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Case study and design:
Adaptable and Prefabricated structure for housing solutions for different climates and realities in Brazil

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ABSTRACT

Brazil is one of the most diverse countries on the planet. Fifth largest country by area and sixth largest by population. In other words, it is clear that within this vast territory there is an incredible variation of fauna, flora, landscapes, climates, people, traditions... All of this makes this country very rich and admired for its cultural diversity. However, this diversity also brings with it consequences that become problematic, such as the housing issue, which was the starting point for this work.

As stated by the Federal Constitution of Brazil, the right to housing is a fundamental right. But the Brazilian reality is far from guaranteeing that this statement is really followed. According to research by Fundação João Pinheiro, in 2019, the housing deficit across Brazil was 5.8 million homes - this number does not only indicate the number of families without a home at all, but also families in need of replacement of precarious and unhealthy housing for better habitation conditions. This deficit is what makes up one of the most critical problems of Brazilian society and one of the most important challenges of urban development in Brazil is precisely to offer low-cost housing for low- and middle-income families. [1]

The purpose of this work comes from the interest in developing and deepening this subject, analyzing the current context and studying possible strategies to solve the inadequacy of housing, especially for low-income groups, with an approach little or nothing done by current public housing policies such as: thermal comfort of the houses, adaptation of the house to the user, adaptation of the house to the climate, use of technologies, different construction methods, sustainability and, why not, using this as a resource for the valorization of the local culture.

In the light of this, the thesis is carried out from the study of the scenario of Brazilian housing in different categories of climates and regions and then, a case of study is developed to respond to the problems raised with a project that combines technical knowledge with a practice adapted to the Brazilian reality. As a result, it was concluded that a promising solution would be a new method of designing social housing that was both standardized and adaptable, to achieve the objectives of constructive efficiency, open to different layouts, thermal comfort and energy efficiency. Finally, it was verified the notion that the housing problem in Brazil is a discussion that involves many factors and there is no easy way out. There are social, cultural, economic and environmental factors that feed a balance hard to equilibrate. The present thesis proved to be promising with a project that looks further than the current projects implemented and also aims to face several fronts that end to culminate in the major deficit in which Brazil finds itself.

1. BRAZILIAN CONTEXT

In order to better understand the situation, a data source was checked, the Climate Watch, and compared Brazil and Italy. The first point analyzed by the difference between the two countries is the emission coming from waste in Brazil (yellow line) and in the European country (blue line). The amount of CO2 emission in the American country was 7 times more in 2018 and represents more than the sum of the three sinks. This is a first sign that the civil construction sector is a very impacting field in terms of greenhouse gas emissions. From 50% up to 70% of all solid waste produced in Brazilian cities originates from construction. Reflection of an extremely precarious construction model, which absorbs surplus labor without the necessary preparation to work in construction. The result of this precariousness is that the waste management estimates that 25% of the whole material purchased for the construction goes to the grave. For every 3 houses we build, we send 1 to the trash. [2] [3]

On the other hand, the energy consumption in the building sector is much lower in Brazil. As the main energy source coming from burning oil, Italy has, in absolute values, a CO2 emission 3 times higher, with a population 3,5 times lower. One reason for this situation is that the Brazilian main energy matrix is renewable energy. Hydroelectric plants represent 46% of all energy production in the country. The world average

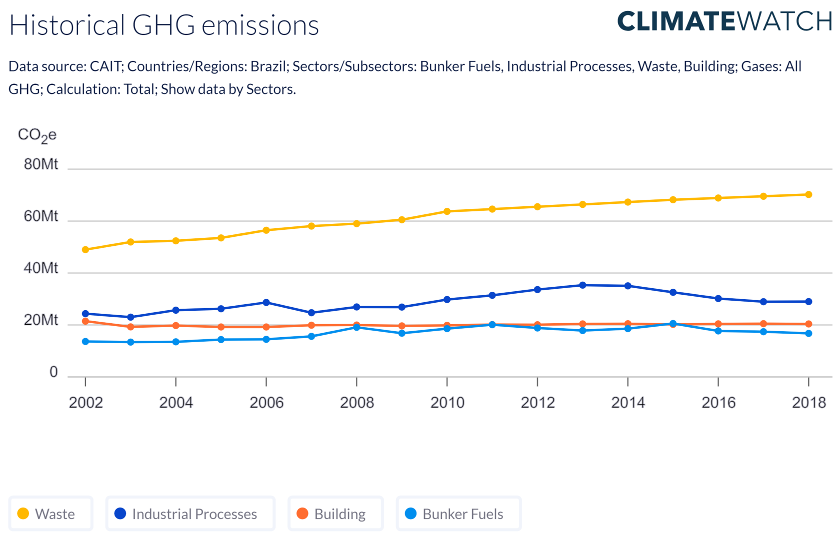


Image 02: Italian GHG emissions

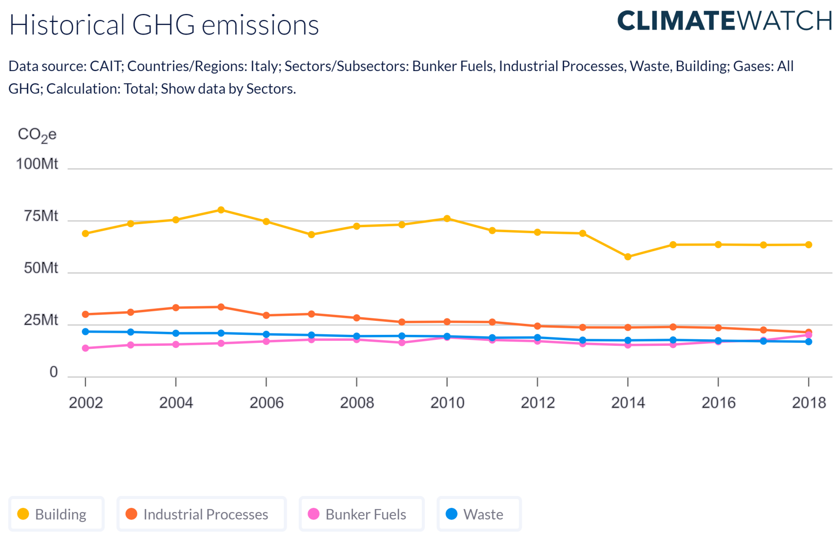


Image 03: Brazilian GHG emissions

is 14%.

In this context, designers should not only seek to obviously lower the operating energy through better passive solutions and by the production of energy on-site, but also lower the embodied energy of building materials, allowing their dismounting with possible reuse. Especially in a country like Brazil, where the great concentrator of greenhouse gas emissions, and consequently of energy, is the production of solid waste, it is essential to think about improving the construction method, the materials used and demolition.

However, the environmental condition and the resource depletion are not the only issues. The social aspect is also crucial to design a sustainable solution for it context. Studies done in 2020 by Brazilian Institute of Geography and Statistics (IBGE) appoint that, there are more than 13 million people in extreme poor situation. The worst scenario is in the north and northwest macro-regions. For example, the state of Maranhão, in the north of Brazil, is estimated that 1 of 5 habitants is in a poor economic situation. Another worrisome data is the dwellings condition in this region. Only 60% of the urban houses have water from the grid and around 82% do not have sewerage. If in one hand the economic situation is worst in the north, on the other hand the number of homeless is higher in the southeast macro-region, where 56% of the 222 thousand people in that situation in the whole country. [4]

As a large and diverse country, it is easy to imagine

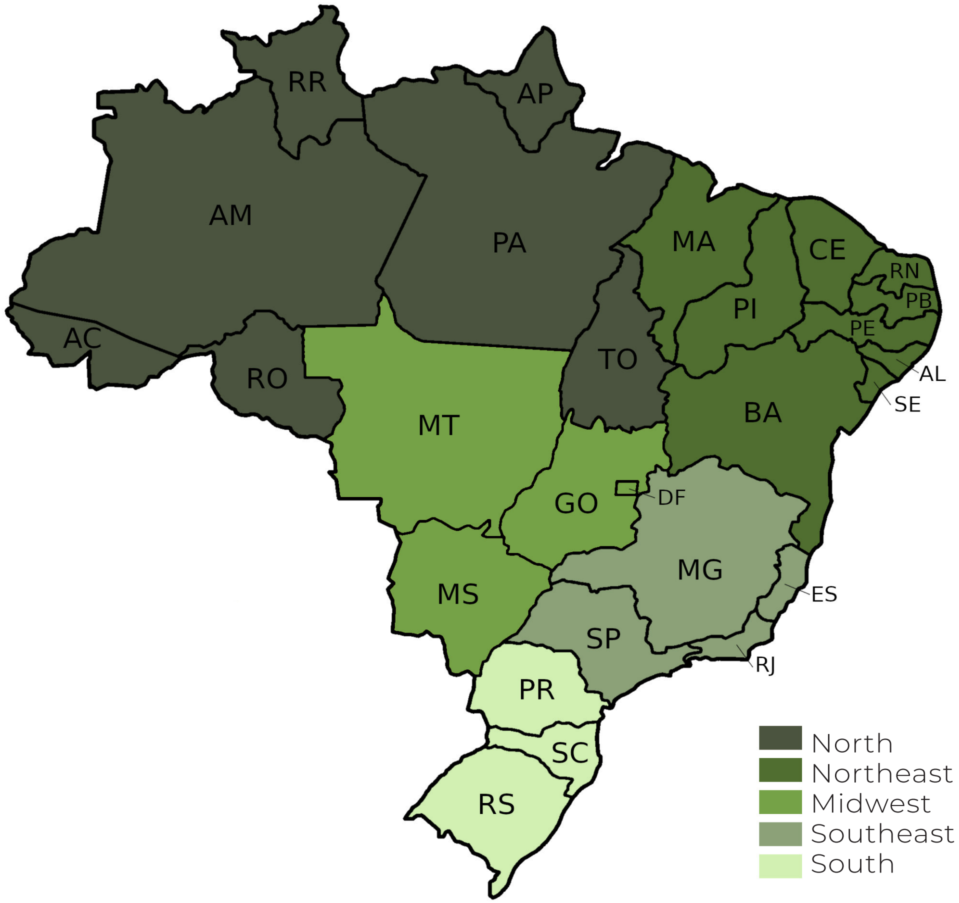


Figure 04: Regions of Brazil

that, in order to start any type of data analysis, we need to understand how Brazilian separation is made by regions. Due to its continental size, each region is still vast and has very specific particularities and diversities that may have been influenced by climate, fauna, landscape, immigration, colonization, culture and many other aspects that make one region very different from the other. Below, each region has been briefly summarized:

1.1 North

The North region is the most territorially extensive region in Brazil, corresponding to 45.27% and is home to only 7.60% of the population. Much of the region is unknown and difficult to access, largely due to the preservation of the Amazon forest, a great national resource and the region's largest source of income, which is based on extractivism from the forest with the exploitation of latex, açai, wood and of chestnuts. [5]

Figure 05: Brazilian urban context (favelas)

Figure 06: House in Marajo island, in the North region

The soil in general is very poor, which generates an exploratory agricultural activity, where the land is abandoned after its resources are exhausted, or used for cattle breeding. This practice generates conflicts over land property between farmers and ranchers and the native Brazilian peoples, and are usually resolved through violence. [5]

The region is characterized by the poverty of stones, which is why reinforced concrete does not perform well. On the other hand, it is very rich in a variety of woods, so most of the popular constructions are made of boards. [5]

1.2 Northeast

The Northeast region is the poorest and oldest region in European occupation: it was there that the Portuguese "discovered" Brazil. The region occupies an area of 18.26% of the territory and is inhabited by 28.13% of the population. The region is divided into two distinct climates, the coastal strip, with a hot and humid climate, and the interior, with a long dry season. [5]

These two climates also divide the region's economy. The climatic conditions that generate a lack of water constitute a major obstacle to modernization, which leads to extreme poverty. As a result, for many decades the population of this region has been looking for a better life in coastal cities, where tourism is a very important generator of wealth, and in the

Figure 07: Small villa and a typical settlement

center-south of the country. [5]

It is in the Northeast that the largest concentration of taipa and adobe constructions are located. A fact related to the poverty of the region, which ends up building houses with the available materials, and also to the extensive knowledge they have about the construction technique. [5]

1.3 Midwest

The Midwest region is the region with the highest agricultural and cattle breeding production in Brazil. Region of the capital Brasilia, it has an area corresponding to 18.87% of the territory and 6.85% of the population. The region, which also has an area of Amazon rainforest, is dominated by the plateaus and the flooded depressions of the Pantanal. [5]

As it is a region of extensive agricultural activity, many cities and small villages within the large farms were formed to accommodate the population that went to work in these areas. In this scenario, a very large social inequality was rooted, with the exploitation of cheap labor in contrast with the few farmers, who were industrialized their productions and, consequently, creating a mass of unemployed people who began to claim part of these immense properties. This is the so-called landless movement, a social event that invariably causes violent conflicts in the region. [5]

Constructively, the region has an area with houses made of industrialized building materials, contrasting with the popular architecture made of mud and wood. Which highlights the inequality that exists in the region. [5]

Figure 08: Small vila in Mato Grosso do Sul

1.4 Southeast

The richest region in Brazil is also the one with the highest population density, housing 42.64% of the population in only 10.85% of the territory. And if the regions presented above have rural or natural landscapes, life here is largely urban. [5]

It is also the region with the major social contrast and housing deficit. The current situation is so relevant that interventions are needed that seek to meet this demand for housing with densifying constructions, in other words, it is necessary to verticalize. This contrast becomes explicit in the presence of large urban slums (favelas), where the poor population settles in the urban voids or abandoned lands of large cities. [5]

In these favelas, a new typology of houses can be observed, the shacks. These are houses built with the most common building materials in the region, industrialized materials, mainly concrete and ceramic tile, but in the favelas the walls are left uncoated and the concrete slab serves as a social area of the house. [5]

Figure 09: A typical favela from Rio de Janeiro. Usually those settlement happens in inclined topographic

1.5 South

This is the smallest region in the country, with 6.75% of the national territory and 14.78% of the population. It is a region with a subtropical climate, with hot and humid summers, cold and humid winters and temperate and relatively dry intermediate seasons, but with intermittent and well-distributed rainfall. [5]

The region has two main sources of wealth, agriculture and the normal services of urbanized regions. This scenario creates a landscape that mixes rural areas, an extensive coastline and large urban centers. [5]

The south was the last region to be occupied and, despite the vast majority of the population having come from other parts of the country, it is a region that received many European and Japanese immigrants, mainly to work with coffee, a product that was widely cultivated in the region. This immigration of non-Brazilian peoples brought a wide cultural diversity to the region, which is also reflected in the diverse architecture. [5].

Figure 10: Small villa with timber houses

2. CLIMATE

Knowing and understanding the climates of different regions of Brazil is primordial to propose a more sustainable architecture. Decreasing the energy demand is a global topic in the field of building and construction. When taken to the Brazilian reality, this discussion becomes even more urgent, due the fact that it is not only about sustainability but also the lack of energy access in several regions and the great variety of different climates that make it impossible to propose a generic solution. Therefore, how to promote thermal comfort for habitations in a sustainable, adaptable and affordable way?

The solution for cases in a Brazilian context demands to design houses according to the specific climate in which this construction will be inserted. To explore the comfort principles, control the solar gains and exploit the natural ventilation can really reduce the energy consumption and provide a good condition of comfort. One more challenge is to design buildings able to integrate physics and comfort information with aesthetics.

Among the climate classifications, the W. P. Köppen, developed in 1900 from the analysis of the relation between climate data and the limits of great vegetation domains, is one of most known and used globally. [6]

Thus, first of all, to collect climatic data from Brazilian territory, the W. P. Köppen classification will be used. In the second place, the data will be interpreted using EPW files. According to the Köpper classification, the climates in Brazil are the following:

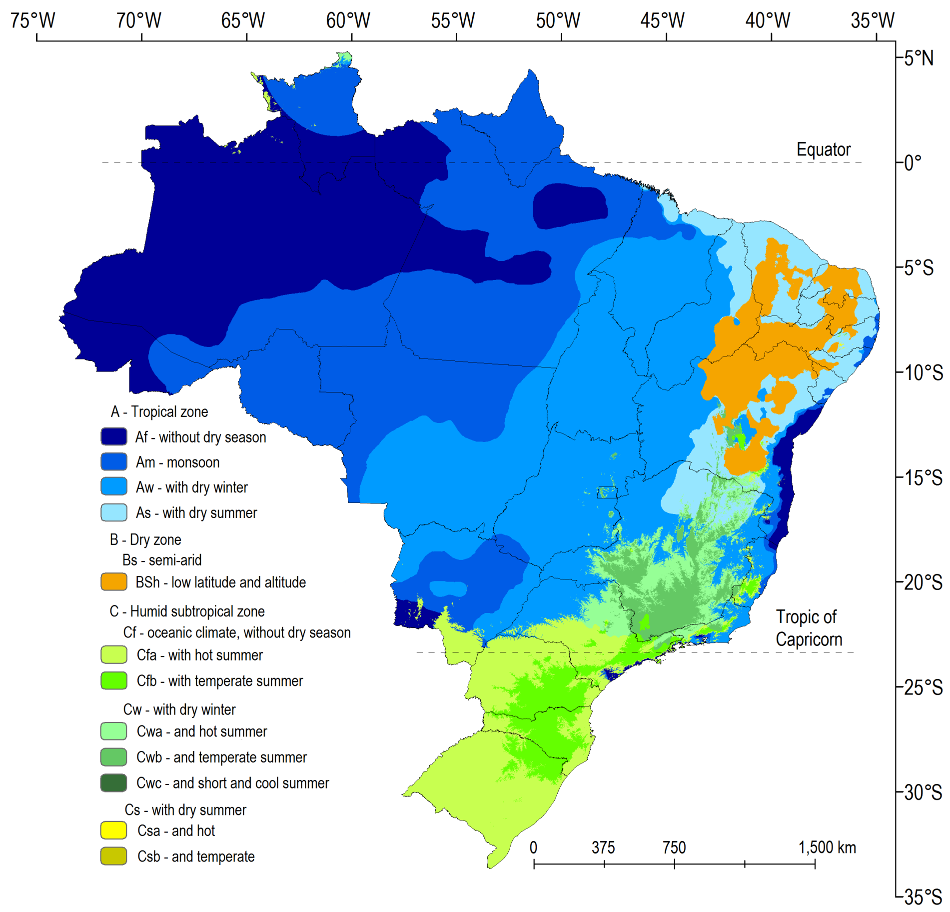


Figure 11: Brazilian Köpper map classification

Classification of major climatic types according to the modified Köppen-Geiger scheme			
letter symbol			
1st	**2nd**	**3rd**	**criterion**
A			temperature of coolest month 18 °C or higher
	f		precipitation in driest month at least 60 mm
	m		precipitation in driest month less than 60 mm but equal to or greater than 100 – (r/25)[1]
	w		precipitation in driest month less than 60 mm and less than 100 – (r/25)
B[2]			70% or more of annual precipitation falls in the summer half of the year and r less than 20t + 280, or 70% or more of annual precipitation falls in the winter half of the year and r less than 20t, or neither half of the year has 70% or more of annual precipitation and r less than 20t + 140[3]
	W		r is less than one-half of the upper limit for classification as a B type (see above)
	S		r is less than the upper limit for classification as a B type but is more than one-half of that amount
		h	t equal to or greater than 18 °C
		k	t less than 18 °C

C			temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month less than 18 °C but greater than −3 °C
	s		precipitation in driest month of summer half of the year is less than 30 mm and less than one-third of the wettest month of the winter half
	w		precipitation in driest month of the winter half of the year less than one-tenth of the amount in the wettest month of the summer half
	f		precipitation more evenly distributed throughout year; criteria for neither s nor w satisfied
		a	temperature of warmest month 22 °C or above
		b	temperature of each of four warmest months 10 °C or above but warmest month less than 22 °C
		c	temperature of one to three months 10 °C or above but warmest month less than 22 °C

[1]In the formulas above, r is average annual precipitation total (mm), and t is average annual temperature (°C). All other temperatures are monthly means (°C), and all other precipitation amounts are mean monthly totals (mm).

[2]Any climate that satisfies the criteria for designation as a B type is classified as such, irrespective of its other characteristics.

[3]The summer half of the year is defined as the months April–September for the Northern Hemisphere and October–March for the Southern Hemisphere.

Data Sources: Adapted from Howard J. Critchfield, General Climatology, 4th ed. (1983), and M.C. Peel, B.L. Finlayson, and T.A. McMahon, "Updated World Map of the Köppen-Geiger Climate Classification," Hydrology and Earth System Sciences, 11:1633–44 (2007).

Figure 12: criteria for Köpper classification

As seen in the table above, it is understood that the regions classified as Tropical (Af, Am, As and Aw) are warm zones, the Dry Zona (Bsh) are zones of low humidity and the Humid Subtropical Zona (Cfa, Cfb, Cwa and Cwb) has temperate climates, with months of high temperature and another months with low temperature. [6]

The classifying factors for Köppen are temperature and humidity. These two factors are important for designing climate-aligned architecture, but they are not the only ones. Two other fundamental factors are radiation and ventilation (speed and direction of prevailing winds). [7]

The first factor that influences how solar energy affects buildings is latitude. Each point on the Earth's surface has a relative position in front of the Sun and the translation and rotation movement of our planet continually changes this position in a continuous cycle. As Brazil is a continental-sized country, each region has a different angle of solar incidence.

The northern part of the Brazilian territory is near to the equator line, at this latitude the Sun incides more perpendicularly, close to the normal angle. Therefore, it is characteristic of this region to suffer from direct radiation of similar intensity in both the North and South orientations. The further south, the more the solar path is towards the north, reducing the direct solar radiation that comes from the south orientation.

The intensity of the radiation is also a factor that influences the gain of energy. About this, there are aspects that affect the intensity of radiation. Like the atmosphere itself. The average power density of solar radiation on a perpendicular surface outside the earth’s atmosphere is about 1370 W/m^2. On the earth’s surface, however, the maximum value rarely exceeds 1100 W/m^2. The attenuation of the radiation is due to the absorption and the scattering caused by the components of the atmosphere. Both phenomena modify the solar spectrum: absorption because it is selective (i.e. it takes place only for certain wavelengths); scattering because the ratio of the energy scattered in all directions (and thus also back

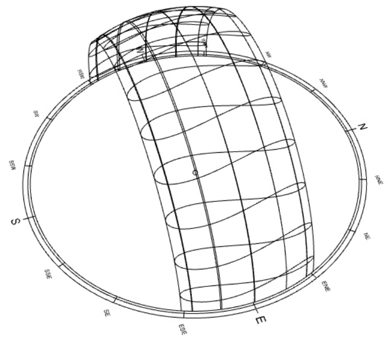


Figure 13: Sunpath for Porto Grande, North

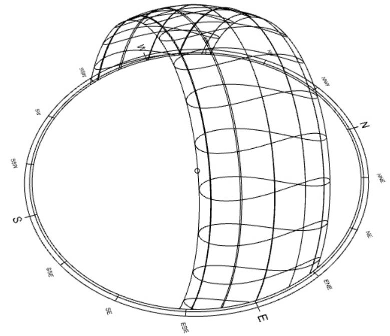


Figure 14: Sunpath for Brasilia, Midwest

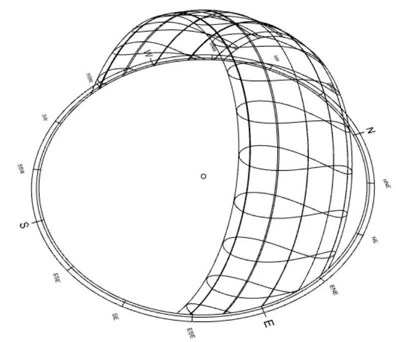


Figure 15: Sunpath for Santa Maria, South

towards space) to that transmitted varies as a function of wavelength and of the characteristics of the medium crossed. The radiation that reaches the surface after the scattering process is called diffuse radiation, while the one that comes directly from the sun and penetrates the atmosphere is called direct radiation. [7]

Another spectrum that affects a building surface is the reflected irradiation, this one depends on the absorbing and the reflective surface and its spatial disposition. On the incident radiation onto the reflecting surface and on the albedo of the reflecting surface. The albedo is the fraction of the total radiation that is reflected from the irradiated surface and characterizes the reflective properties of a surface, of an object or of an entire system.

It is due to all these factors that the energy coming from solar radiation has different intensities in each region, even in two places with the same latitude and the same climatic classification.

