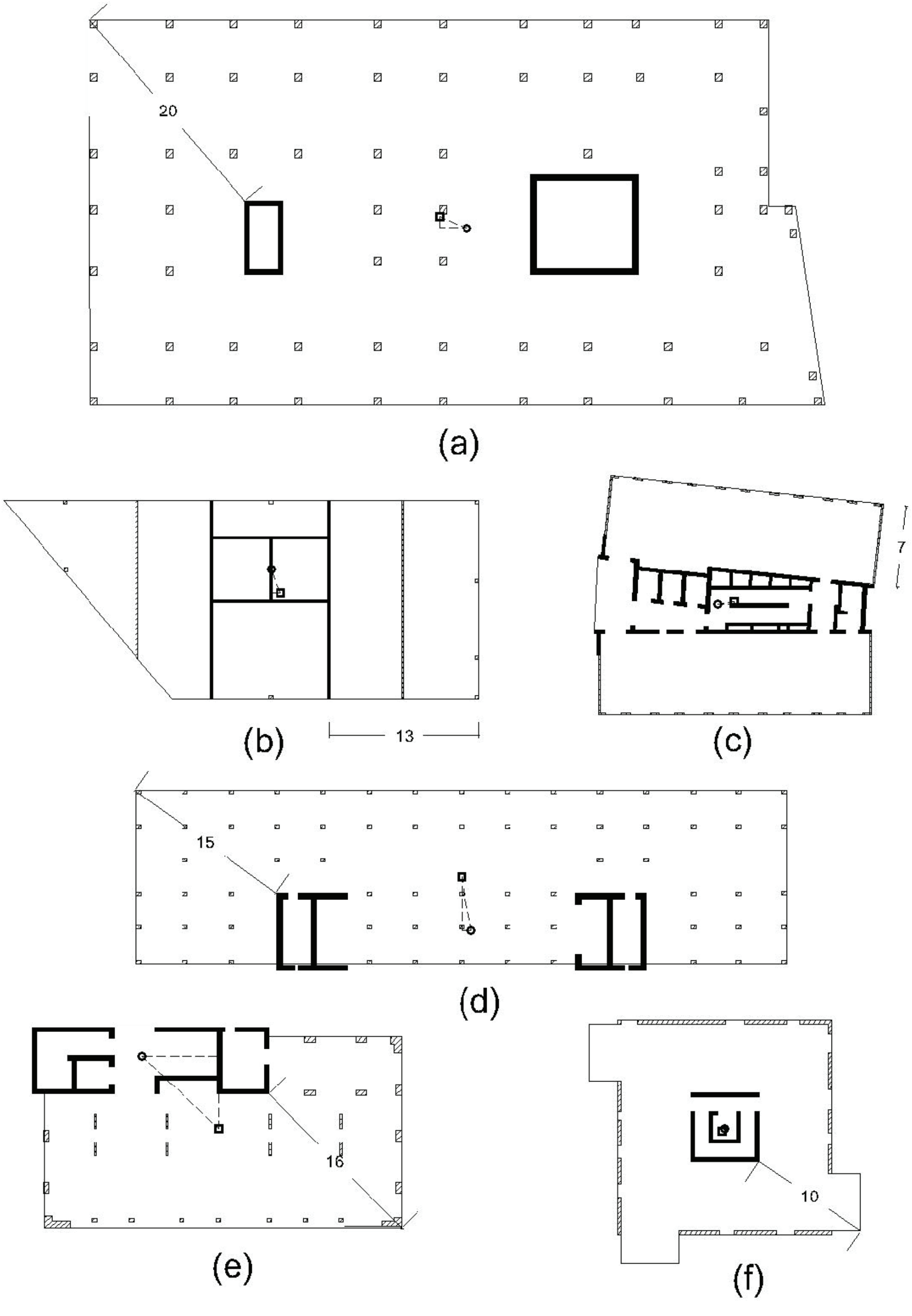

***Figure 6:*** *Al six building plans with the distance Rigidity Center, Mass Center and D displayed. (a) Ascent, (b) Hault, (c) HoHo (d)Brock Commons, (e) LCT One, (f) WoodCube*