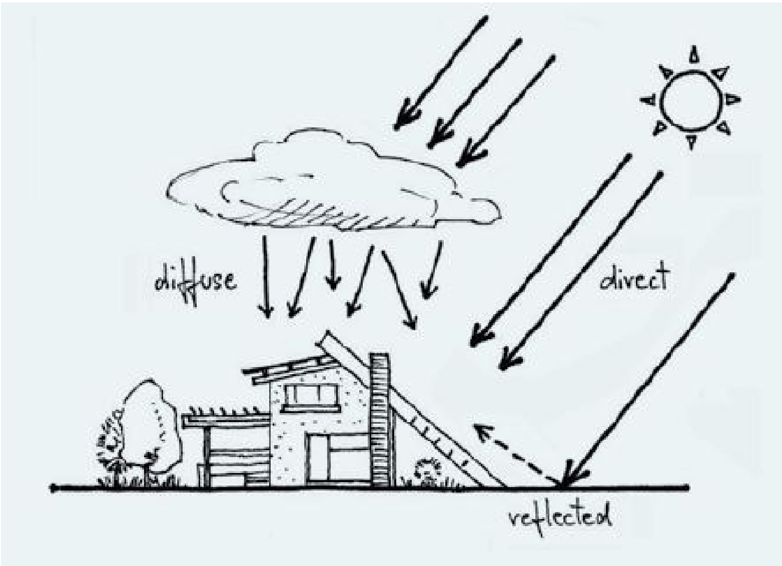


Figure 16: The three kinds of radiation

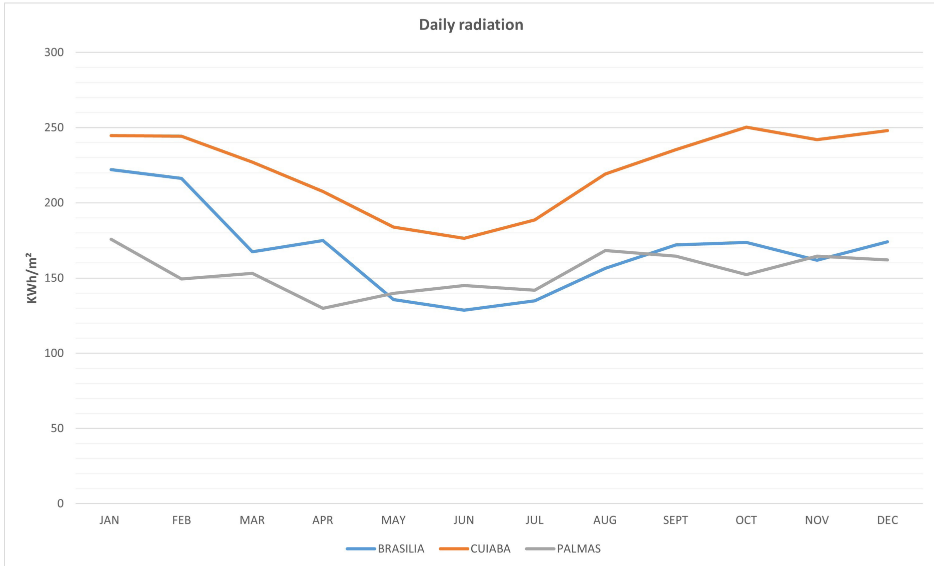


Figure 17: Different radiations in cities with the same climatic classification

Also, wind, a natural phenomena of movement of air masses caused by differences in atmospheric pressure, can be exploited to increase the comfort of buildings, especially when it comes to hot regions, where natural ventilation can remove hot air mass and renew it with fresh air at a lower temperature.

Wind is the movement of air masses caused by differences in atmospheric pressure related to land, water and air temperature gradients. They can occur as a regional level (between one geographical region and another) or at a local level, as a combination of contrasting thermal environments, such as the soil-water temperature difference between seas, lakes and the continent soil, and with different topographies. [7]

3. BRAZILIAN CONSTRUCTIVE TYPOLOGIES

The Brazilian population was able to make a great diversity and adaptations of types of housing throughout its history and until the present day in the different regions of the country. Several factors such as: climate, region, external influence, immigration, local material, exerted an influence on the plurality of housing systems in Brazil. In such a broad topic, it would be daring to try to cover each typology of popular architecture, but a closer look will be given into the most common systems over time and along the country: wood and ceramics.

The Brazilian Institute of Geography and Statistics conducts annual surveys to discover the predominant characteristics of Brazilian housing, considering the materials used to build walls, ceilings and floors. According to the most recent survey, the material most used on the walls is ceramic or taipa, with the vast majority in relation to walls built with veneered wood. The survey does not provide information on which material is used as load bearing, but it is safe to say that reinforced concrete is the most used structural system. [8]

Based on this survey, three constructive typologies of Brazilian popular housing can be highlighted: wooden structure and walls, wooden structure and clay wall, and reinforced concrete structure with ceramic wall. Following these 3 common use typology of wall and what is exposed in the brazilian literature, it was presented.

3.1 Wooden house

The constructions that use wood in their structure are of the most varied typologies and arise from the same structural premise, to create a skeleton of vertical and horizontal pieces that serve as support for the most diverse sealing materials. As described above, the main ones are with wooden or clay walls. Those that use exclusively organic material are Portuguese

Figure 18: Typical wooden house

heritages, with the fixing of nabos (stakes) in the ground or the use of diagonal bracings, such as bracing, according to the influence of the North European tradition. [9]

These houses supported their structure on a concrete foundation, in which stability is guaranteed by the fixing of the wall boards. Thus, the construction continues with the construction of a skeleton, frame type, which defines the geometry of the construction and the use of temporary bracings to stabilize the structure, in order to, in a second moment, close the walls with the nailed boards, either horizontally called the skirt and shirt, or vertically in a mata junta style. [9]

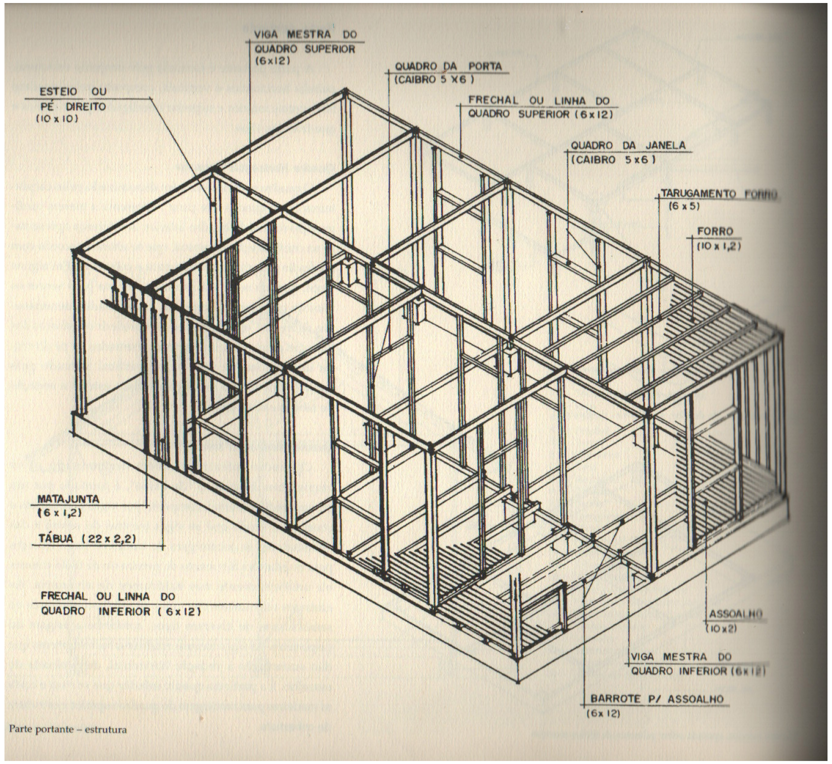


Figure 19: Timber frame skeleton

These houses are predominantly ground-floor and are found either detached from the ground or supported on a floor made of cement or stone. When detached from the ground, the structure is very similar to the walls, with a series of wooden beams and boards closing on top, like a deck. The roof is made with Roman type shears, supported on the frame structure and on the ceiling and with French type clay screens. [9]

This constructive typology was largely used in the first decades of the 20th century, when the supply of industrialized materials was low and the availability of wood was very high. That's why these are houses that are more than 5 or 6 decades old, that is, they already have an advanced lifespan for single-family houses. And this is one of the problems with this type of construction, the state of conservation they are in. Due to the fact that they have a series of deficiencies in terms of constructive details, especially when it comes to avoiding humidity and the drying of wooden pillars, the vast majority of houses of this typology are already condemned, renovations can be more complex and expensive than demolition and construction of a new home.

About the thermal comfort, we can evaluate the thermal transmittance values of the wall, ceiling and floor components and confirm if they are satisfactory following the reference values of the revision of the Brazilian standard.

	MATERIALS	THICKNESS (m)	THERMAL CONDUCTIVITY (W/mK)	THERMAL TRANSMITTANCE (W/m²K)
Wall	Wood	0.02	0.29	**2.01**
	Air cavity	0.10	-	
	Wood	0.02	0.29	
Floor	Concrete	0.10	1.75	**4.80**
Roof	Ceramic tiles	0.02	0.90	**4.55**

Table 01: Strategraphy and thermal transmittance of the wooden house

Figure 20: Typical taipa house

3.2 Taipa house

The second constructive typology that uses wood are the so-called "pau a pique" constructions. The technique consists of using considerably straight trunks and branches and fixing one end to the ground and the other to a horizontal support that acts as a beam. In the most common form of use, an internal and external seal made of clay was placed (taipa), so that the woods were fully protected. In other forms of use, branches, leaves, different layers of taipa could be used as seal and, of course, there is also a variety of wood used, both in size of branches and in the species used. [10] [5]

Figure 21: Timber structure to recieve the compact mug

As clay is a hydrophilic material, which means that it has a great power of water absorption, this can prejudice the performance and durability of the clay. That's why the trace of water and the protection of these constructions from the water are important to avoid pathologies. In some cases a layer of plaster is made to help with protection. The floor and roof are similar to those of wooden buildings, with the roof usually having a lighter structure, with tiles made from clay to a vegetable covering. [10]

The floor of this type of house is usually without any type of finish, it is simply a manual soil compaction and nothing else. This typology suffers to some extent from the same problem of preservation as wooden house. Due to the usually older age and the poor quality of construction of these houses, they suffer from preservation and humidity.

As for comfort, the thick walls help to reduce the heat flow through the wall, as we can see in the table.

	MATERIALS	THICKNESS (m)	THERMAL CONDUCTIVITY (W/mK)	THERMAL TRANSMITTANCE (W/m²K)
Wall type C	Mug (taipa)	0.20	0.56	**1.90**
Roof type A	Ceramic tiles	0.02	0.90	**4.55**

Table 02: Strategraphy and thermal transmittance of the taipa house

3.3 Brick and concrete house

Finally, the most widespread construction system in Brazil is the construction of reinforced concrete and slab walls. This typology is widely found in all regions of the country and is made by a column structure and upper and lower beams of reinforced concrete with the walls of 6-hole ceramic brick accented standing (thickness of the finished walls of +-15cm). [10]

These houses always have their foundations in the ground (baldrame beam), with a concrete floor/slab, which may or may

Figure 22: Concrete post and beam structure and brick wall

not have some tile on it. In addition, the roofs are mostly made of ceramic tile, with or without a concrete slab under the roof.

This type of construction uses, with the exception of the roof structure that is usually made with wood, industrialized materials, which obviously facilitates the diffusion of this constructive typology. However, it performs poorly in terms of Uvalue.

This ease of access to industrialized materials, which at first is something beneficial, has made the construction of houses in cities far from the big centers very problematic. This, because there is not the necessary knowledge to build good houses with this constructive technique.

Figure 23: Typical brick and concrete house

The architect Gustavo Utrabo, when visiting a clay-walled house in the North region, stated "... next door, this neighbour built a concrete block house and he couldn't live there, because it was absurdly hot; because they know to build, in terms of proportion with clay (adobe or taipa) and the other house, because it changed material, would have to be built in another way". [11]

This massified creates a type of architecture that was no longer related to the environment, culture, materials, knowledge and local climate. The result, in practical terms, is a construction difficult to inhabit, either culturally or for reasons of comfort. [7]

	MATERIALS	THICKNESS (m)	THERMAL CONDUCTIVITY (W/mK)	THERMAL TRANSMITTANCE (W/m²K)
Wall type A	Plaster	0.025	1.15	**2.28**
	Ceramic brick	0.10		
	Plaster	0.025	1.15	
Floor type A	Ceramic tiles	0.01	1.00	**3.57**
	Plaster	0.01	1.15	
	Concrete	0.10	1.75	
Roof type B	Cement-fiber tiles	0.012	0.65	**1.93**
	Concrete ceiling	0.05	1.75	
	Ceramic (ceiling)	0.05	1.00	

Table 03: Strategraphy and thermal transmittance of the brick and concrete house

In the example above, of the concrete block house versus the taipa house, we see in practice how thermal comfort is closely linked to building materials and facade, and how comfort is vital for people to be able to inhabit their homes. Also during this lecture, Utrabo mentions that in the concrete house, the person would have to install an air conditioner, to acclimatize the environment, but, in that reality, it was something completely utopian, because people are not able to financially bear the energy consumption that an air conditioning machine demands. In other words, reducing energy demand in the residential sector is more than a sustainable need, it is also, in the Brazilian context of very low-income communities, a financial need.

In the light of this, a qualitative analysis of the buildings and their facades is essential to understand what the current reality is and how and where the proposal can improve this situation.

For a first interpretation of the presented values of thermal transmittance, the Brazilian recommendation of these values for the different regions was used. In 2012, some Brazilian institutions came together to launch some recommendation on the subject, which resulted in the RTQ-R document (Technical quality regulation for the energy efficiency level of residential buildings). In order to ensure the energy efficiency of residential buildings and considering the need to create equitable rules of public knowledge for residential projects and constructions, the recommendation establishes, among other things, parameters and constructive requirements for facades and water heating systems, to have energy efficient buildings.

Looking at building fabric requirements, the recommendation uses the classification made by the Brazilian standard (NBR 15575), which divides the country into 8 bioclimatic regions. For each region, the RTQ-R specifies a thermal transmittance value for walls, roofs and windows, illustrated in the following table.

Zona Bioclimática	Componente	Absortância solar (adimensional)	Transmitância térmica [W/(m²K)]	Capacidade térmica [kJ/(m²K)]
ZB1 e ZB2	Parede	Sem exigência	U ≤ 2,50	CT ≥ 130
	Cobertura	Sem exigência	U ≤ 2,30	Sem exigência
ZB3 a ZB6	Parede	α ≤ 0,6	U ≤ 3,70	CT ≥ 130
		α > 0,6	U ≤ 2,50	CT ≥ 130
	Cobertura	α ≤ 0,6	U ≤ 2,30	Sem exigência
		α > 0,6	U ≤ 1,50	Sem exigência
ZB7	Parede	α ≤ 0,6	U ≤ 3,70	CT ≥ 130
		α > 0,6	U ≤ 2,50	CT ≥ 130
	Cobertura	α ≤ 0,4	U ≤ 2,30	Sem exigência
		α > 0,4	U ≤ 1,50	Sem exigência
ZB8	Parede	α ≤ 0,6	U ≤ 3,70	Sem exigência
		α > 0,6	U ≤ 2,50	Sem exigência
	Cobertura	α ≤ 0,4	U ≤ 2,30	Sem exigência
		α > 0,4	U ≤ 1,50	Sem exigência

Figure 24: Reference values for thermal transmittance for the different regions

The table shows average thermal transmittance values of 3 W/m²K for walls and 2 W/m²K for roofs. Following these values of thermal transmittance of the Brazilian standard, the composition of the walls are performing well and the roofs, have a thermal transmittance above the threshold value. For the case of the brick house there are 2 different stratigraphic commonly used, with or without the concrete ceiling. The roof with the concrete ceiling has the thermal transmittance in accordance with the Brazilian standard, the roof without the concrete ceiling are above the threshold value for the Uroof.

	COMPONENTE	WOODEN HOUSE	TAIPA HOUSE	BRICK AND CONCRETE HOUSE
ZB1 e ZB2	Wall	YES	YES	YES
	Roof	NO	NO	YES
ZB3 a ZB6	Wall	YES	YES	YES
	Roof	NO	NO	YES
ZB7	Wall	YES	YES	YES
	Roof	NO	NO	YES
ZB8	Wall	YES	YES	YES
	Roof	NO	NO	YES

Table 04: Checking the Uvalues for wall and roof of the constructive typologies

The map shows the percentage of different building typologies throughout the Brazilian territory. This survey is carried out by the IBGE and they grouped the mud houses with those of masonry and concrete, which makes it impossible to fully understand the percentages.

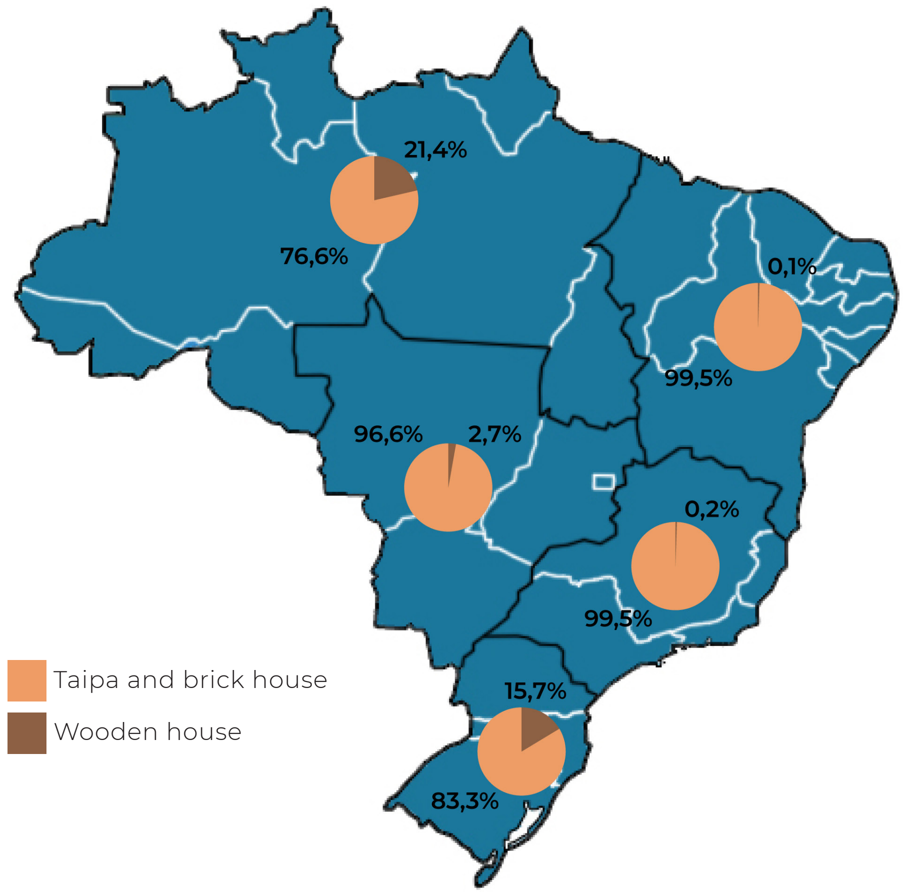


Figure 25: Frequency of the constructive typologies along the country

4. UNDERSTANDING THE PROBLEMATICS

After the analysis made from the perspective of the Brazilian socio-economic and housing/constructive situation, it was observed that there are many issues to be discussed to improve housing conditions. The main one would be to cover the astonishing housing deficit. There is an urgent demand for housing for families who have nowhere to live. This is a very profound discussion in large urban centers. Some government actions were made to face this question, the most important is called the "Minha Casa, Minha Vida" program. The implementation of this program brought to light an expected fact: densifying large cities is the best urban solution for the current moment. This is because fighting the large housing deficit with single-family homes on the outskirts of cities generates many other problems in urban dynamics, not to mention that it is not efficient to build a building per family, and the queue of people in need of a house is enormous. [12]

Figure 26: One of the many Minha Casa Minha Vida neighborhood

Therefore, this work is interested in thinking about the condition of small towns, where smaller communities, which have great difficulty in accessing more efficient services, including those related to construction, end up being on the sidelines of any social assistance. In the approach of these cities, the problems and challenges to offer quality housing are diverse and challenging.

The first point of need is the lack of manpower in places far from urban centers. There is indeed a knowledge, which is disappearing little by little, of how to build with local materials and with the traditional local technique. However, taking into account the challenges of solving the large housing deficit, it is necessary to build with an industrialized system and materials. And to build this type of house in a constructively correct way, the local workforce often does not have access to the necessary knowledge.

The second point is a criticism of government programs that try and/or tried to combat the housing deficit. Programs such as "Minha casa, minha vida" facilitate the access to economic financing for buying homes. However, no architectural and engineering support is offered in the elaboration of these projects. The result of this combination are buildings constructed by companies that, seeking a profit at any cost, standardize and repeat the same house project in entire neighborhoods in the most different regions of Brazil. This production logic leads to three main problematic consequences.

The first is the rigidity of the program and layout, which proved to be incompatible with the plurality of Brazilian families. The familiar types are diverse, and by building a series of houses with the same floor plan, you are excluding a large portion of families that either cannot afford a house that is too large for them, or cannot accommodate everyone in a limited number of rooms. The particularities of each reality are forgotten by an excluding standardization.

The second consequence is that Brazilian climates are diverse and require different architectural solutions, implantations and facades to be comfortable. A construction that does not adapt to the climate and surroundings that will be inserted generates discomfort and, probably, the increase in the need for artificial air conditioners, which can lead to indebtedness for many families who cannot afford the energy bills.

And the third is that, with the mass construction power of these construction companies, it distorts the market and creates unfair competition with local builders, which further degrades the economy and blocks the growth of local constructive knowledge. In other words, both money and knowledge are increasingly accumulating in the hands of a few and in large urban centers.

In the light of these issues, particular characteristics of housing will be proposed within this work, which goes through design ideas and construction processes, which can be an effective response to face these problems.

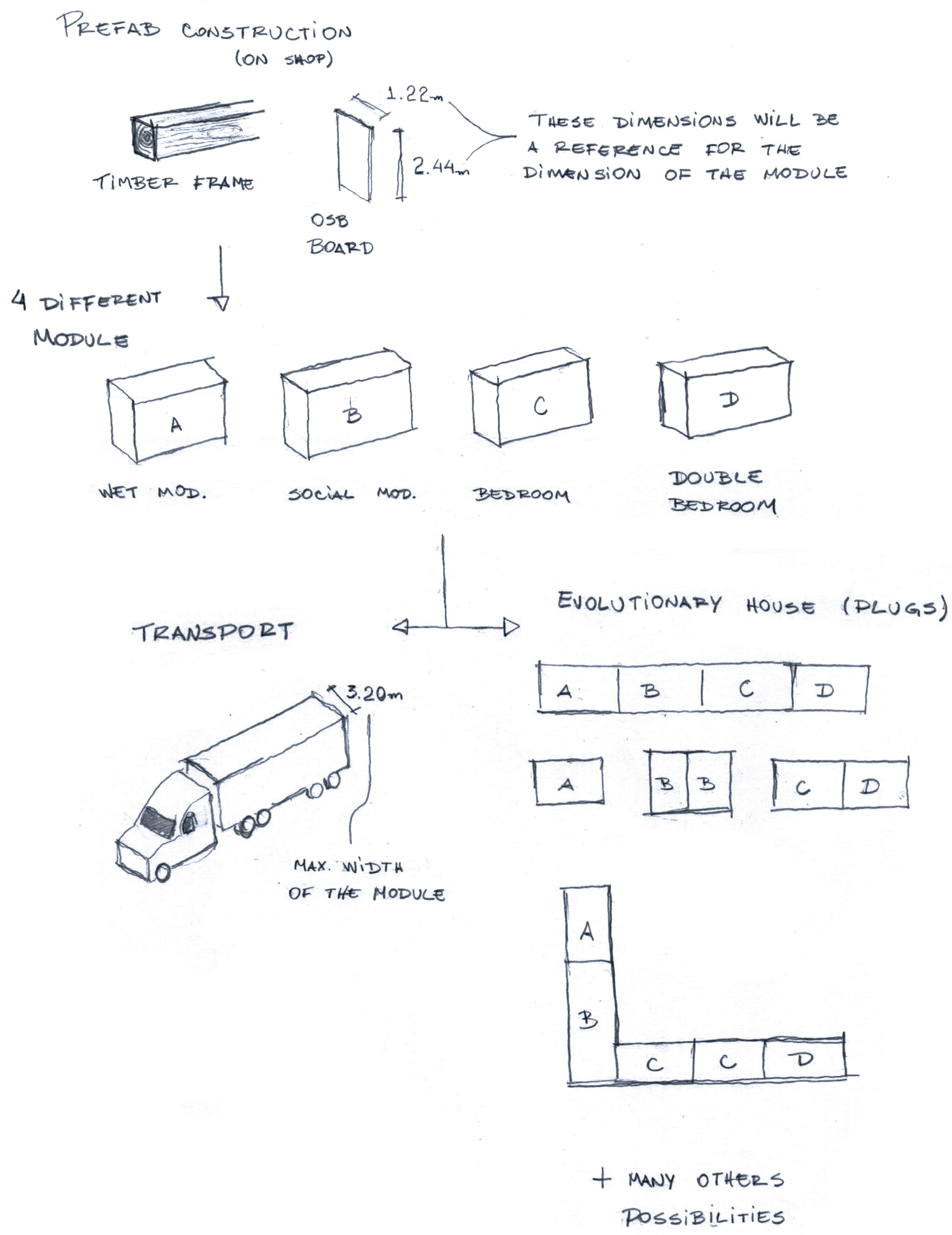
Thus, the guidelines for designing these houses are: (i) Propose a prefabricated construction, which is largely done on shop, to guarantee the quality and correct execution of the construction. In addition to being a very efficient type of construction, mainly for projects that start from a standardized project premise; (ii) Create specific project points that can adapt to the climate in order to have an effective reduction in the demand for energy in the house and increase the comfort of users; (iii) Diversify the layout and propose an evolutionary house that can fit into different family realities. Through a modular construction, it is possible to achieve this objective, combining standardization and customization in the same project; (iv) It is necessary to economically develop small Brazilian cities and towns. Within a model of prefabricated houses, which is the model proposed in this work, the concentration of money is for the industries of the urban centers. In order to even out this balance, some works will take place on site and made with local manpower and materials, to promote the circular economy; (v) Finally, a construction that can be transported, assembled and dismantled has the qualities of moving with families in possible migrations to other regions, which is something very common, and also creates an end-of-life that can reuse the parts in other constructions and purposes.

5. METHOD: THE CONCEPTS

To attend all these points in an efficient and simplified way, it was necessary to create a design method. A line of reasoning that guided the project and the solutions developed. As it is a project that intends to serve all of Brazil, or at least not restrict any part of it, the method is a guide, in which by changing the inputs, we will have different outputs.

The method proposed for this work links climatic factors to possible global passive strategies within the constructive process implemented. These strategies are grouped together and generate different design solutions in response to the search for climate comfort. The climate is also a factor that shows which is the best façade composition for each case, both for the opaque part and for the movable elements, such as windows and doors.

Meanwhile, the modules were determined from the dimensions of the truck transport, the main means of transport in Brazil, from the size of the materials used and the construction system. The association of these modules house the main layouts of wet areas (kitchen, bathroom and service/technical areas), bedrooms and social/dining area. These modules allow a series of different combinations and compositions, to better house the family nuclei and the possibility of implantations

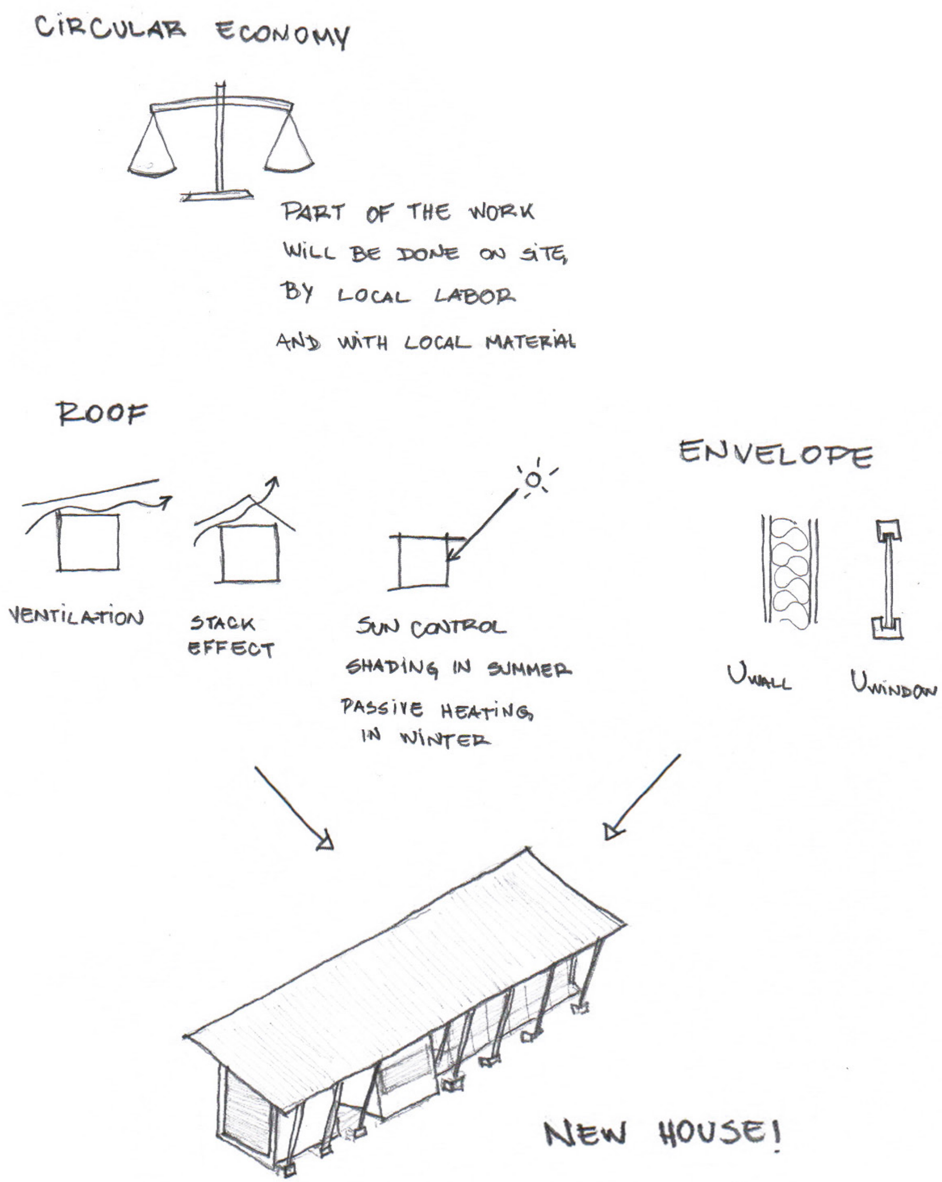


The result of the association of the possibilities of plugs, façade and design solutions is the house itself. Feeding the method with different inputs, we will generate different outputs that will best respond to the demands of each local reality.

5.1 Module

The start is a module. As a block toy, the initial premise of this work is to create a design that fits the different demands of families and the Brazilian territory. Of course a rigid, non-adaptable design could never fulfill this mission. However, an open project, without a unitary architectural and engineering logic, would result in an inefficient and contradictory project that would fail the mission as well. The module is a clear response, as it is efficient and proposes a construction prefabricated and transportable, two solutions that benefit from standardized solutions. This is the main goal of the module, standardize first and then adapt.

Driven by this inicial scope, the need was to develop a lightweight, frame structure, that would allow easy transportation over long distances. In the light of this, building this habitation through the wood frame constructive method appeared as a good alternative. Also, added to the fact that wood is a accessible material all over Brazil, sustainable source, reusable and, as seen previously in this work, widely accepted



culturally due to the fact it has been used for a long time in the country, which also provides historic constructive knowledge, facilitating the implementation of the proposal.

The start point for the design is the dimensions of materials and transport available to serve the entire country. The module's internal width and height was defined by the dimension of the OSB board, components responsible for closing and for the bracing of the frame structure. By repeating the board size in the module dimension we will have a reduction in waste and a smarter process construction. The module length dimension is a result of the truck trailer width and good use of materials. The Brazilian road transport legislation allows the circulation of trucks up to 3.20m. As the intention is that the modules can be transported assembled, this maximum dimension was respected. The final external dimension of 3.05m was established taking into account the size of the osb. Dividing the board into 4 equal sizes, we have a dimension of 0.61m, so 2.44+0.61 is the final dimension for the best use.

For the frames we will use the young eucalyptus species, which is a low density wood (400kg/m3). This species has a good development on Brazilian soil, it is a reforestation species and has a large offer throughout the country. The pine, a species commonly used in countries in the Northern Hemisphere for this type of construction, has a good development and growth in Brazilian soil, but it does not adapt

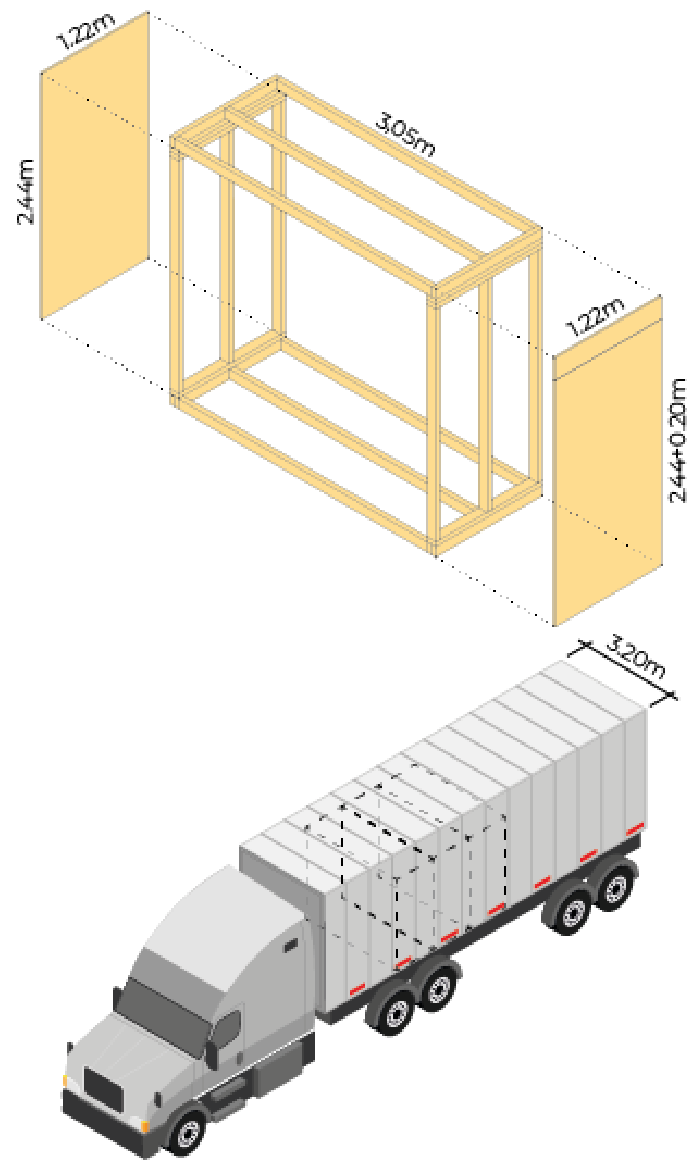
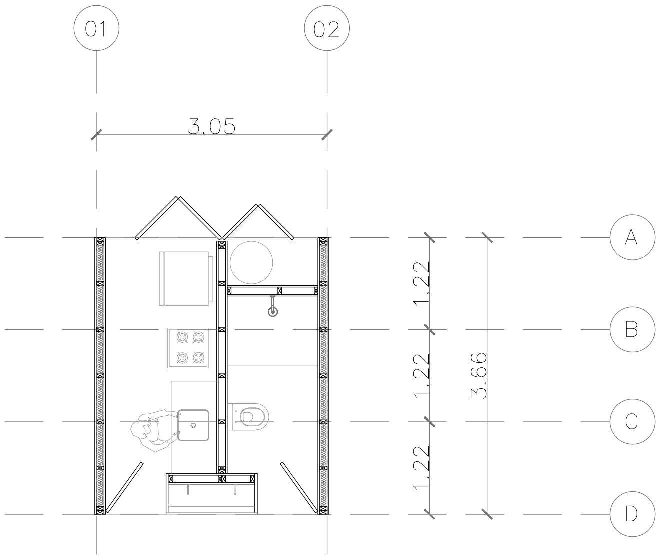


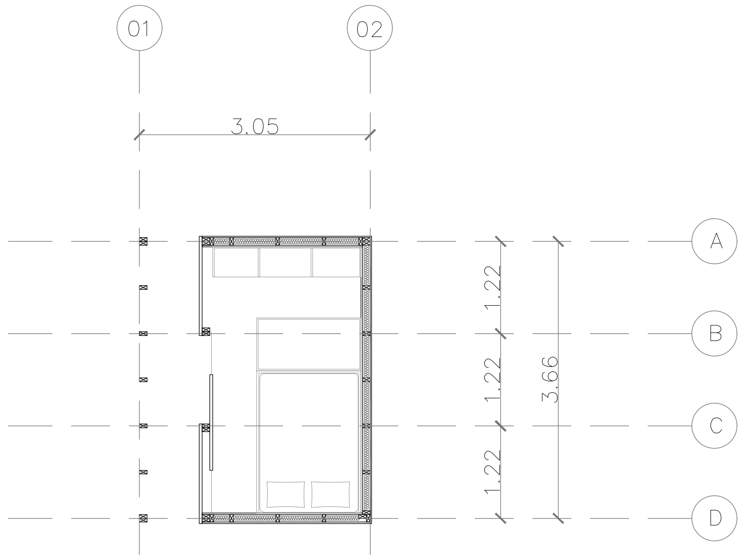
Figure 27: Relation between the module and the truck size

very well to civil construction applications. This is because it is susceptible to xylophagous agents and would have to be impregnated with chemicals to be usable.

From this base of dimensions, the layout of four main areas of the house was elaborated: the Wet Block, which has bathroom, kitchen and service, the Single Room Block, which accommodates 2 to 4 people, the Double Room Block and the Social Block, this one with an open layout. Defining these base blocks is crucial for the further studies of layout possibilities and how the passive solutions will fit to this building.



WET MODULE
SCALE 1:100



SINGLE BEDROOM MODULE
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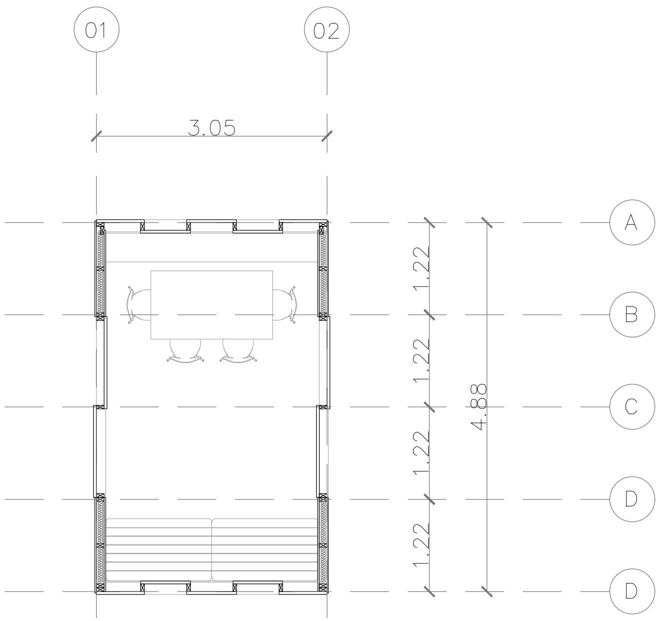
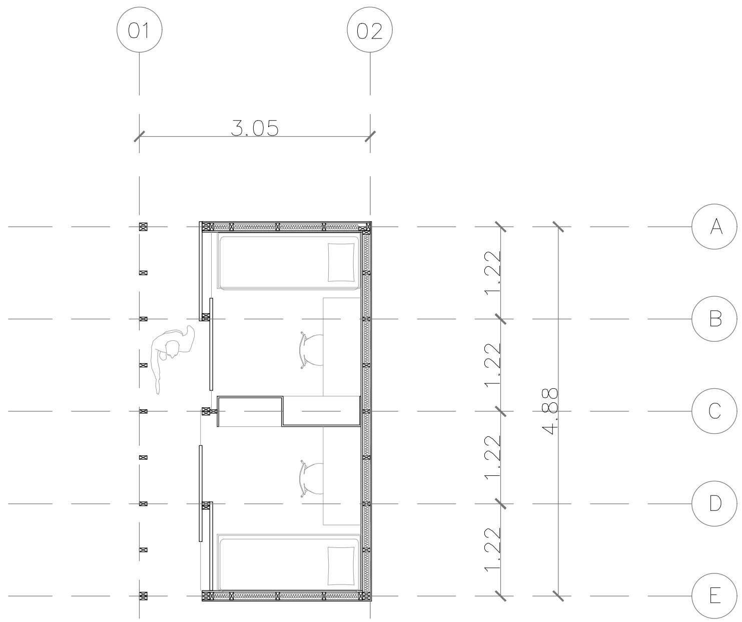


SOCIAL MODULE
SCALE 1:100



DOUBLE BEDROOM MODULE
SCALE 1:100

Drawing 01: The four modules

5.2 Plugs

The blocks are the first step to plan the proposal layout. Once modular constructions have been standardized for greater constructive efficiency, the second step is to explore and propose a variety of plug compositions between these modules to materialize the design of a house.

The main point for this approach was to think about the climate, more specifically about ventilation and insolation. How will these factors influence the layout? Thus, we arrived at 4 types of implantation: linear, square, with an internal yard and in a cross. Each of these typologies has a distinct adaptation to climatic factors.

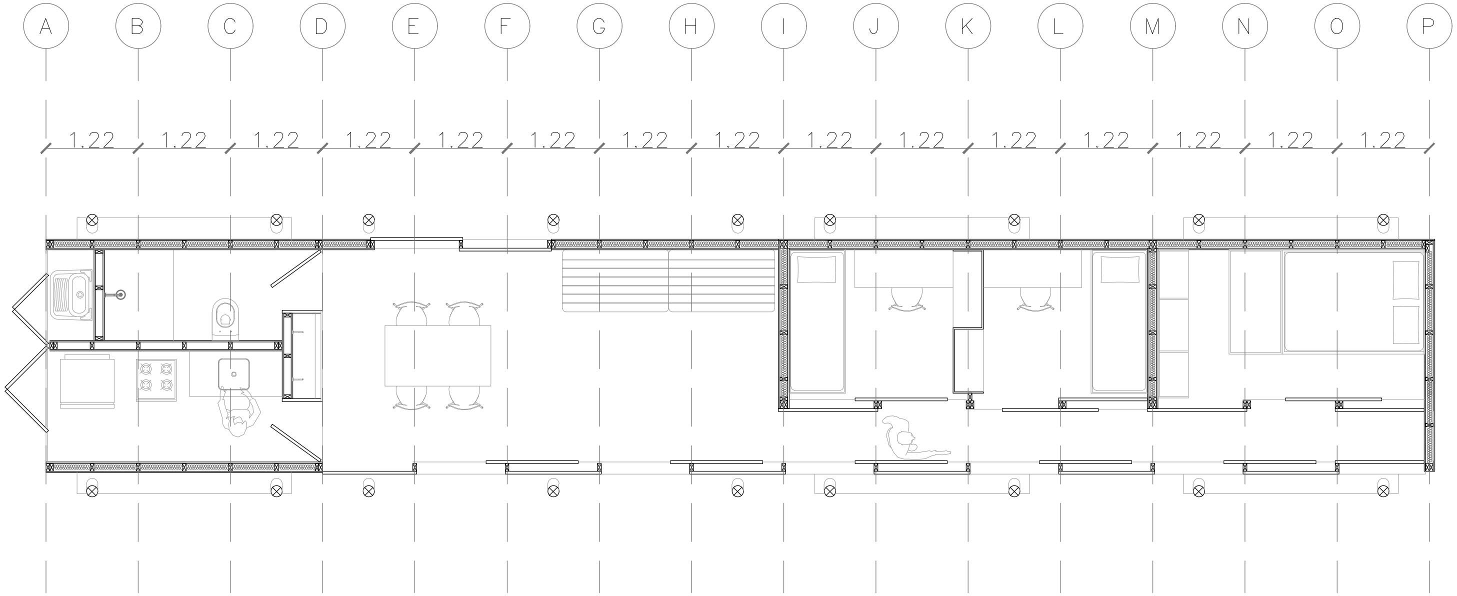
The linear implantation favors the North-South insolation, which facilitates the control of the radiation. Designing a roof that projects beyond the perimeter of the house, it is possible to avoid the radiation of these two types of insolation, especially for regions close to the equator, where the sun does not tilt too much in relation to the normal line. Further to insolation, this deployment allows greater freedom in spacing the blocks, dividing the house into parts, to allow greater ventilation.

The square implantation is a more conventional option in terms of plant layout, as it has the most connected spaces. Regarding insolation, it is an implantation that exposes the vertical facades more to radiation compared to the linear option. Due to its geometry, it is not possible to privilege one specific orientation. With this in mind, this option should favor North-South openings. The rooms are positioned to receive the morning sunlight, facing east, and the wet block positioned facing west, to block the afternoon sun. This type tends to adapt better to the southern region of Brazil.

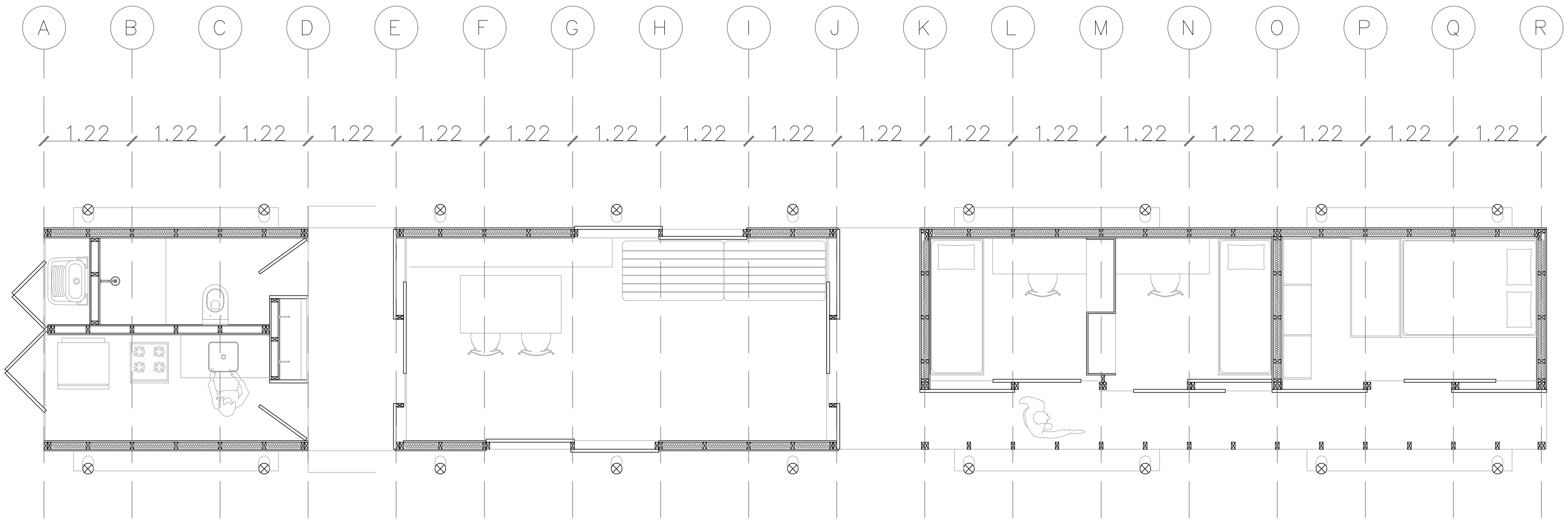
The internal yard type is an alternative widely used in hot-arid climates. In a courtyard a pool of cool night air can be retained, as it is heavier than the surrounding warm air. If the courtyard is small (width not greater than height), breezes will leave such pools of cool air undisturbed. The small patio is an excellent thermal regulator. The walls cut off the sun, except for midday hour, and the shades during the day prevents excessive heating. Moreover, the soil beneath the yard draws heat. During the night the heat accumulated during the day is dissipated by re-radiation. The heat dissipation through the internal walls should be assisted during the night by adequate ventilation. Thus, the design of the openings should be guided by two requirements: during the day small openings would be most desirable; during the night the openings should be large enough to provide adequate ventilation and also to dissipate the heat emitted by the walls and the floor of the courtyard.

Finally, the cross, L and T options are great for situations where the desired insolation and the dominant wind are in different directions.