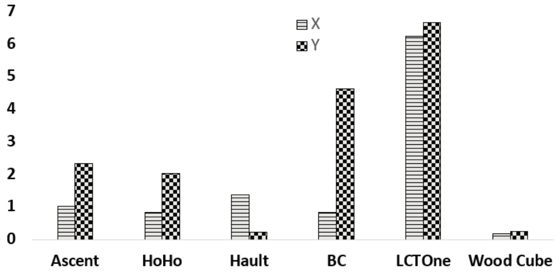

***Figure 7:*** *Eccentricities for each building*

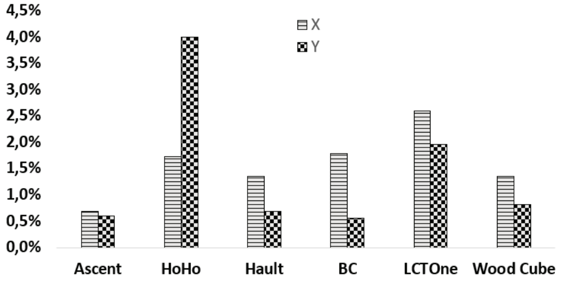

***Figure 8:*** *Wall Densities for each building*

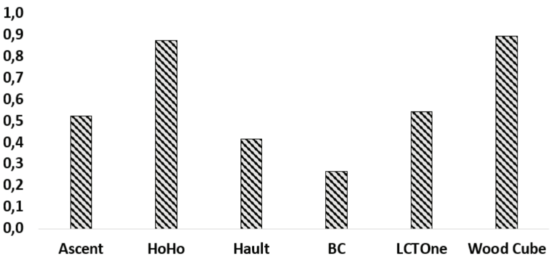

***Figure 9:*** *Slenderness for each building*

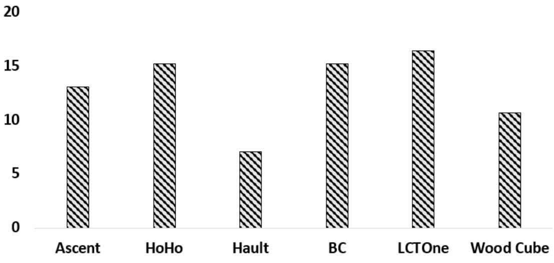

***Figure 10:*** *Maximum distance between the concrete core and the edge of the building for each building*

## 4 DISCUSSION

The study of the six TWBs with RC cores provides information on the morphological parameters required to develop efficient designs for TWBs with RC cores. The qualitative analysis of each building's structural floor plans allows to identify and compare the eccentricities by direction, the density of shear walls by direction, the slenderness ratio, and the maximum distance between the concrete core and the edge of the building.

One of the most significant findings is that all six buildings had relatively low slenderness ratios, indicating that a squat and stable design is preferable for TWBs with RC cores, which is consistent with current design practices. Regarding the eccentricities, none of the studied buildings present perfect symmetry, and both BC and LC One have a considerable distance between their CM and CR. The density of shear walls varied significantly between the buildings, which indicates that there is no universal solution for designing TWBs with RC cores. However, there is some correlation between the slenderness of the building and the wall density indexes. The distance between the concrete core and the edge of the building also varied significantly between the analysed buildings, which may be related to different architectural requirements or loading conditions.

## 5 CONCLUSIONS

The analysis of the buildings reveals that the floor plans exhibit strong axes of symmetry and tend to be more square shaped in general. However, it is noteworthy that the buildings with lower slenderness ratios have the highest eccentricities. This can be attributed to the design approach of these buildings, which allows for larger open floor spaces compared to other buildings. There is a trade-off between maximizing floor space and minimizing eccentricities in the design of tall wood buildings. Designers should carefully balance these factors to ensure adequate structural performance and minimize the risk of structural failure.

In general, the studied parameters exhibit slight variations and fall within the following ranges: eccentricities ranging from 6 [m] to 0.2 [m], wall density ranging from 0.5% to 4%, slenderness ratios ranging from 0.3 to 0.6, and maximum distance from the core to the edge ranging from 7 [m] to 20 [m].

Although the study only considers six buildings, the number of wooden buildings with RC cores is not very high, and some of the buildings considered were identified as the tallest buildings with this typology according to Huseyin Emre [4]and Ražnjevi´c[7]. The building with the longest slab extension from the core is the most recent building, which is likely attributed to the development of the slabs used. It is noteworthy that this was achieved even with the use of cross-laminated timber (CLT) slabs instead of composite slabs (CLT RC). This suggests that advancements in timber technology are allowing for greater spans and more efficient use of materials in construction. Additionally, the use of timber slabs offers a more sustainable and environmentally friendly option compared to traditional concrete slabs.

It can be observed that there is no direct relationship between wall density and height or eccentricity. However, some correlation between wall density and slenderness was founded. An example of this is the HoHo building, which has the highest wall density, but this is not necessarily due to lateral demands, but rather a design decision that allowed it to become the first 24-story wooden building. However, the variable of wall density appears to be particularly interesting in seismic territories when considering the study of damage in buildings after the Maule 2010 earthquake presented by Juneman[9], where it is defined that buildings with reinforced concrete walls that presented lower structural damage had a wall density greater than 2%. Given the great variability of wall densities in the studied buildings, and the lack of a clear trend on the seismicity of their zone, the study of wall density is proposed as an interesting topic by classifying their seismic zone. Nonetheless, the range defined can support the idea that timber buildings with RC cores should consider a wall density near a 2% on high seismic zones.

The performance of wooden buildings with RC cores has been studied due to the high applicability of this typology for buildings in seismic zones. The ductility of this material (i.e., using RC shear walls as lateral system) allows for much more favourable modification factors for seismic design, resulting in lower wall densities, if using CLT shear walls vs RC walls. However, the use of different lateral resistance systems implies uncertainty in the definition of the modification factor. It is recommended not to use CLT shear walls and RC shear walls together as lateral system in highly seismic zones. It is worth noting that two of the studied buildings, Hault and WoodCube, have CLT shear walls along concrete cores, but the studied parameters indicate that they could preliminarily do without them as stiffening elements, due to the amount of RC walls and the seismicity of their zones. This is particularly evident in the case of Hault, which has an RC core that varies along its height and replaces them with CLT walls, having more CLT walls and less RC walls in higher stories. This analysis is beyond the scope of this study and is proposed as a topic for further investigation.

The ranges for the morphological parameters studied in this article should be used only as references based on case studies, not as a design value, since no verification has been carried out and the dimensions used are approximate. Further research considering seismic zone and different typologies are being studied for future investigations.

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