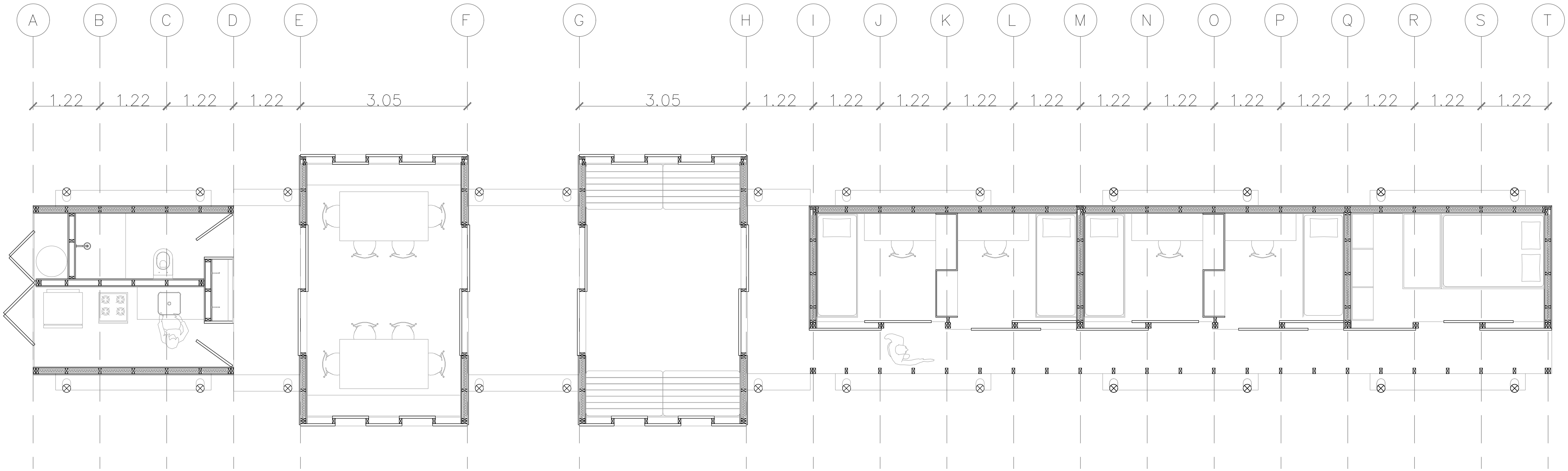
Drawing 02:
Possible plans



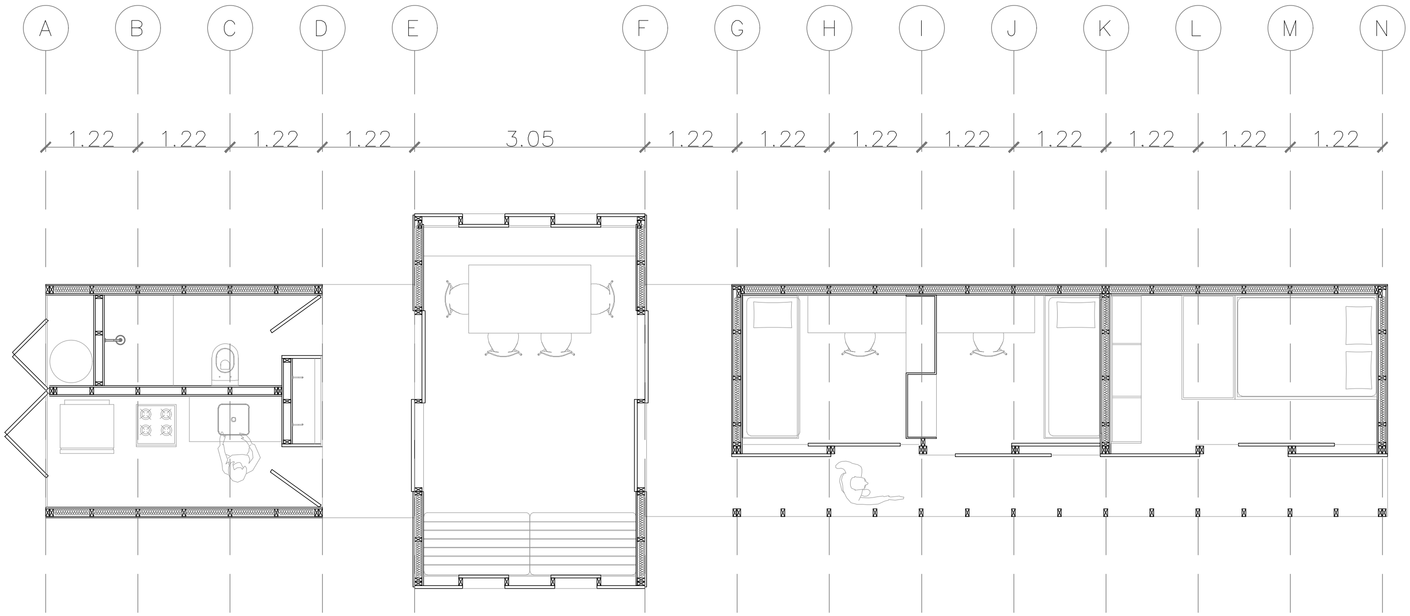
LINEAR PLAN 1
SCALE 1:100



LINEAR PLAN 2
SCALE 1:100



LINEAR PLAN 3
SCALE 1:100



LINEAR PLAN 4
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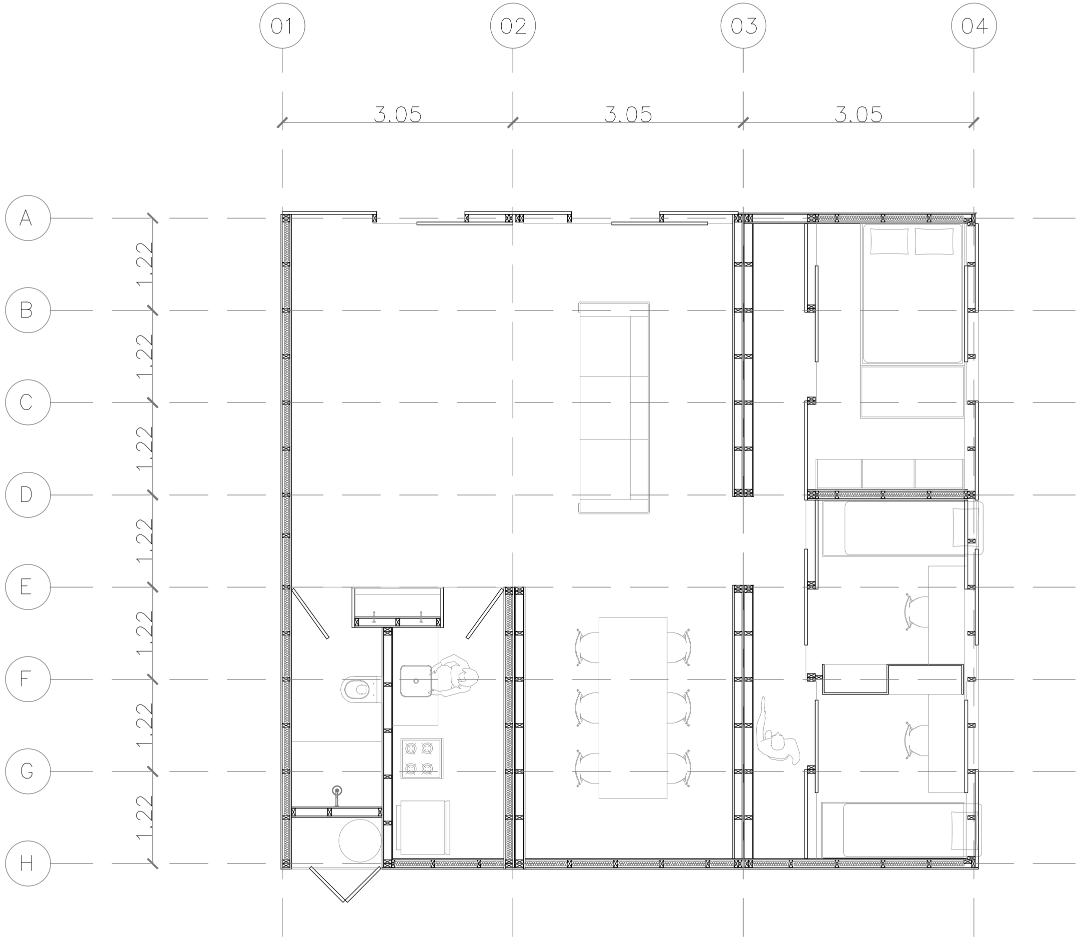
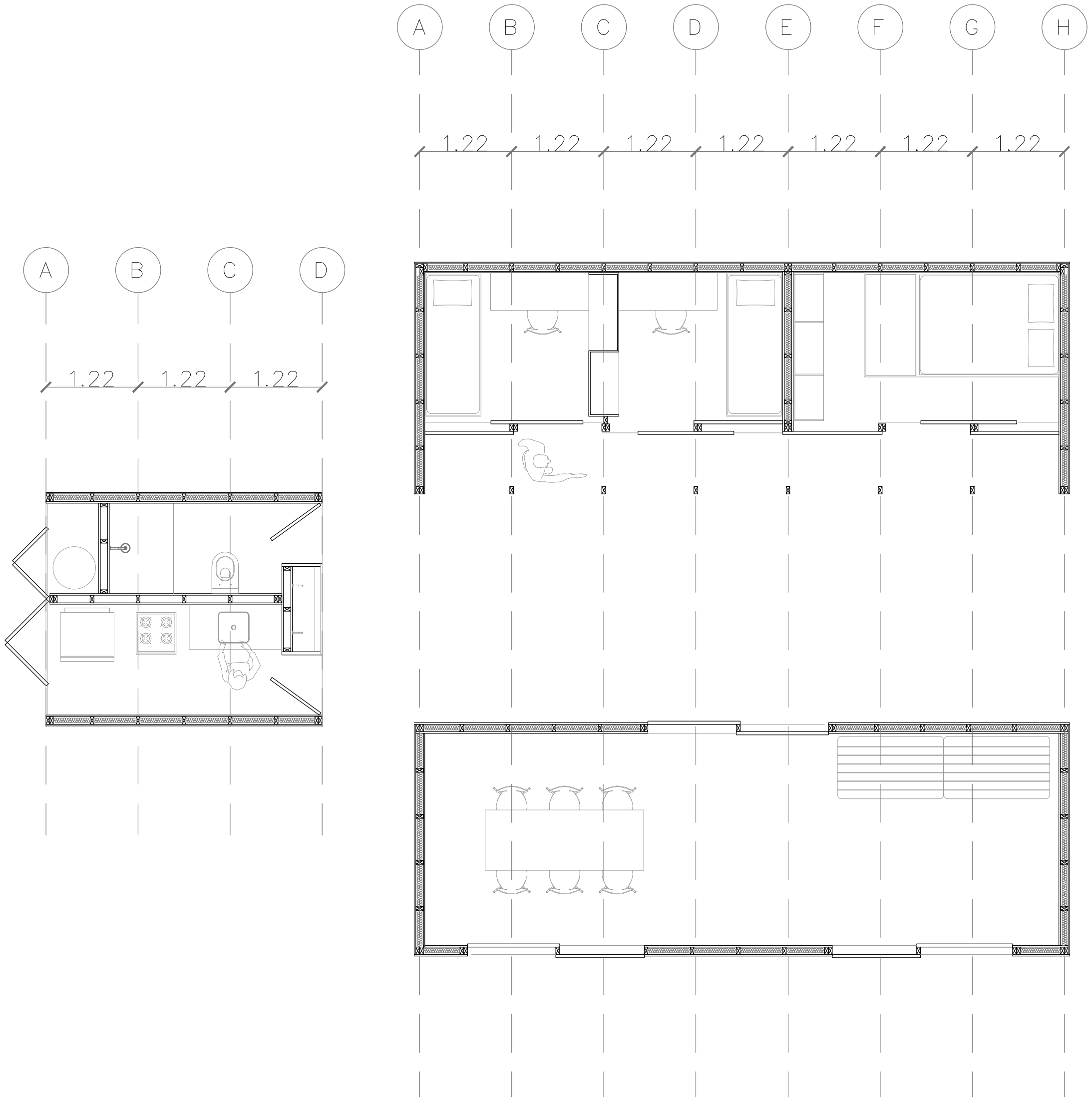
Drawing 03:
Possible plans



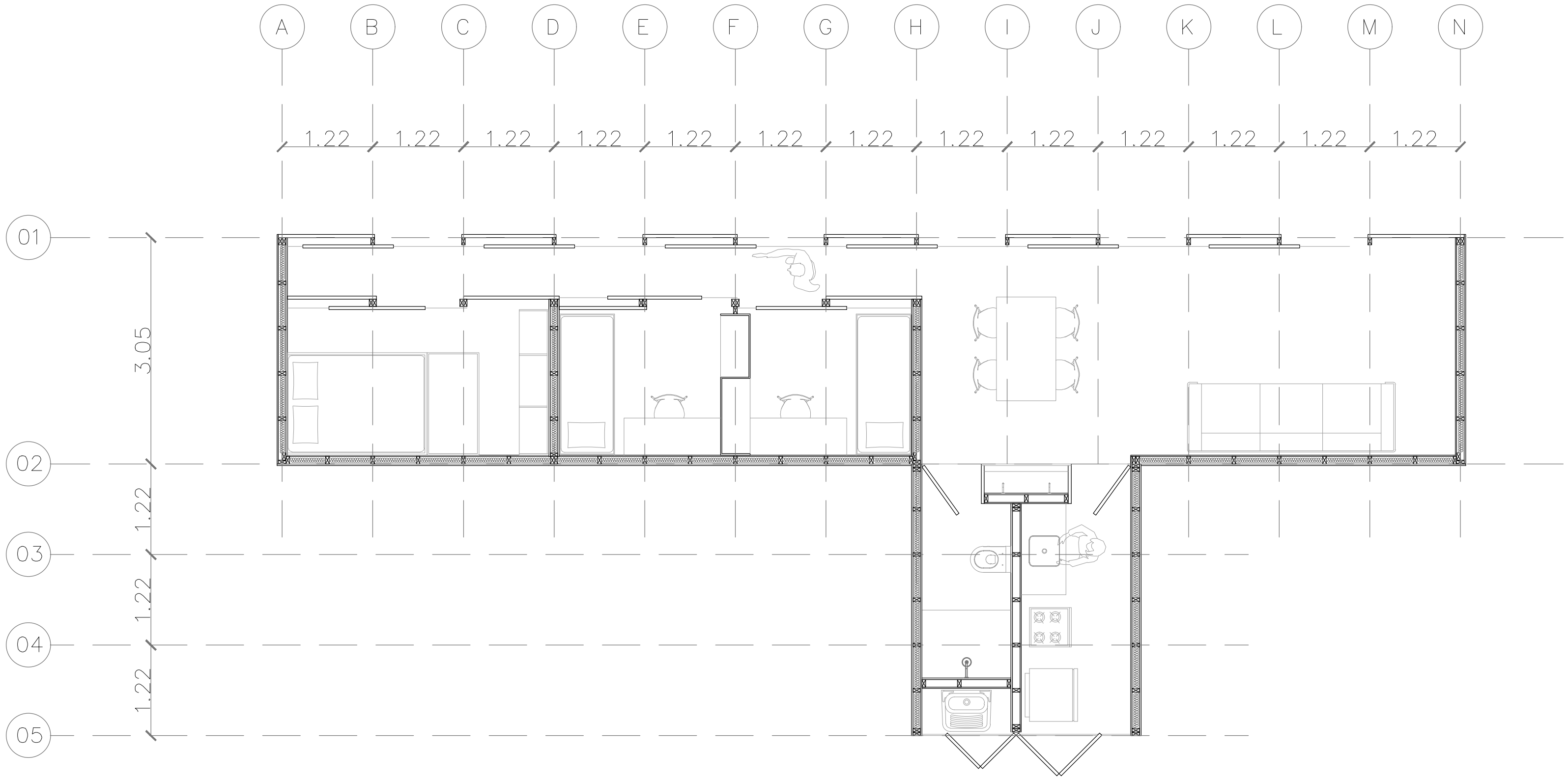
RECTANGULAR PLAN 1
SCALE 1:100

Drawing 04:
Possible plans



COURTYARD HOUSE PLAN 1
SCALE 1:100

Drawing 05:
Possible plans



AXIAL PLAN 1
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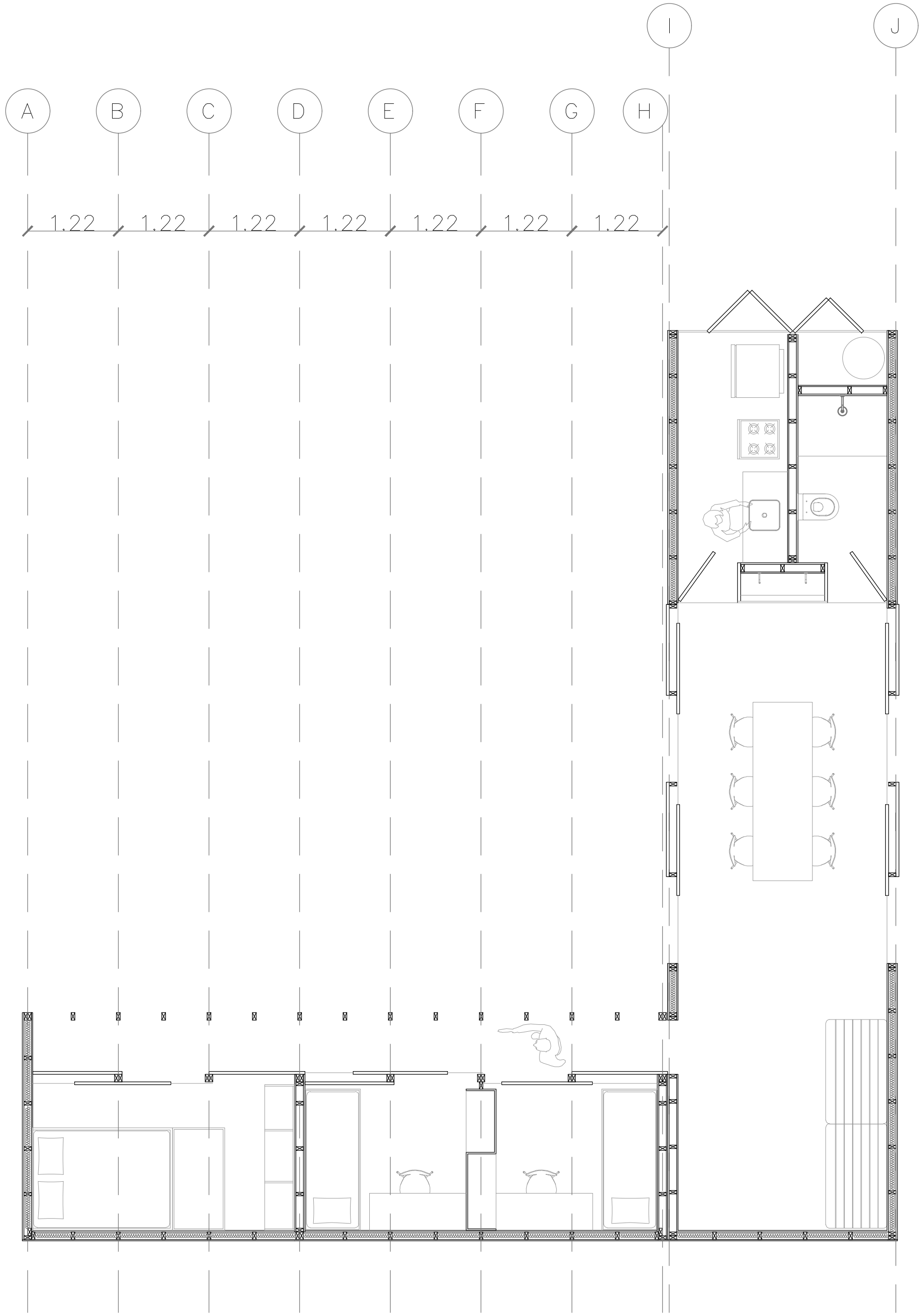
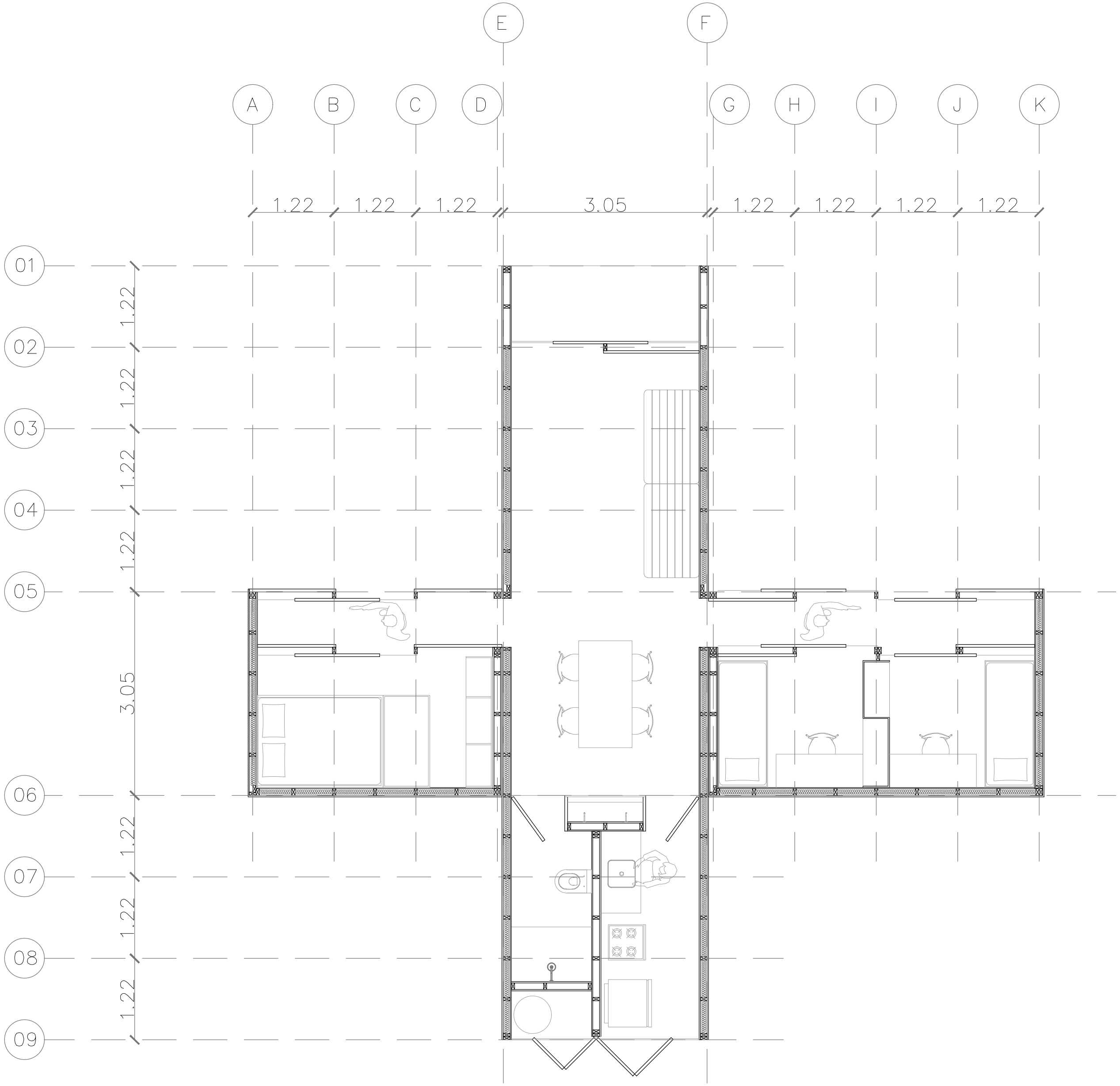
Drawing 06:
Possible plans



AXIAL PLAN 2
SCALE 1:100

Drawing 07:
Possible plans



AXIAL PLAN 3

SCALE 1:100

Drawing 08:
Possible plans

5.3 Climate

As seen previously, the Brazilian climate is quite diverse. And as it is a country of continental size, with cities in differentes latitudes and altitudes, Brazil is home to many biomes and climatic features.

The pursuit of this work is to propose housing designs driven to reduce energy demand with an architecture solution that is a response to the climate where the built belongs. Thus, the climate data is an input that transforms the output. To produce a work with this scope, it is necessary to study and narrow down such data and classifications.

The approach to define how climates are grouped was based on the passive design. The term “passive design” refers to a building whose architectural features take advantage of the local climatic resources to provide an indoor environment which is as comfortable as possible, thus reducing energy consumption due to the no need for mechanical heating or cooling. This concept has a relation with the term “Bioclimatic architecture”, which was introduced for the first time by Olgyay (1963) and later developed by Givoni (1969). The second actor has an important contribution for this work, because his charts will be used as a starting point to understand which strategy should be adopte. There are different types of Givoni charts, adapted to specific climates. The values of temperature and humidity, suggests the best strategies and shows the corresponding improvement in the comfort conditions for each strategy.

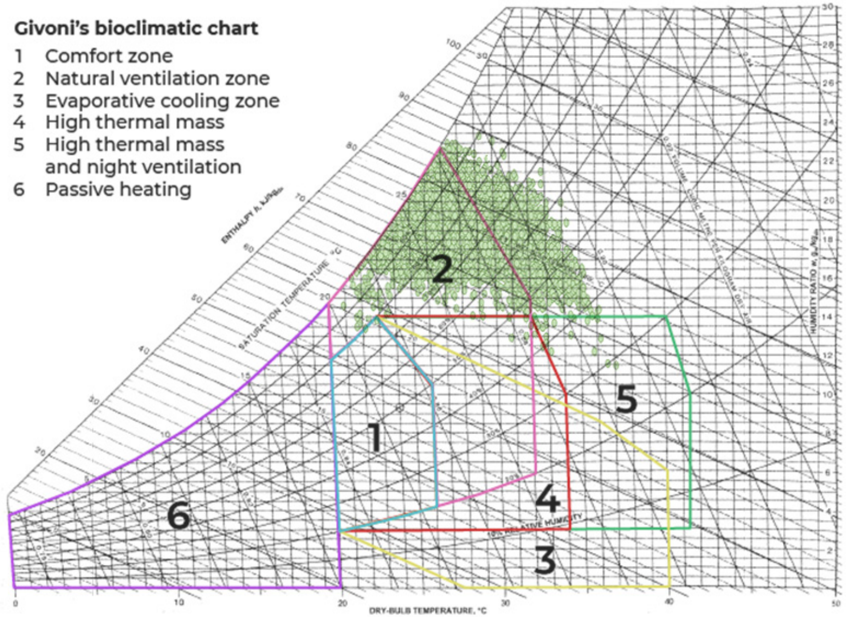


Figure 28: Givoni charts for Manaus, Amazonia (Af)

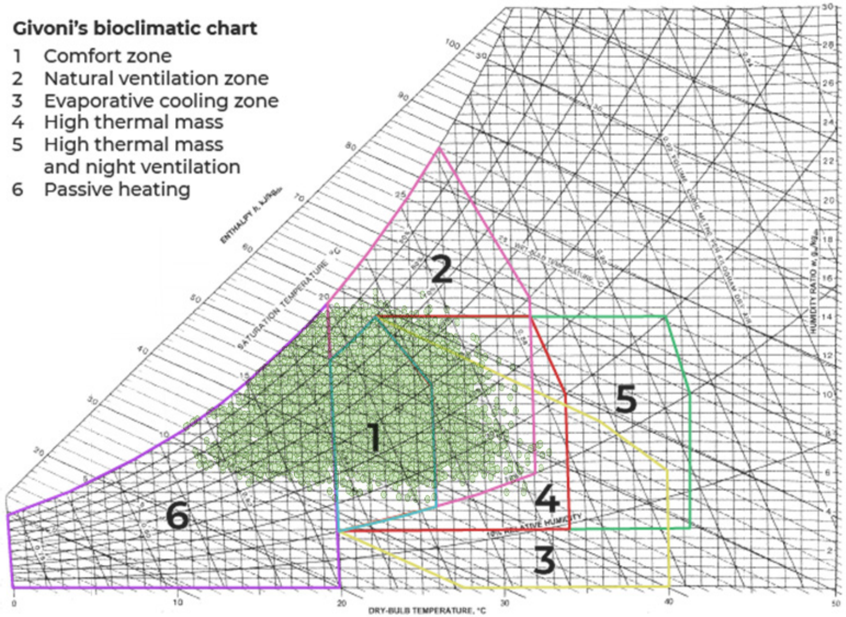


Figure 29: Givoni charts for Brasilia, FD (Aw)

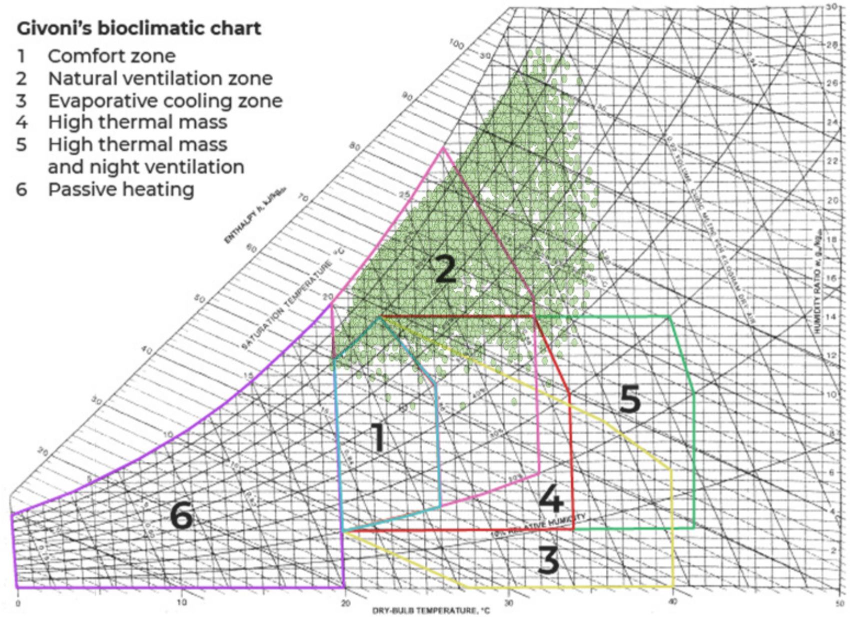


Figure 30: Givoni charts for Porto Grande, Amapá (Am)

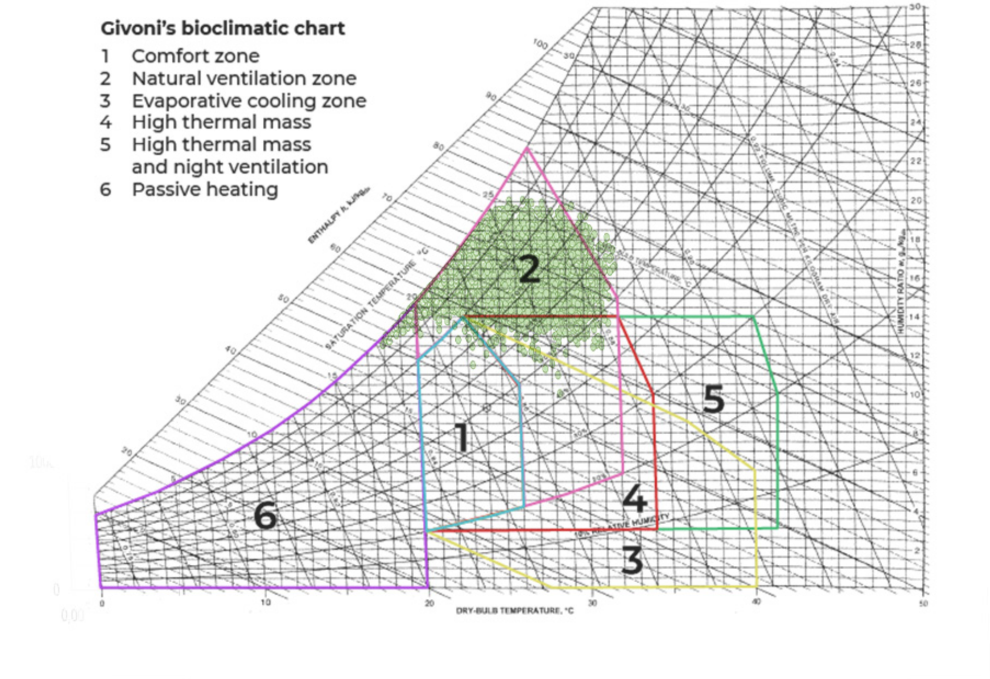


Figure 31: Givoni charts for Recife, Pernambuco (As)

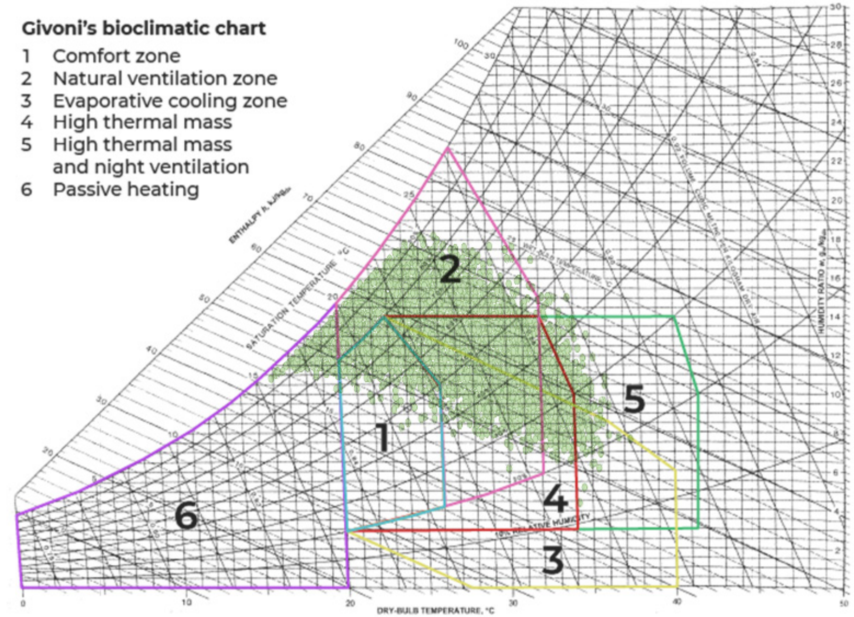


Figure 32: Givoni charts for Uauá, Bahia (Bsh)

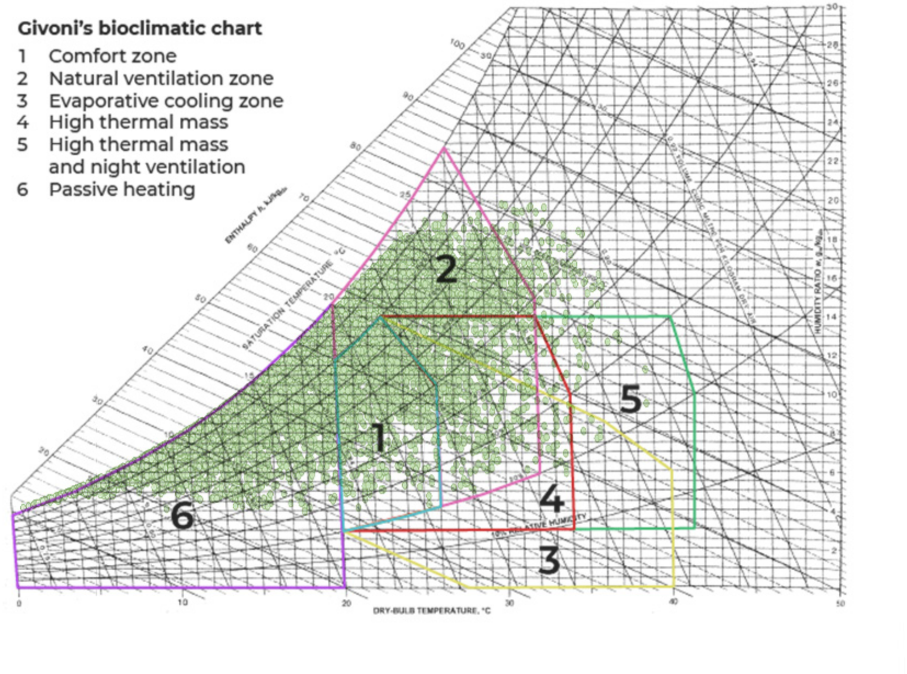


Figure 33: Givoni charts for Santa Maria, Rio Grande do Sul (Cfa)

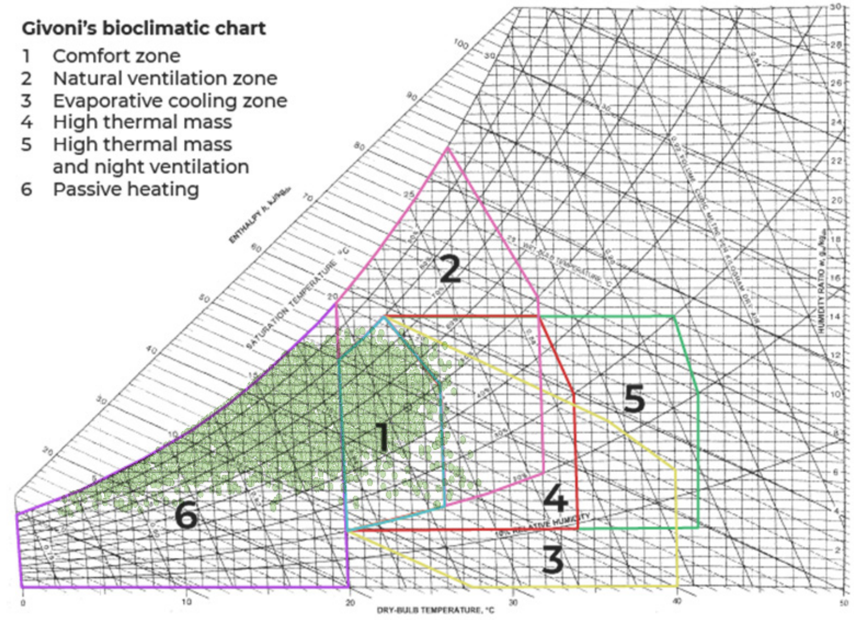


Figure 34: Givoni charts for Campos do Jordão, São Paulo (Cfb)

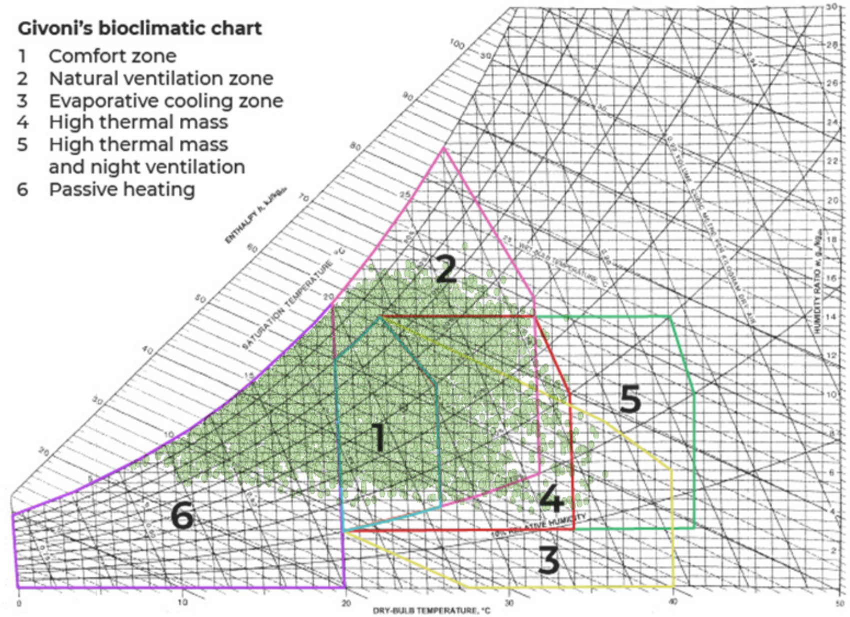


Figure 35: Givoni charts for Casa Branca, São Paulo (Cwa)

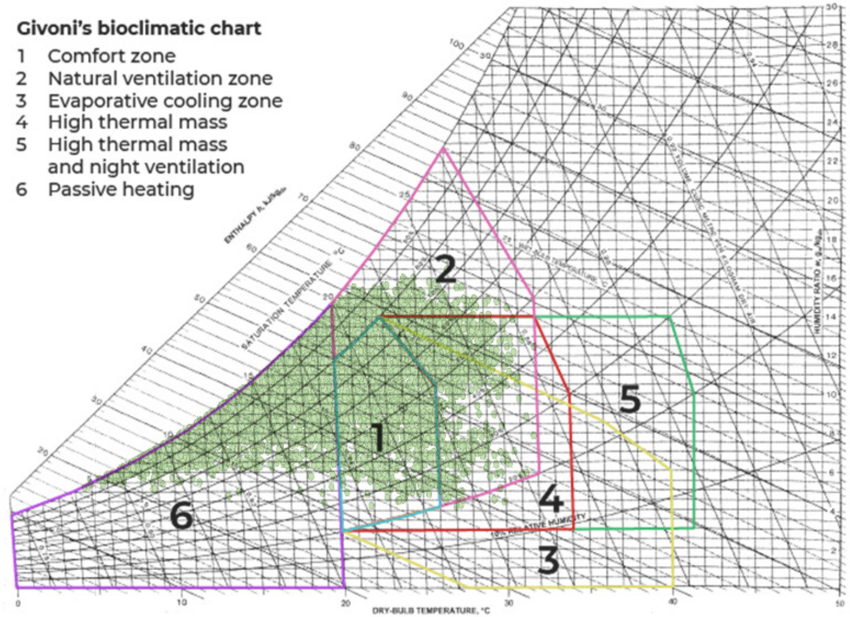


Figure 36: Givoni charts for São João da Mata, Minas Gerais (Cwb)

Next, the Givoni's charts are deepen for each of the nine climates of the Brazilian territory. Analyzing the graphs and the groupings made by Givani according to the passive strategy for each thermodynamic point, it is possible to see similarities in many of the climates. These approximations are clearly observed in the climates of the same global group (tropical and humid subtropical), and the difference between the three global groups (tropical, dry zone and humid subtropical) is also remarkable.

In the light of this, the sub-classifications will be considered grouped and design strategies will apply to the global classification only. Thus, it is possible to synthesize the climates and evolve this climatic condition into a solution of passive thermal comfort, both in terms of architectural design and the composition of the facades.

Koppen classification	
Letter	**Criterion**
A	Temperature of coolest month 18 °C or higher
B	Dry climate (70% or more of annual precipitation falls in the summer half of the year and r less than 20t + 280, or 70% or more of annual precipitation falls in the winter half of the year and r less than 20t, or neither half of the year has 70% or more of annual precipitation and r less than 20t + 1403
C	Temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month less than 18 °C but greater than –3 °C
1. In the formulas above, r is average annual precipitation total (mm), and t is average annual temperature (°C).	

Tabela 05: The climate grouping: A way to summarize the 9 differents climates

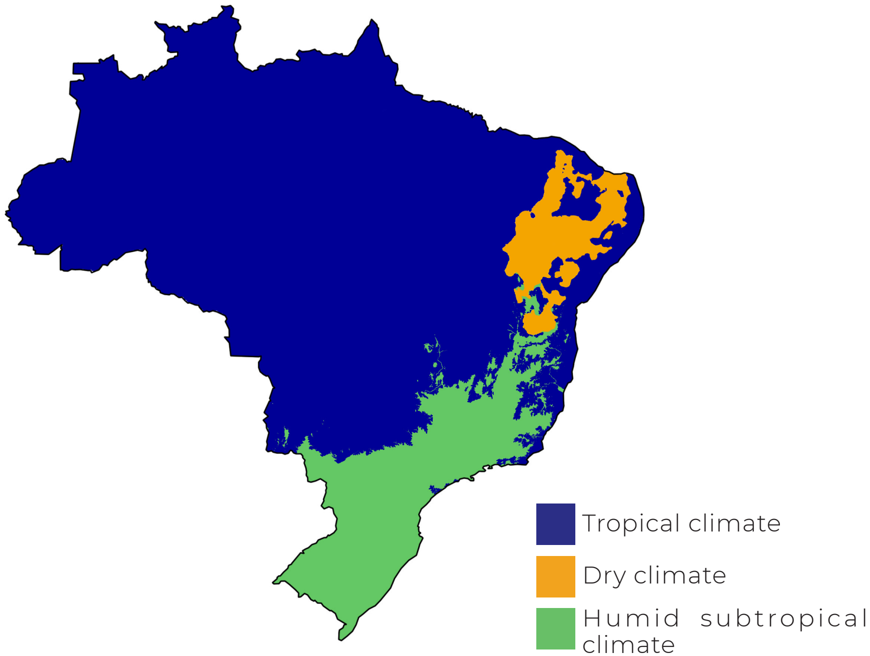


Figure 37: Brazil climate classification used during the design process

5.4 Passive strategies

Each of these 3 climates have their own characteristics and generate, to some degree and at some time of the year, discomfort in people.

Tropical climates (A) are characteristically warm throughout the year and are, on average, high in humidity. The discomfort for users of a house in this type of climate is due to the high temperatures, both during the day and at night, and is also related to high humidity, which can generate an excess of sweat in people, but, on the other hand, generates a more refreshing breeze. [6]

Cities classified in the dry climate (B) are characteristically hot throughout the year, but with a greater difference in temperature between day and night; the average relative humidity is medium or low, with little rain and dry periods and the winds are weak and without a predominant direction. The discomfort for users of a house in this type of climate is due to high temperatures, especially during the day due to high radiation (around 7 kWh/m2). [6]

The humid subtropical climate (C) has greater temperature variation between seasons. In the hot months, temperatures are high and in the cold months temperatures are low, especially at night. Therefore, the discomfort can be caused by heat in some periods and by cold in others.

The conclusion is that we are working with two hot climates, but very different relative humidities, and one climate with hot and cold seasons. From this classification, it is possible to plan which are the best passive strategies to increase the thermal comfort of the house. Such strategies must be answered within the project through architectural solutions, choice of materials, facade composition, choice of components, etc. And that is exactly what the propose design are going to do in this work: understand the best passive comfort strategies and to develop coherent solutions within the housing design. The main strategies are listed in the following table.

Passive strategies	
Climate	**Passive strategies**
Tropical	Natural ventilation Solar shading
Dry	Natural ventilation Solar shading High termal mass evaporative cooling
Humid subtropical	Natural ventilation[1] Solar shading[1] Passive heating[2] Medium thermal mass
1. Passive strategies for Summer; 2. Passive strategies for Winter	

Tabela 06: Passive strategies for each climate

5.4.1 Natural ventilation

This term is used to indicate the use of solutions to intentionally make the air flow through windows, doors and openings without the use of fans. It is a good thermal regulator because it provides flow of external air that, if the outdoor temperature is lower than the indoor, subtracts heat to the internal space or adds heat if the outdoor temperature is higher than the indoor. Besides that, it directly influences thermal comfort because the air velocity affects the body's energy. The higher the air velocity, the greater the body's heat loss. [7]

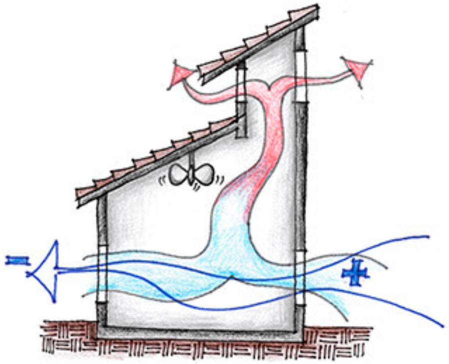


Figure 38: Natural ventilation

Passive ventilation systems rely on differences of pressure to move fresh air through buildings. Pressure differences can be caused by wind or temperature differences, which configure two main types of passive ventilation: cross ventilation and stack ventilation. [13]

By the so-called stack effect, the cooler, denser air exerts positive pressure, the warmer air, by becoming less dense, exerts low pressure and tends to rise creating convection currents. [13]

In cross ventilation, the negative and positive pressure effects that the wind exerts on the building or any other surface are explored. To provide good natural ventilation it is necessary to position the openings in zones of opposite pressure. Cross ventilation promotes heat removal by accelerating convection exchanges and also contributes to improving occupants' thermal sensation by increasing evaporation levels. [13]

5.4.2 Solar shading

Shading is a key strategy for reducing solar gains across the building envelope. A correctly designed sun protection should prevent solar gains in the hottest periods. Avoiding radiation, both in opaque facades and especially in glass, is very important in hot climates. [13]

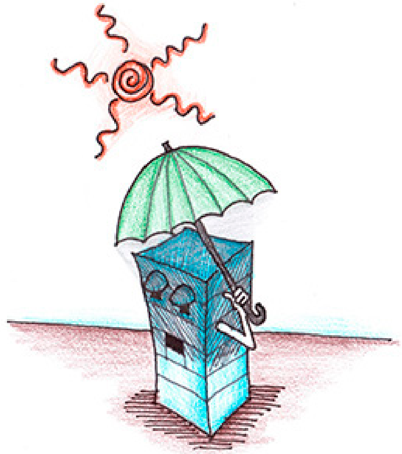


Figure 39: Solar shading

A Poorly designed sunshade can block direct sunlight that would make it possible to use diffused sky light for daylighting.

5.4.3 Thermal mass

A building with high thermal inertia will provide a decrease in internal thermal amplitudes and a thermal delay in the heat flow due to its high capacity to store heat, causing the internal temperature peak to present a delay and a damping in relation to the external one. In fact, high thermal inertia components work as a kind of thermal battery: During the summer they absorb heat, keeping the building comfortable and in winter, if well oriented, it can store heat to release it at night, helping the building to stay warm. [13]

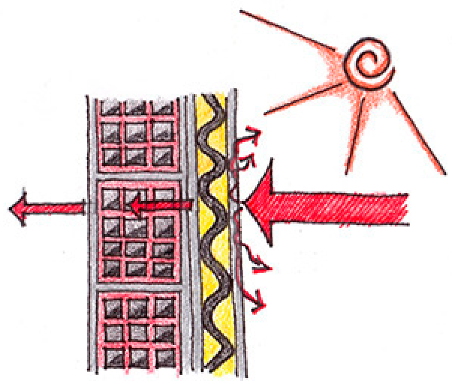


Figure 40: Thermal mass

The total thermal inertia of the building depends on the characteristics of the envelope (the type of floor, wall and roof) which must be composed of generally dense materials with a high thermal capacity. In addition, the thermal admittance of the material will influence its ability to absorb and store heat. A material of high thermal admittance absorbs and releases heat quickly. [13]

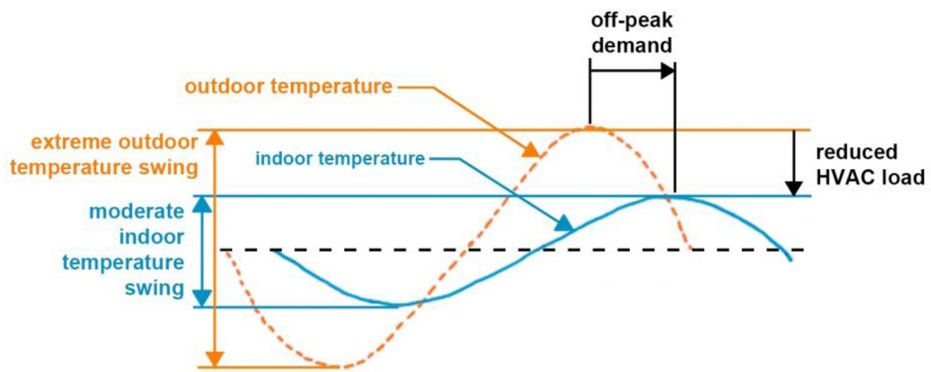


Figure 41: Effect of thermal mass

5.4.4 Evaporative cooling

The physical process of evaporative cooling is based on the process of evaporating water that takes heat from the environment or material on which evaporation takes place. [13]


Figure 42: Evaporative cooling

The degree of cooling is determined by the rate of evaporation: the faster the evaporation process, the greater the temperature drop. [13]

The rate of evaporation in an open space will be faster the greater the surface area of the water and the air velocity and the lower the relative humidity. The drier the climate, the greater the applicability of such systems. When the air becomes saturated, the evaporation process ceases and also the reduce of temperature. [13]

5.4.5 Passive heating

Passive solar heating is a strategy that consists of using direct solar radiation to heat the building.

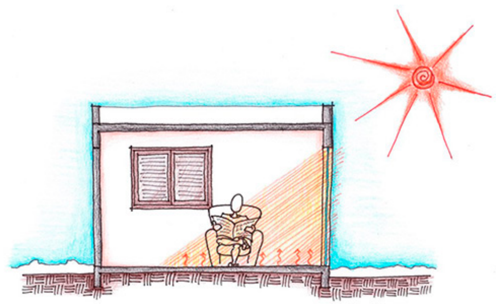


Figure 43: Passive heating

In direct solar heating, solar radiation is admitted directly into the environment through openings or glazed surfaces, obtaining an immediate heating response. Due to the greenhouse effect, the radiation, when passing through the glazed surfaces, is absorbed and reflected by the internal surfaces in the form of a long wave, remaining inside the building, since the glass is opaque to the long wave. [13]

Indirect solar heating is when solar radiation heats an opaque surface and heats the internal environment by convection.

5.5 Passive design solutions

Once we understand the predominant climates in the Brazilian territory and what are the best passive strategies to generate more comfort for constructions, specific solutions were developed, in specific components, to be able to incorporate these solutions into the modules. Here, the focus will be on architectural design strategies. The facade solutions are another extremely important point for comfort and reduction of energy demand, this subject will be addressed at another time.

The adoption of the evaporative cooling strategy was immediately discarded, as it was understood that such solution would not be applicable as a global project and would have low efficiency.

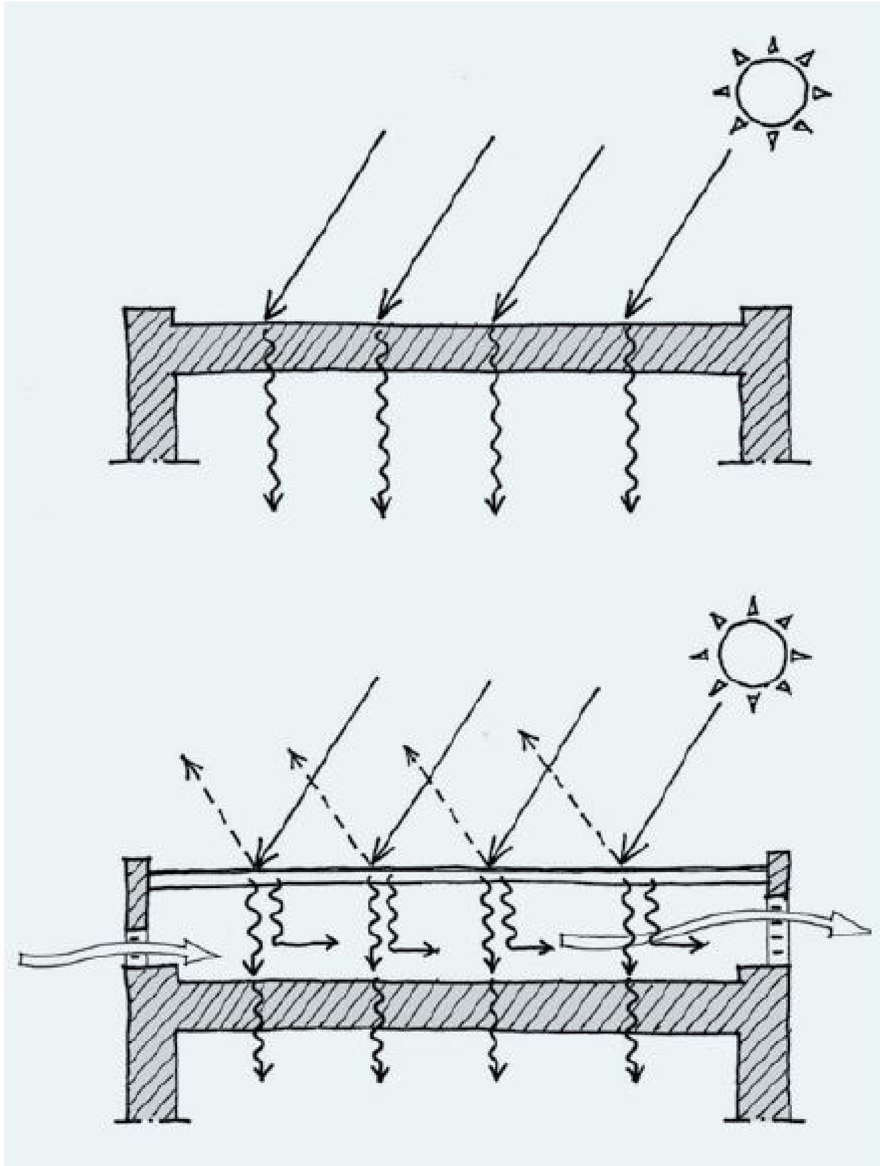


Figure 43: Flat roof and ventilated roof

The option to increase the thermal mass of the envelope is a possible strategy. Although it seems conflicting at first, because the premise of the work is to create a light and transportable construction and to increase the thermal mass it is necessary to use dense and heavy materials. However, the building envelope could be work using materials with high heat capacity, which helps to increase the time lag.

However, the most promising strategy is the natural ventilation and solar shading, as all three climates need of these characteristics at some point in the year. Therefore, these two strategies were promptly adopted and incorporated into the design. Along with the solar shading strategy, in regions with a humid subtropical climate, it is recommended to allow northern sunlight to warm the interior spaces during the winter.

With these three points into perspective, came the conclusion that the roof would be a key element to achieve the expected performance of the building.

First, because the roof is a critical element in terms of sun exposure. As it is a horizontal surface, or close to it, it receives a large amount of energy from solar radiation and part of this energy is transmitted to the internal environment. That's why the roof + ceiling set plays an important role in the internal comfort of the house.

Second, it is the element responsible for creating shading for the house, if used with an eaves. Therefore, to prevent radiation from reaching the vertical facades in a very harmful way, it is beneficial to use the roof as a radiation regulating element, blocking or allowing the entrance of North and South sunlight.

Third because, within the constructive logic that is being established for this project, it is an element that can be associated with the modules in a complementary way, as an accessory. This gives us greater freedom to adapt the solution to different climates. The module, although it allows the creation of different plant possibilities, is a more rigid structure, due to the issues of transport, mobility, and the dimension of the materials. The roof, on the other hand, can be an adaptable structure, which allows more variations and can be plugged into the structure of the on-site models.

In the light of was exposed during this chapter, we designed three roof typologies. Each of them has a different physical body, they associate with some specific plants and they perform better in a specific climate.

The first of them is the shed roof. This roof typology aims to shade the vertical facades and allow good ventilation between the roof and ceiling. Thus, the roof receives radiation from the sun and transmits part of it to the interspace between the tile and the ceiling. However, this heat is not trapped in that space, because the natural ventilation of the place will remove this heated air mass and dissipate the heat before it enters

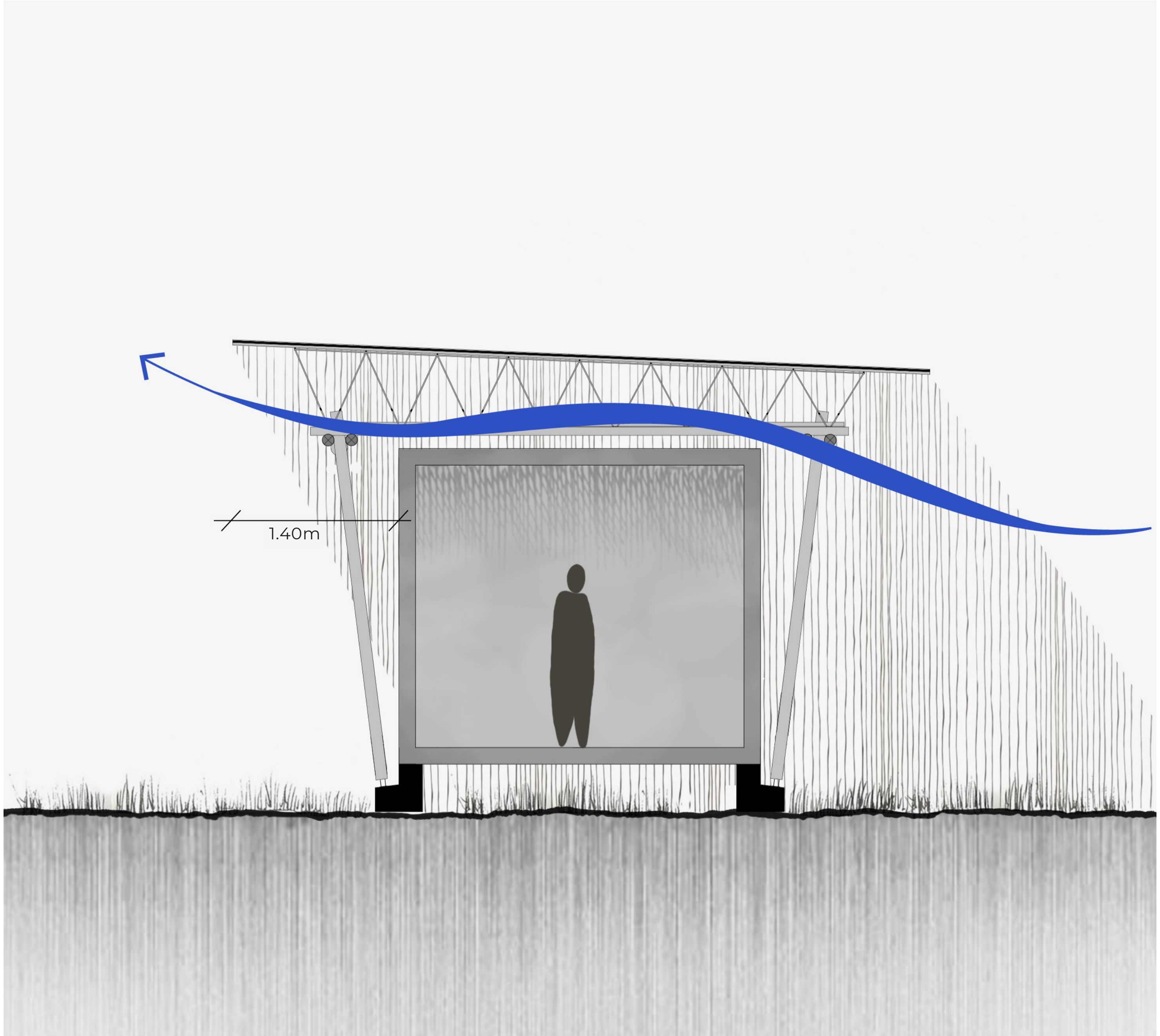


Figure 44: Roof type A

the environment. Using an insulator on the ceiling, we have a typology that works very well for hot climates with good ventilation, that is, especially for **tropical climates (A)**.

The second roof typology is a gable roof with an exhaust at the ridge. This kind of roof also provides total protection against radiation on the vertical walls facing North and South and also has a natural mechanism to remove the mass of heat that tends

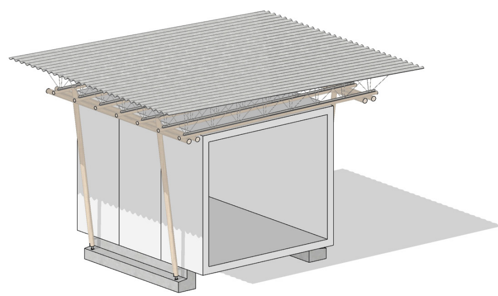


Figure 45: Isometric roof type A

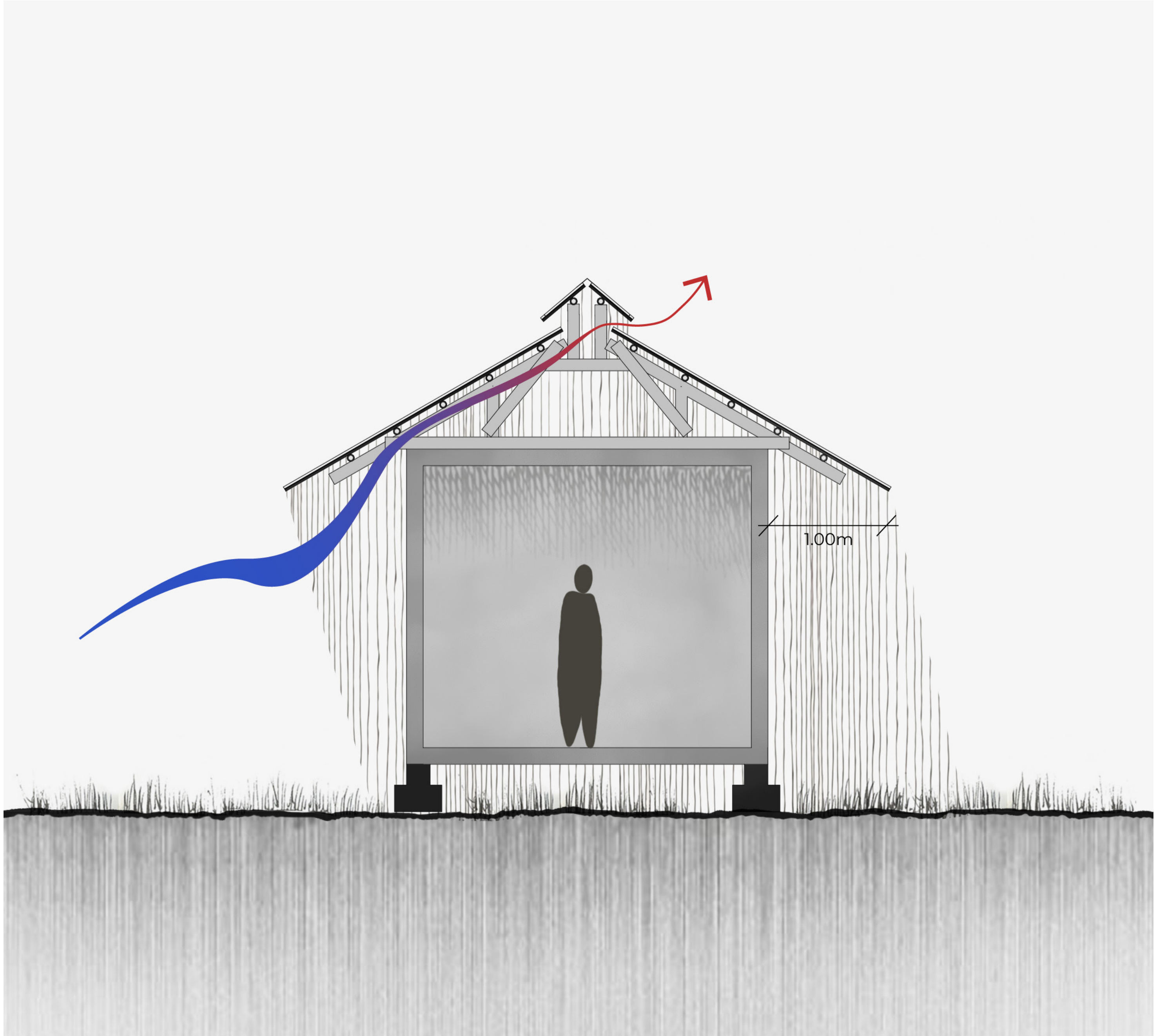


Figure 46: Roof type B

to accumulate between the roof and the ceiling. Here, natural ventilation acts indirectly, through the so-called stack effect. Due to the pressure difference, the warm air is taken out by the vented ridge of the roof and renewed by cooler air coming from the bottom to the top. This solution is more effective for hot regions without higher intensity winds, that is, especially for **dry climates (B)**.

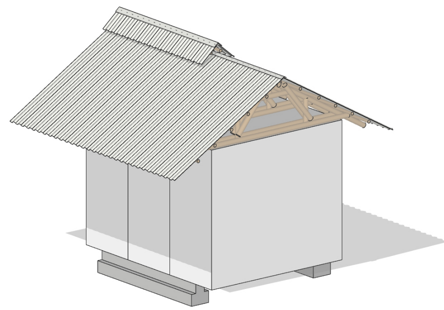


Figure 47: Isometric roof type B

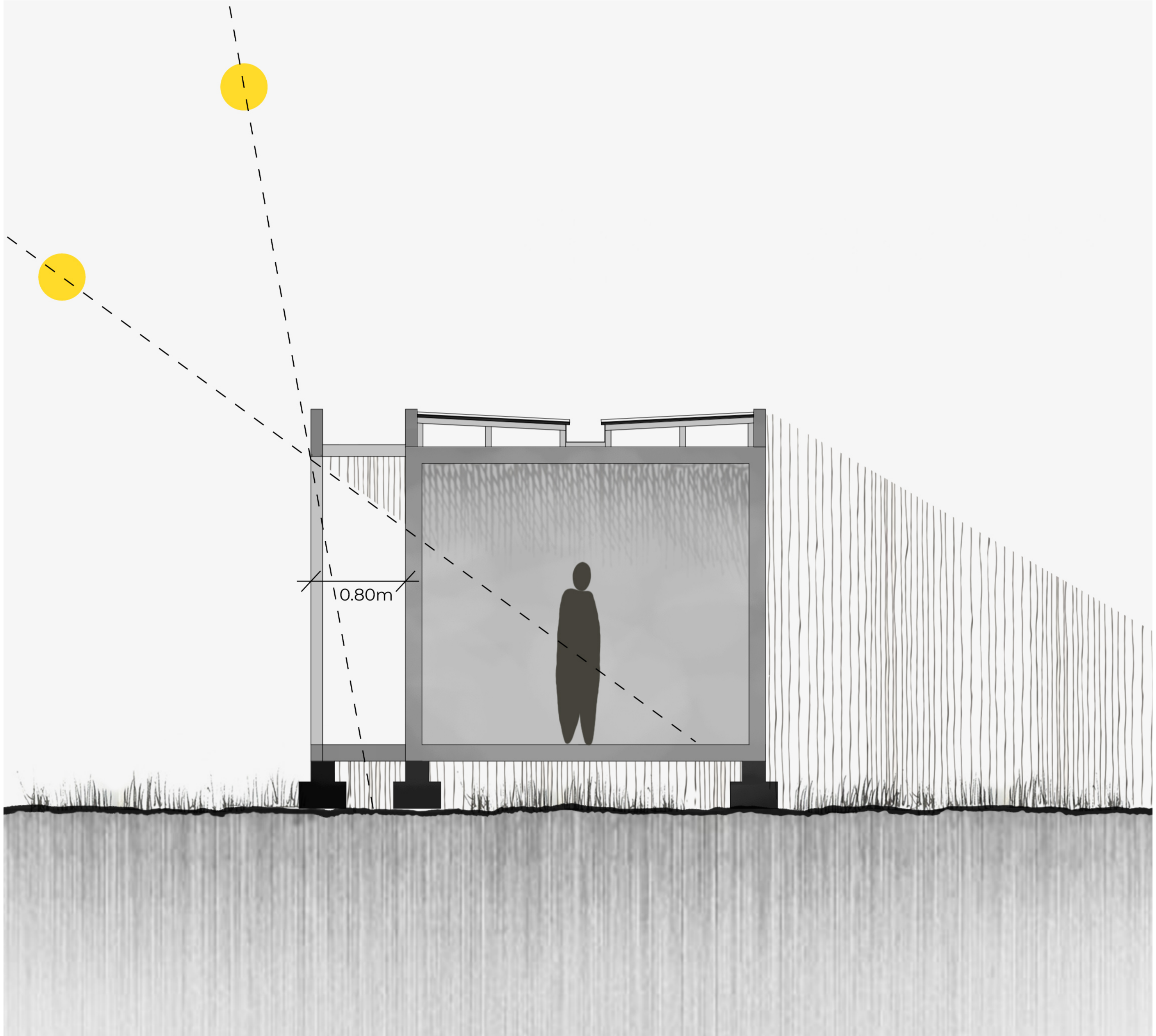


Figure 48: Roof type C

Finally, a third option presents the use of a built-in roof associated with a balcony. This solution allows for more square plants and has the function of block the sun on the north facade during the summer and allowing the radiation to reach the house during the winter, to promote passive heating. This solution works well for **humid subtropical climates (C)**.

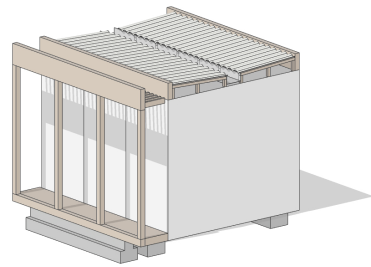


Figure 49: Isometric roof type C

5.6 Façade

As previously mentioned, the good performance of a building is closely related to the ability to integrate the different disciplines that work in the building. Therefore, if on one hand passive solutions are crucial to reduce the energy demand of a building, on the other hand correctly dimensioning the building fabric and the system are as much as important too.

The facade is the envelope of the inhabited area. It is the boundary that determines where our thermal zone is. The characteristics of the envelope material determines the intensity of the heat flow between interior and exterior, the tightness of the thermal zone, the thermal inertia and thermal bridge. One of the most important properties is the thermal transmittance (U-value). It is the physical characteristic that relate how much heat will pass through 1m2 of the enclosure.

To determine the physical properties of the envelope in order to have a good performance, we sought to find the Brazilian recommendations on the subject. Then, the RTQ-R classification, already presented in the Brazilian constructive typologies chapter, was used.

Despite being an advance for a country that does not even have such a reference table, the proposed values does not seen very restrictive. Therefore, other reference values were seek in technical literature, in addition to recommendations about the capacity to store heat (thermal inertia), time lag and more in-depth issues such as ventilated facades, reflectivity of materials to create a radiant barrier.

The tables presented below were made using the following equations:

$$U = \frac{1}{\frac{1}{h_i} + \frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2} + \cdots \frac{s_n}{\lambda_n} + \frac{1}{C} + \frac{1}{h_o}}$$

where:

U = overall heat transfer coefficient [W/m2K];

h = surface heat transfer coefficient [W/m2K];

s = thickness [m];

λ = thermal conductivity [W/m K].

$$\varphi = 0.023 \cdot s \sqrt{\frac{1}{\alpha}}$$

where:

φ = time-lag [h];

s = thickness of the element [m];

α = diffusivity of the material = λ/ρc [m2/s].

For the **climate A**, the vertical partitions should be as light as possible with minimal heat storage capacity: the diurnal temperature swing is small and for buildings occupied at night thermal mass is a disadvantage since the heat stored in the structure will contribute to discomfort by overheating the space when the occupants are sleeping. [7]

Walls should be shaded as much as possible. If, however, they are exposed to the sun, they should be built in the form of a ventilated double leaf construction, the inner leaf having a reflective surface on its outer side (or on the inner side of outer leaf). [7]

The roof should be made of lightweight materials with low thermal capacity and high reflectivity. It should be ventilated or well insulated to reduce heat gain due to solar radiation. If the roof is not insulated, a ceiling is needed and the space between the roof and the ceiling should be ventilated, to reduce thermal discomfort; it is better if the ceiling is also insulated. [7]

MATERIALS (Wall for climate A)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
OSB board	1,8	0,13	600	1450	**0,53**	**4,7**
XPS insulating panel	5,0	0,04	40	1450		
OSB board	1,8	0,13	600	1450		
Diffusion-open film	-	-	-	-		
Ventilated gap	6,0	-	-	-		
Aluminium foil	-	-	-	-		
Marine plywood	1,8	0,13	600	1450		

MATERIALS (Roof for climate A)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
OSB board	1,8	0,13	600	1450	**0,53**	**3,6**
XPS insulating panel	5,0	0,04	40	1450		
OSB board	1,8	0,13	600	1450		

MATERIALS (Floor for climate A)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
Double OSB board	3,6	0,13	600	1450	**2,24**	**2,1**

Tabela 07, 08 e 09: Strategraphy of wall, roof and floor for climate A

For **climate B**, Walls with a time lag of 11-12 hours are excellent for dayrooms, provided that the rooms are adequately ventilated at night. To improve comfort during the night, bedroom walls should be lightweight. [7]

Roof should be made of heavyweight materials with high reflectivity. They should be ventilated. Alternatively, if the roof is lightweight, the ceiling should be heavyweight, and the attic ventilated. [7]

MATERIALS (Wall for bedrooms in climate B)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
OSB board	1,8	0,13	600	1450	**0,53**	**4,7**
XPS insulating panel	5,0	0,04	40	1450		
OSB board	1,8	0,13	600	1450		
Diffusion-open film	-	-	-	-		
Ventilated gap	6,0	-	-	-		
Marine plywood	1,8	0,13	600	1450		

MATERIALS (Wall for living in climate B)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
OSB board	1,8	0,13	600	1450	**0,39**	**10,4**
High-density wood fiber insulation	10,0	0,05	220	2100		
OSB board	1,8	0,13	600	1450		
Diffusion-open film	-	-	-	-		
Ventilated gap	6,0	-	-	-		
Marine plywood	1,8	0,13	600	1450		

MATERIALS (Roof for climate B)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
OSB board	1,8	0,13	600	1450	**0,47**	**7,9**
High-density wood fiber insulation	8,0	0,05	220	2100		
OSB board	1,8	0,13	600	1450		

MATERIALS (Floor for climate B)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
Double OSB board	3,6	0,13	600	1450	**0,52**	**4,1**
Rock wool insulation	5,0	0,03	100	1030		

Tabela 10, 11, 12 e 13: Strategraphy of wall, roof and floor for climate B

For **climate C**, medium-weight walls, floors and ceilings are recommended for the best exploitation of passive solar gains. [7]

Roofs can be light or heavy but they must have a good insulation value. Ventilation of roof cavities or the underside of ceilings may not be necessary. [7]

As for the openings, for hot climates (A and B) movable wooden louvres will be used, since glass are expensive elements and would not bring advantages for thermal comfort. For climate C, it is necessary to use glass windows to allow the entry of radiation during the winter. In this case, a double low-e glass would be the best option, but remembering that it is an expensive and unusual component in the Brazilian context.

MATERIALS (Wall for climate C)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
OSB board	1,8	0,13	600	1450	**0,39**	**10,4**
High-density wood fiber insulation	10,0	0,05	220	2100		
OSB board	1,8	0,13	600	1450		
Diffusion-open film	-	-	-	-		
Ventilated gap	6,0	-	-	-		
Marine plywood	0,0	0,00	0	0		

MATERIALS (Roof for climate C)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
OSB board	1,8	0,13	600	1450	**0,37**	**5,3**
High-density rock wool insulation	8,0	0,04	100	1030		
OSB board	1,8	0,13	600	1450		

MATERIALS (Floor for climate C)	**THICKNESS** (cm)	**THERMAL CONDUCTIVITY** (W/mK)	**DENSITY** (kg/m³)	**HEAT CAPACITY** (J/kgK)	**THERMAL TRANSMITTANCE** (W/m²K)	**TIME LAG** (h)
Double OSB board	3,6	0,13	600	1450	**0,52**	**4,1**
Rock wool insulation	5,0	0,03	100	1030		

Tabela 14,15 e 16: Strategraphy of wall, roof and floor for climate C

6. THE IMPLANTATION PROJECT

After developing a design methodology, the next step will be to unravel how the construction process of these buildings will be. Both stages are very important for a standardized project, which seeks its architectural value both in design and in the logistic/construction process.

This stage consists of the parts of manufacturing the modules, transport, assembly, in loco work and services and renewables. All these processes will be described and detailed for this study case, as it is a proposal with much more than one single final result, a final output house will be used as a way of summarizing and illustrating the process.

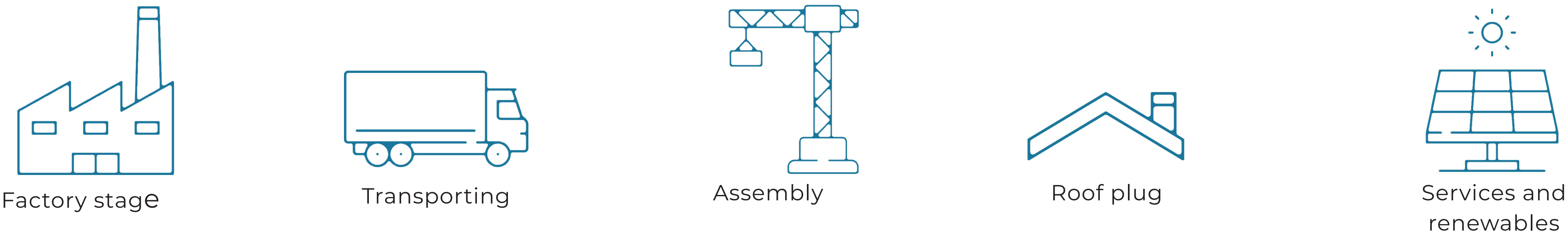
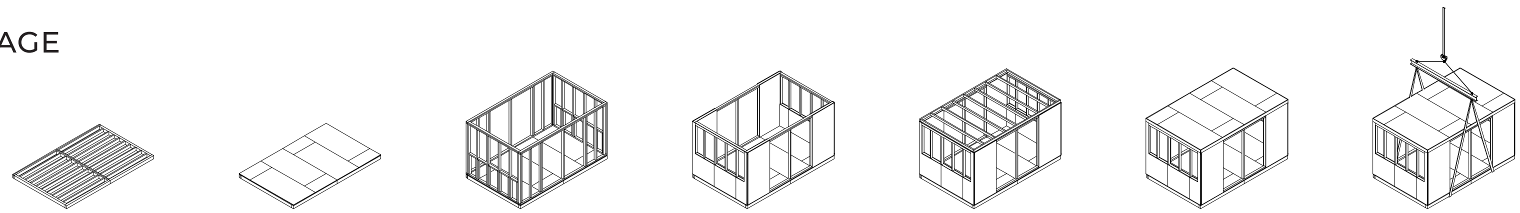


Figure 50: Render of the linear plan with roof type A

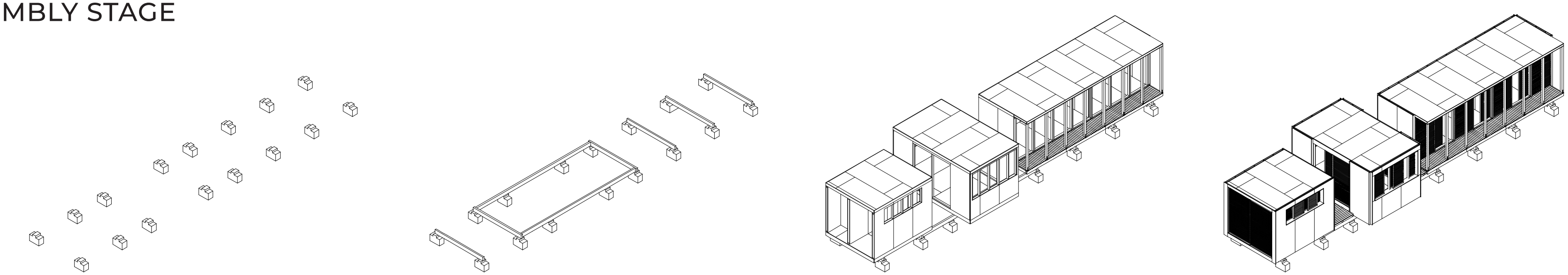
Figure 51: Render of the linear plan with roof type A

Figure 52: Render of the linear plan with roof type A

FACTORY STAGE



ASSEMBLY STAGE



IN LOCO STAGE

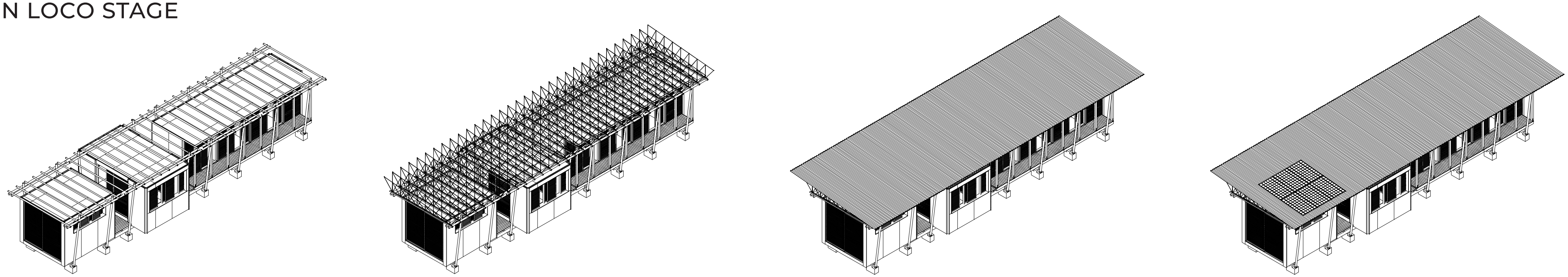


Figure 53: Construction steps

6.1 Factory stage

This is the process of taking the manufacturing products to create fabricated elements for buildings, in this case the modules. The key feature that defines fabrication from the other processes of manufacturing is the concept of fastening. “Joining,” or bringing two or more manufactured pieces together. [14] And this is the main focus of this project stage. Design and detail how the walls, floor and roof/ceiling are done and connected for be transportable later.

The work proposes that the modules be transported assembled, to reduce in loco work. This logistics requires that the following works take place on shop: Assembly of the frames; OSB board fastening; location of electrical and hydraulic infrastructure; installation of insulating wool; dry closing of walls, floors and ceilings; crockery installation; fastening of the waterproofing membrane and installation of the frames.

The first work to be done is the assembly of the wall, floor and ceiling structures. These structures are of the wood frame type which are composed of vertical columns or posts and horizontal spanning elements such as beams or girders. Frames are inherently gravity loadbearing, but rake under later loads due to wind, seismic, or other dynamic loads such as disproportionate live loading. Therefore, frames require some type of lateral load-resisting system, the bracing. To guarantee the resistance to support these loads, it is used the OSB board, which are fixed with nails or screws in the frames. The fixing of the OSB board is fundamental from the factory because the lifting of the frame and modules generates shear forces in the structure, which are resisted without damage thanks to the bracing. These components are manufactured inside the factory to be joined together to form the modules.

Later on, it is necessary to locate the hydraulic and electrical parts, since these modules will be taken assembled to the site. This net that runs through the entire structure must be connected to power generators (grid or photovoltaic panels), water supply (grid or local resource) and disposal of dirty water. That is, they are nets that have a local input or a local sink to work. Therefore, this pipework is installed at the factory and goes on-site with connections that will be finished in loco.

Finally, the installation of the insulators, the closing and finishing of the walls and the installation of the waterproof blanket are also made in the factory.

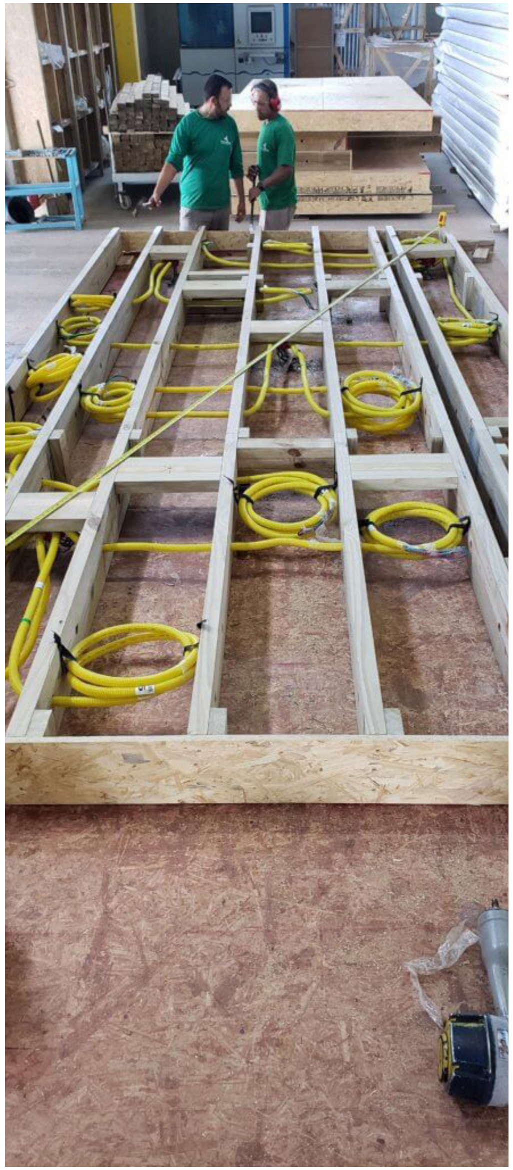
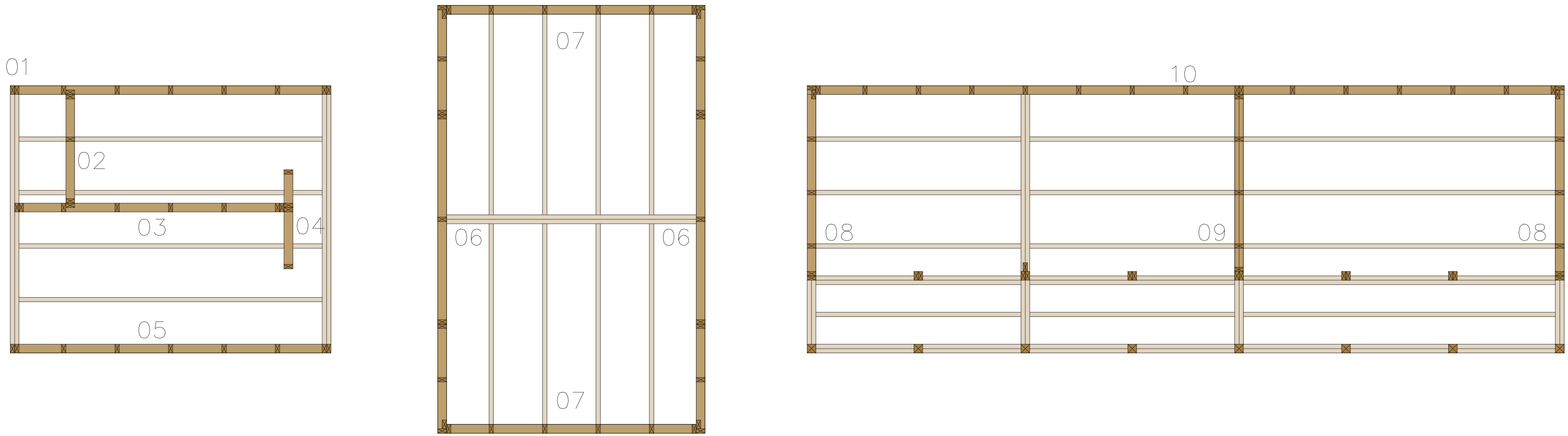


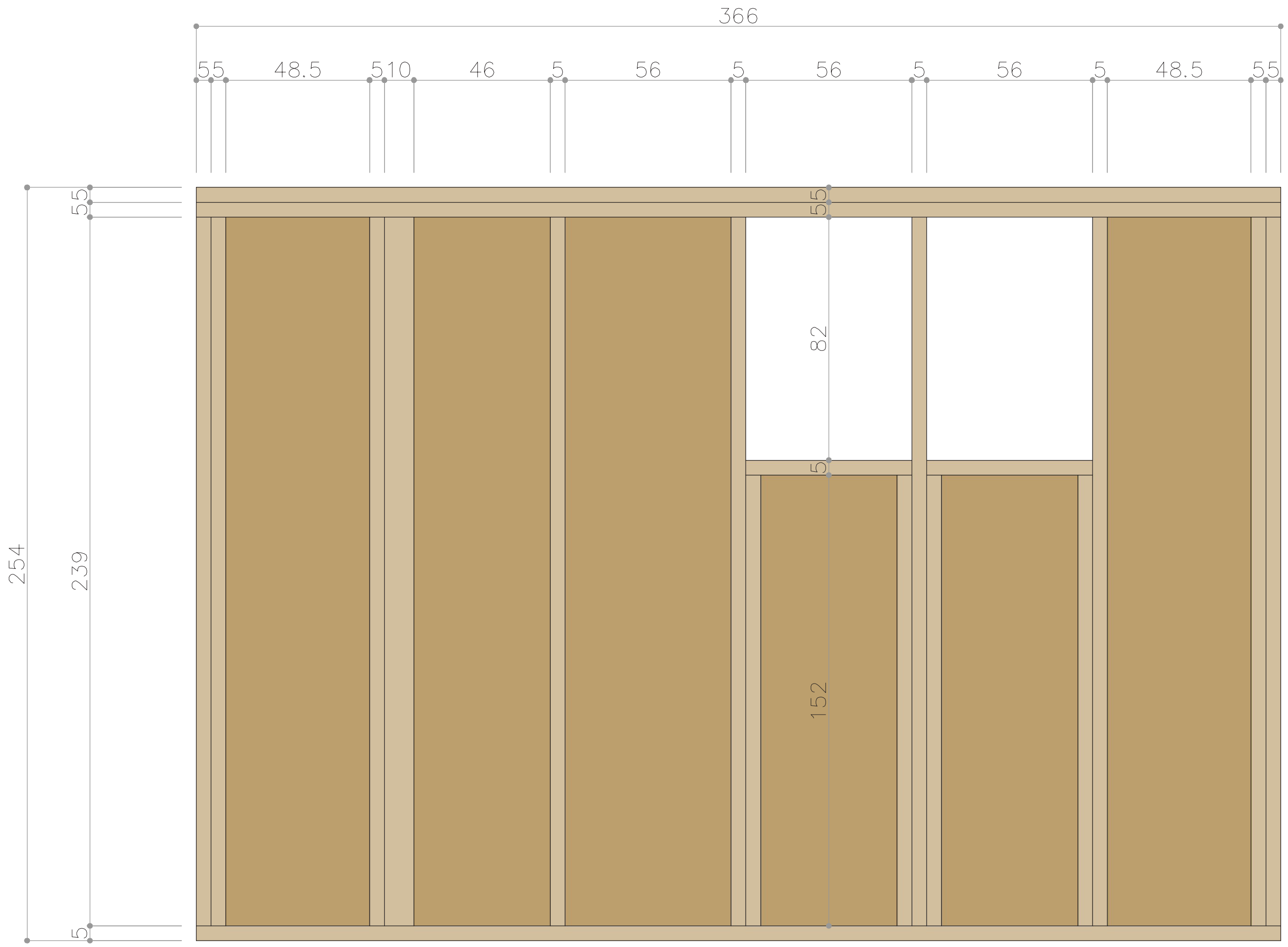
Figure 54: Wood frame fixing; figure 55: OSB board fixing; Figure 56: Instalations and pipe work; Figure 57: Placing the isolation; Figure 58: Transport

Drawing 09: Structural plan

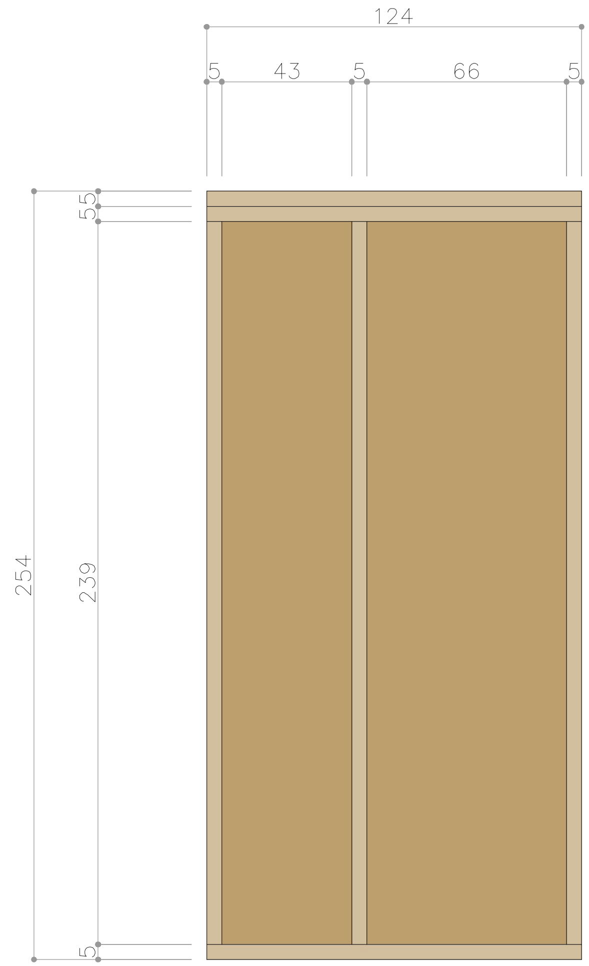


STRUCTURAL PLAN
SCALE 1:75

Drawing 10: Wall frame 01
Drawing 11: Wall frame 02

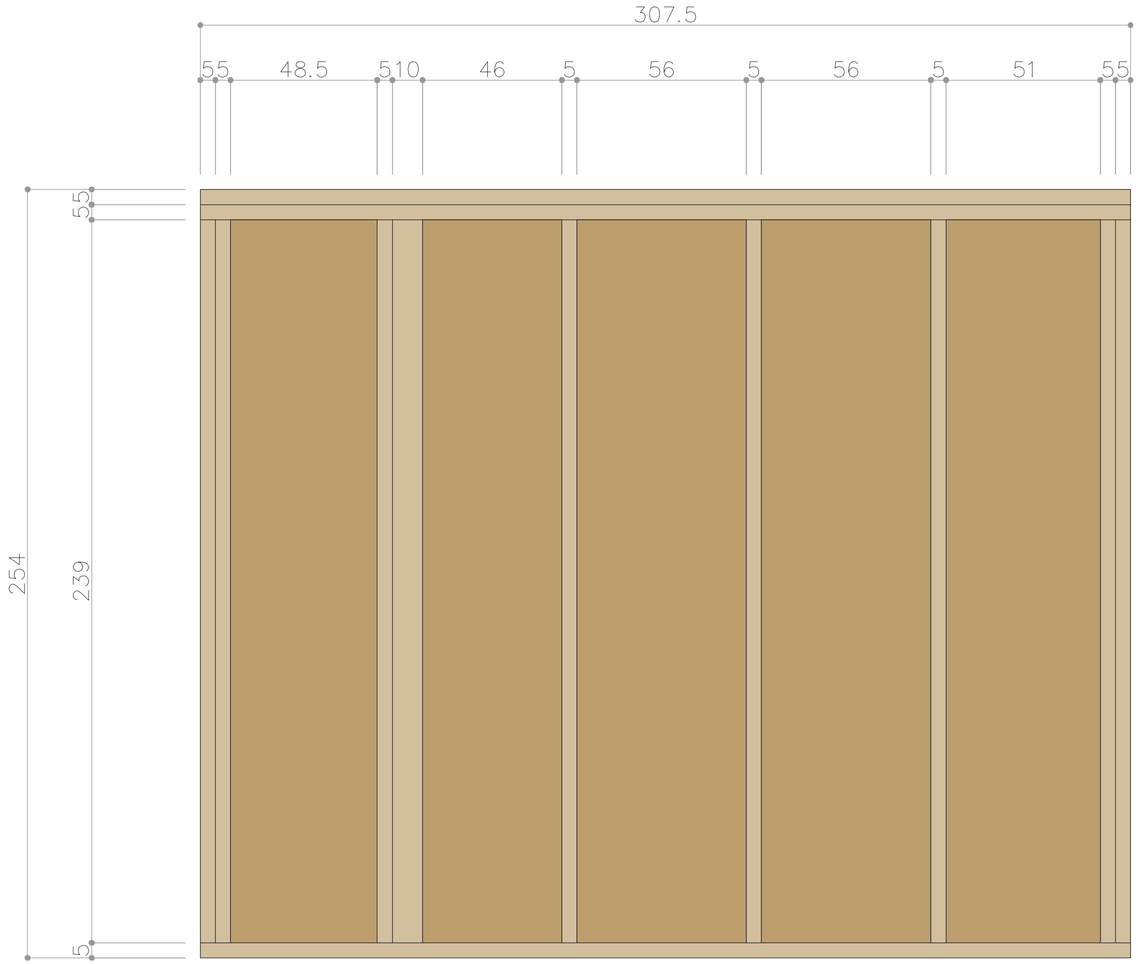


WALL FRAME 01
SCALE 1:50

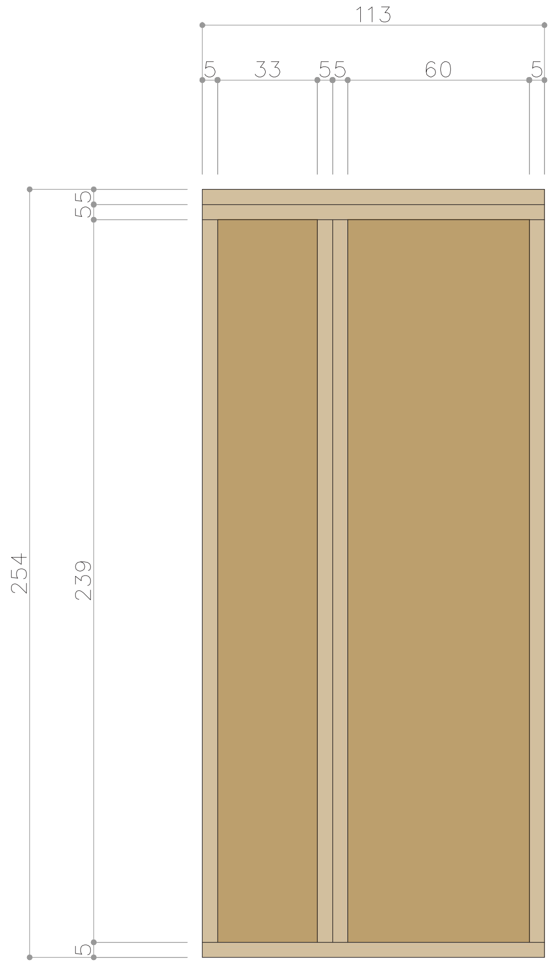


WALL FRAME 02
SCALE 1:50

Drawing 12: Wall frame 03
Drawing 13: Wall frame 04

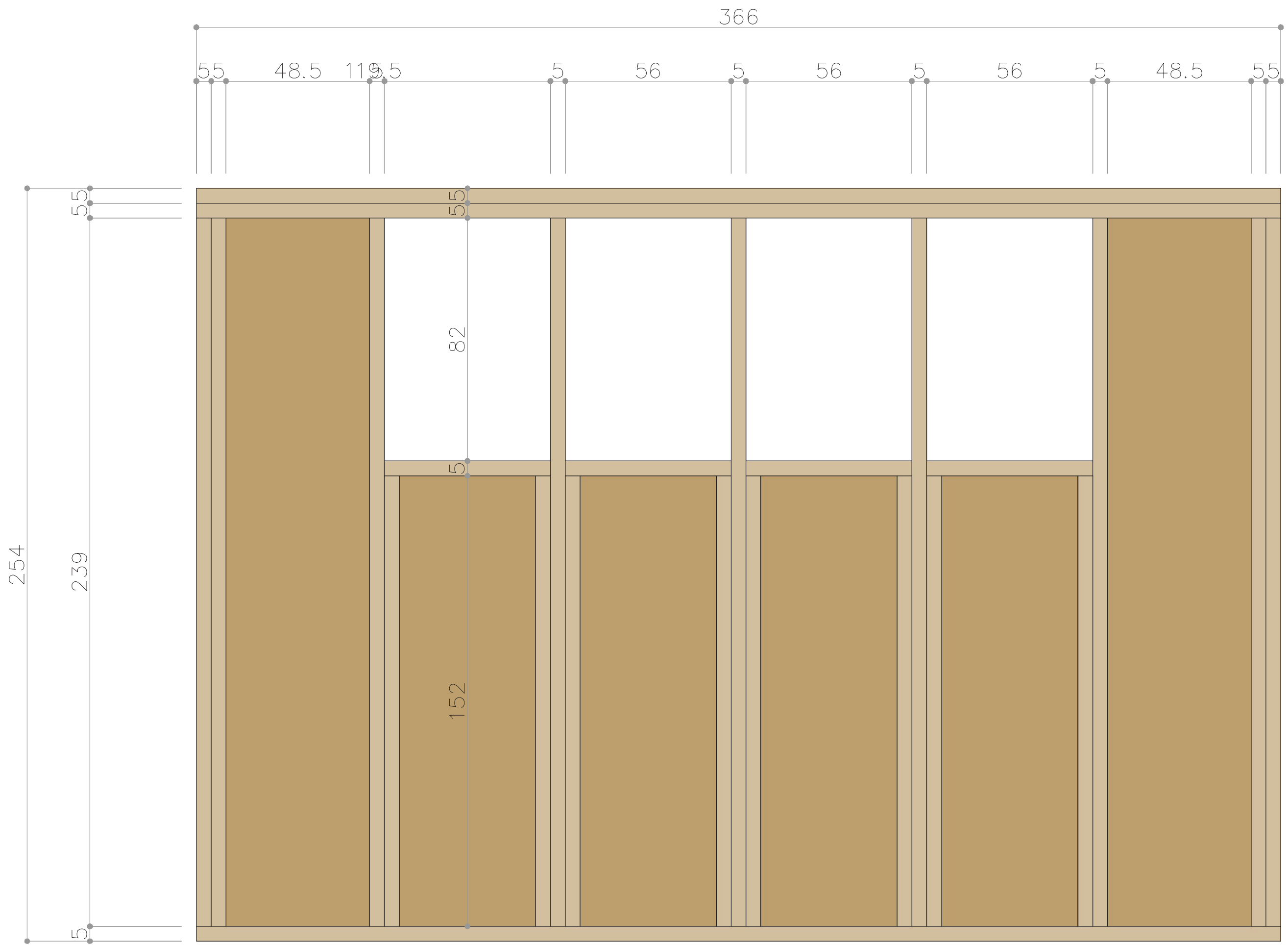


WALL FRAME 03
SCALE 1:50



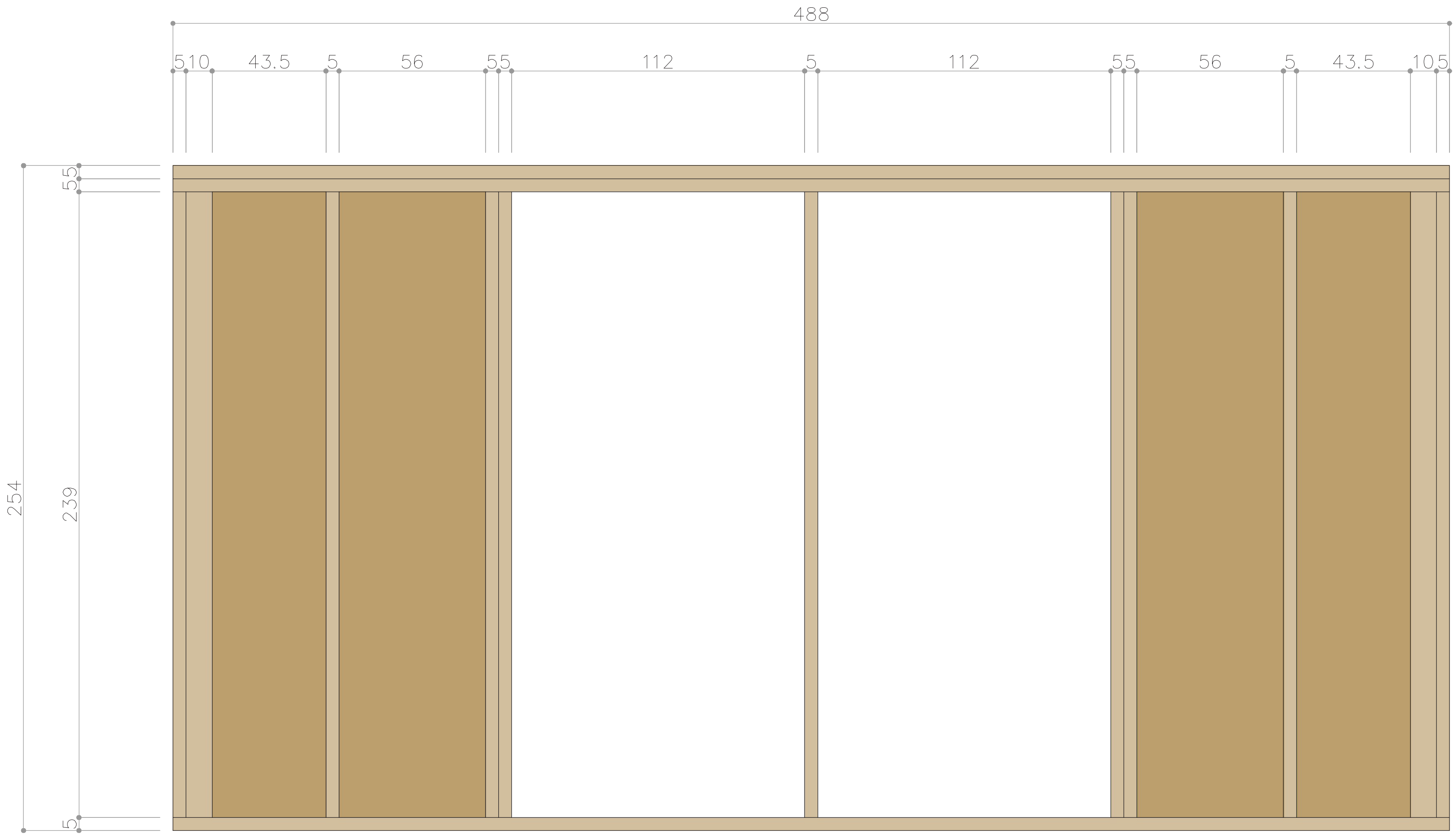
WALL FRAME 04
SCALE 1:50

Drawing 14: Wall frame 05



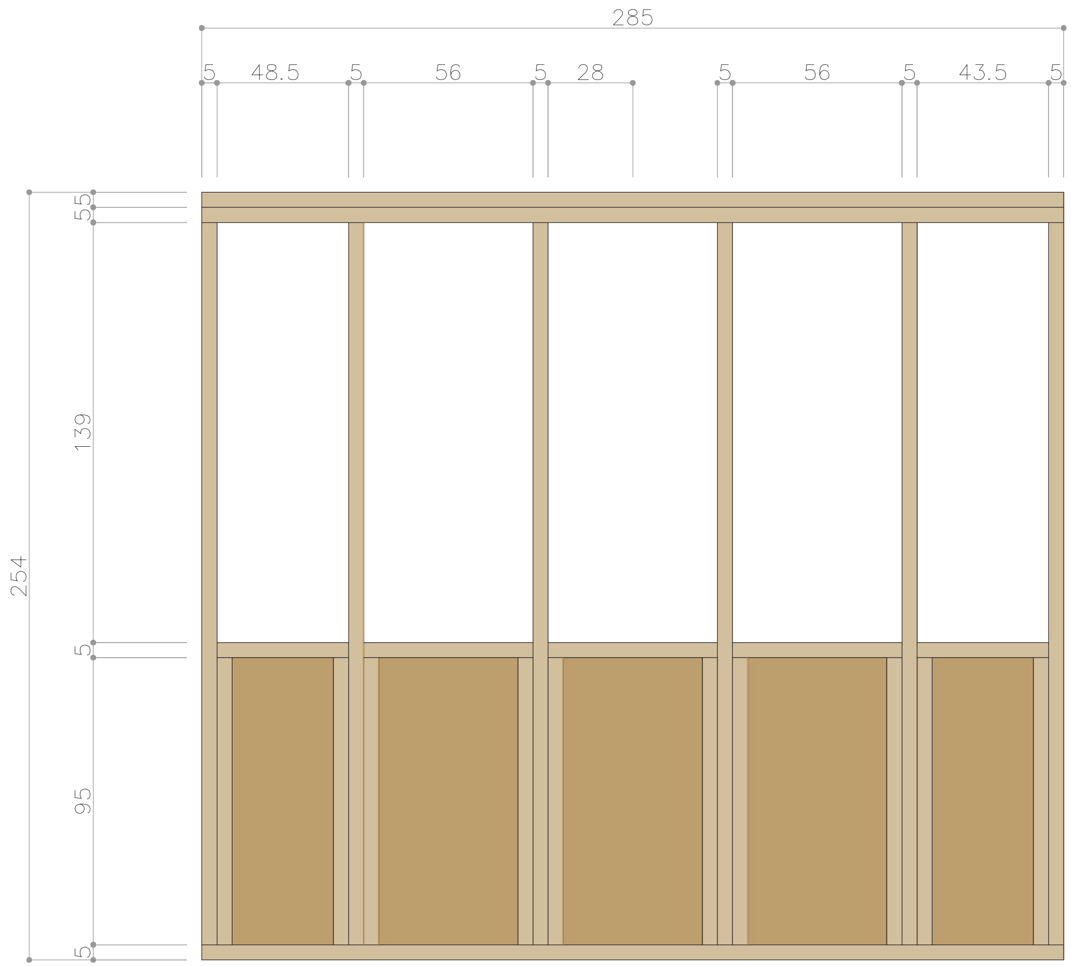
WALL FRAME 05
SCALE 1:50

Drawing 15: Wall frame 06



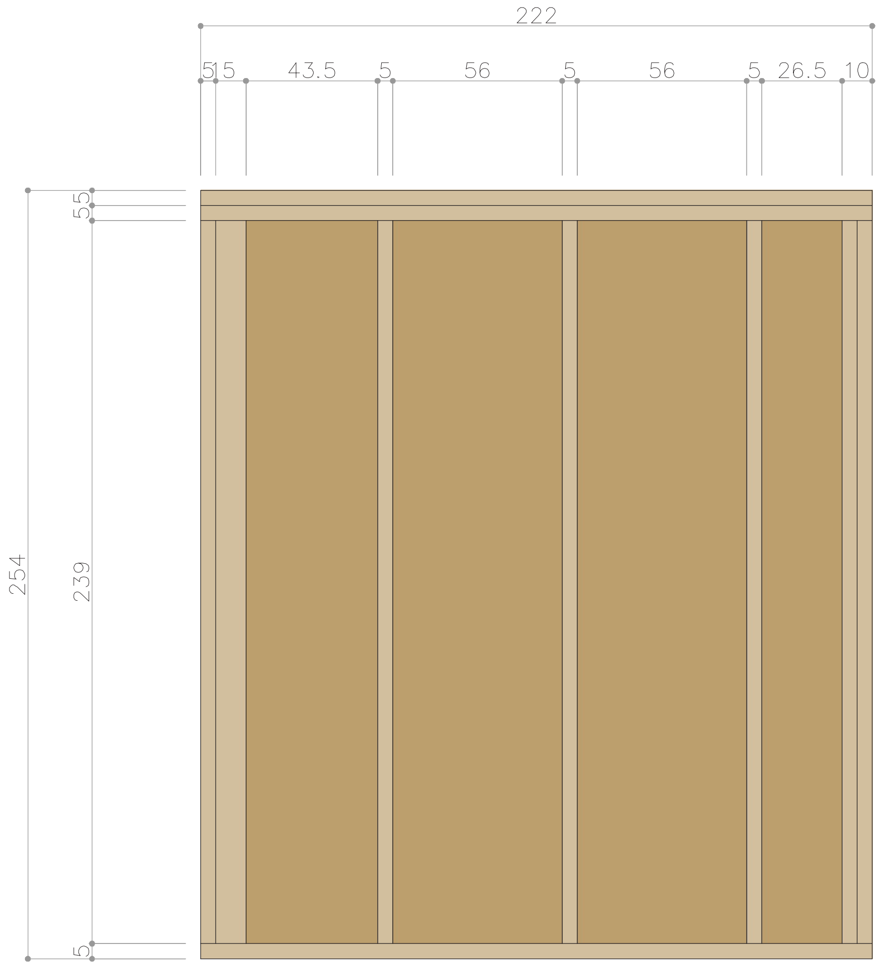
WALL FRAME 06
SCALE 1:50

Drawing 16: Wall frame 07

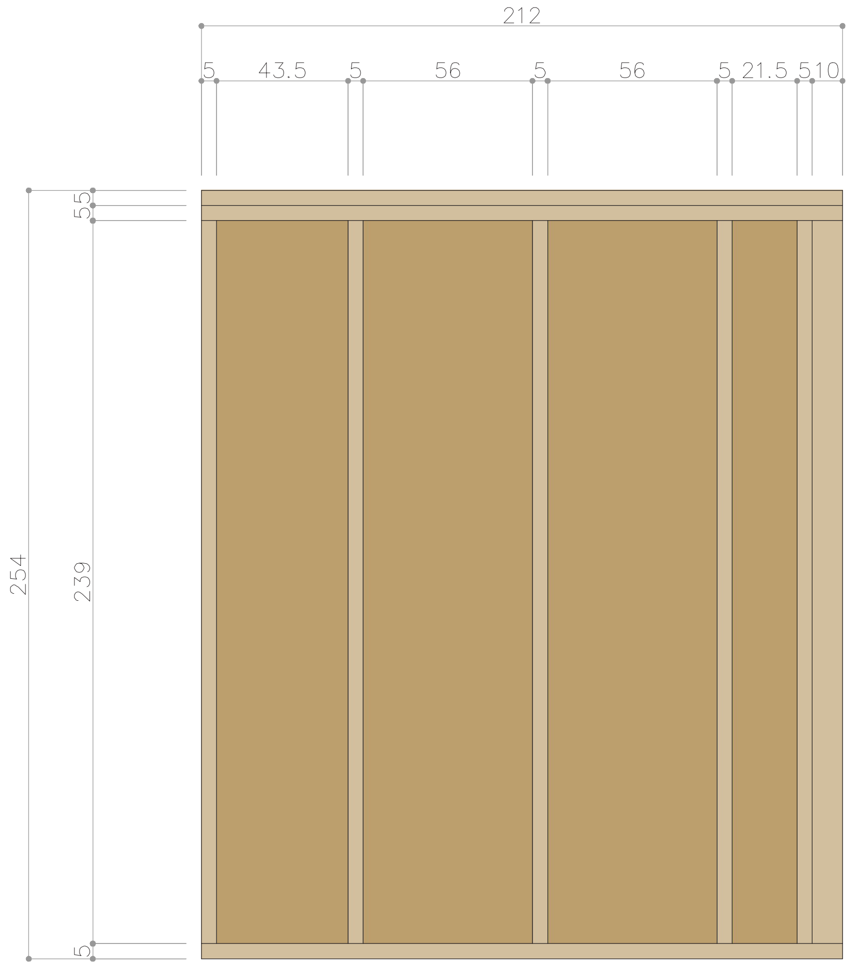


WALL FRAME 07
SCALE 1:50

Drawing 17: Wall frame 08
Drawing 18: Wall frame 09

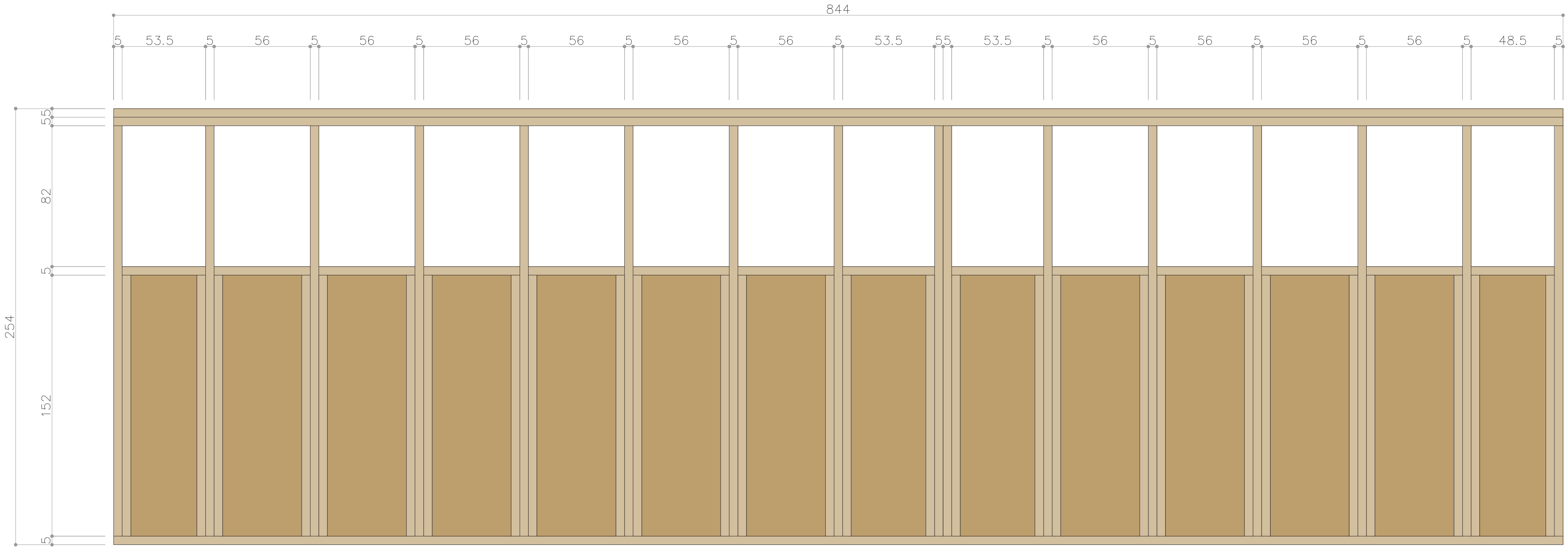


WALL FRAME 08
SCALE 1:50



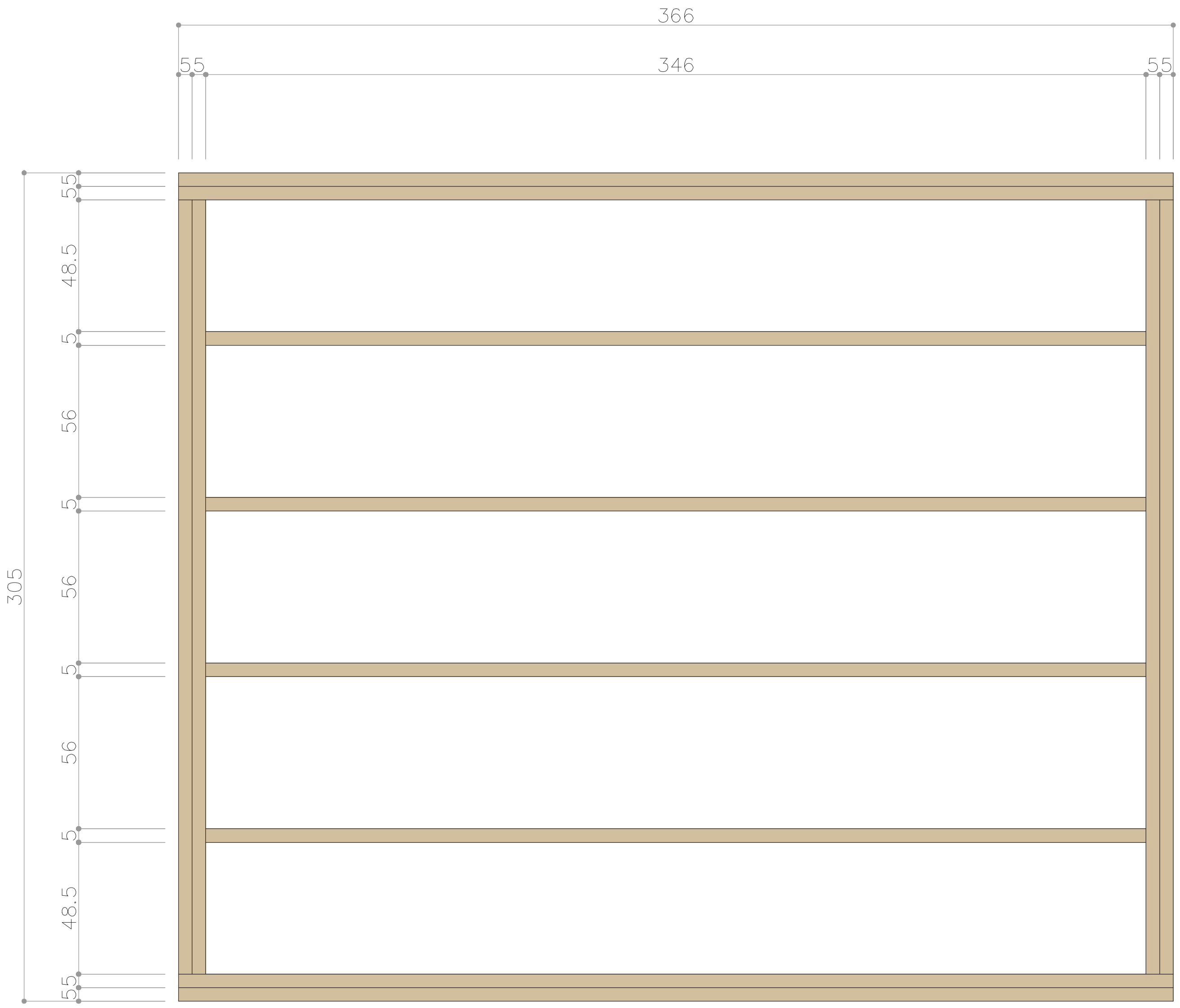
WALL FRAME 09
SCALE 1:50

Drawing 19: Wall frame 10



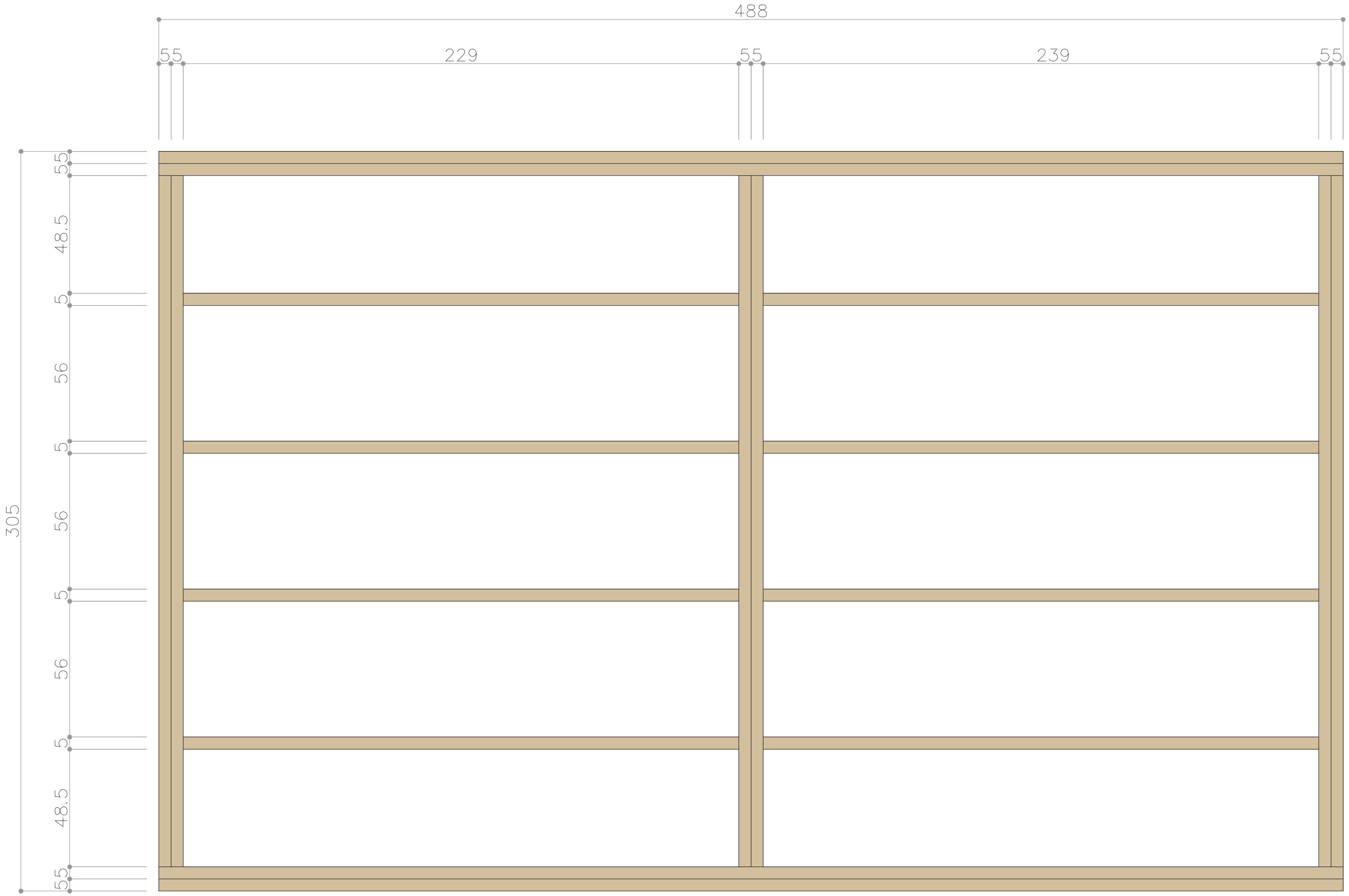
WALL FRAME 10
SCALE 1:75

Drawing 20: floor frame 01



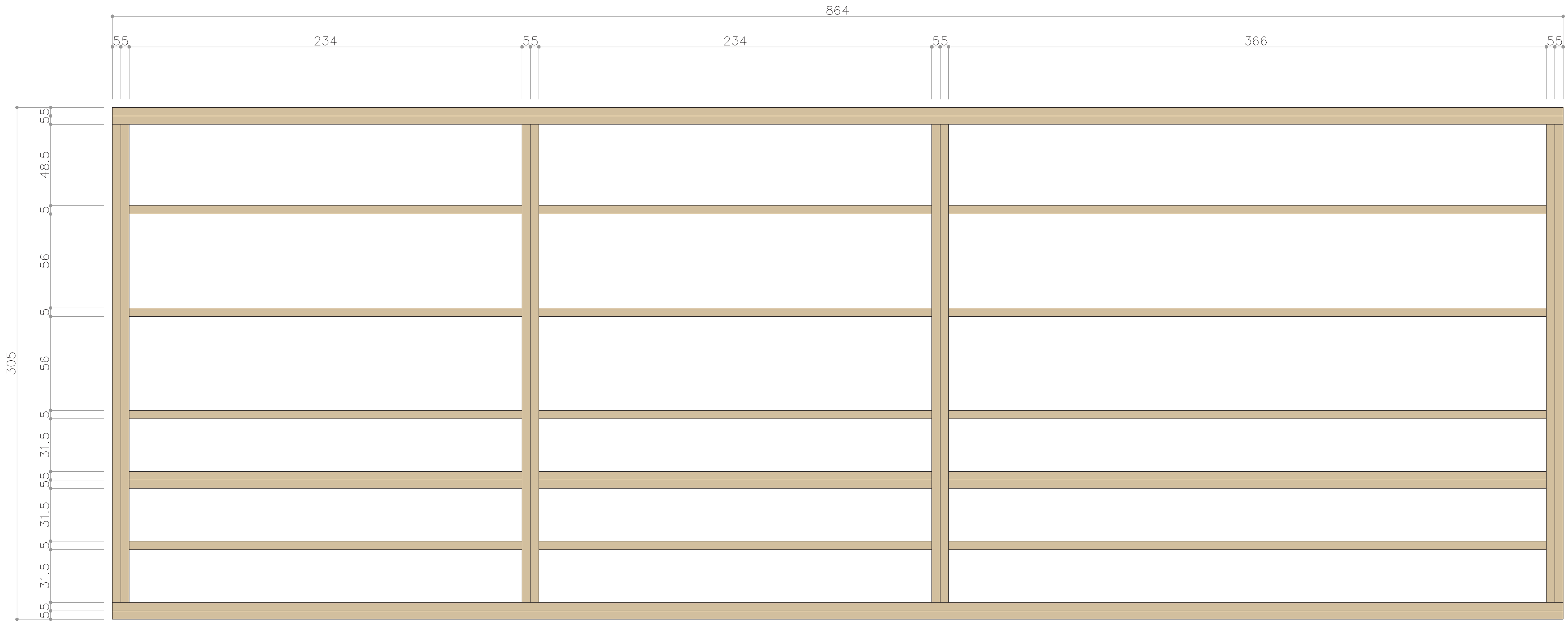
FLOOR FRAME WET MODULE
SCALE 1:50

Drawing 21: floor frame 02



FLOOR FRAME SOCIAL MODULE
SCALE 1:50

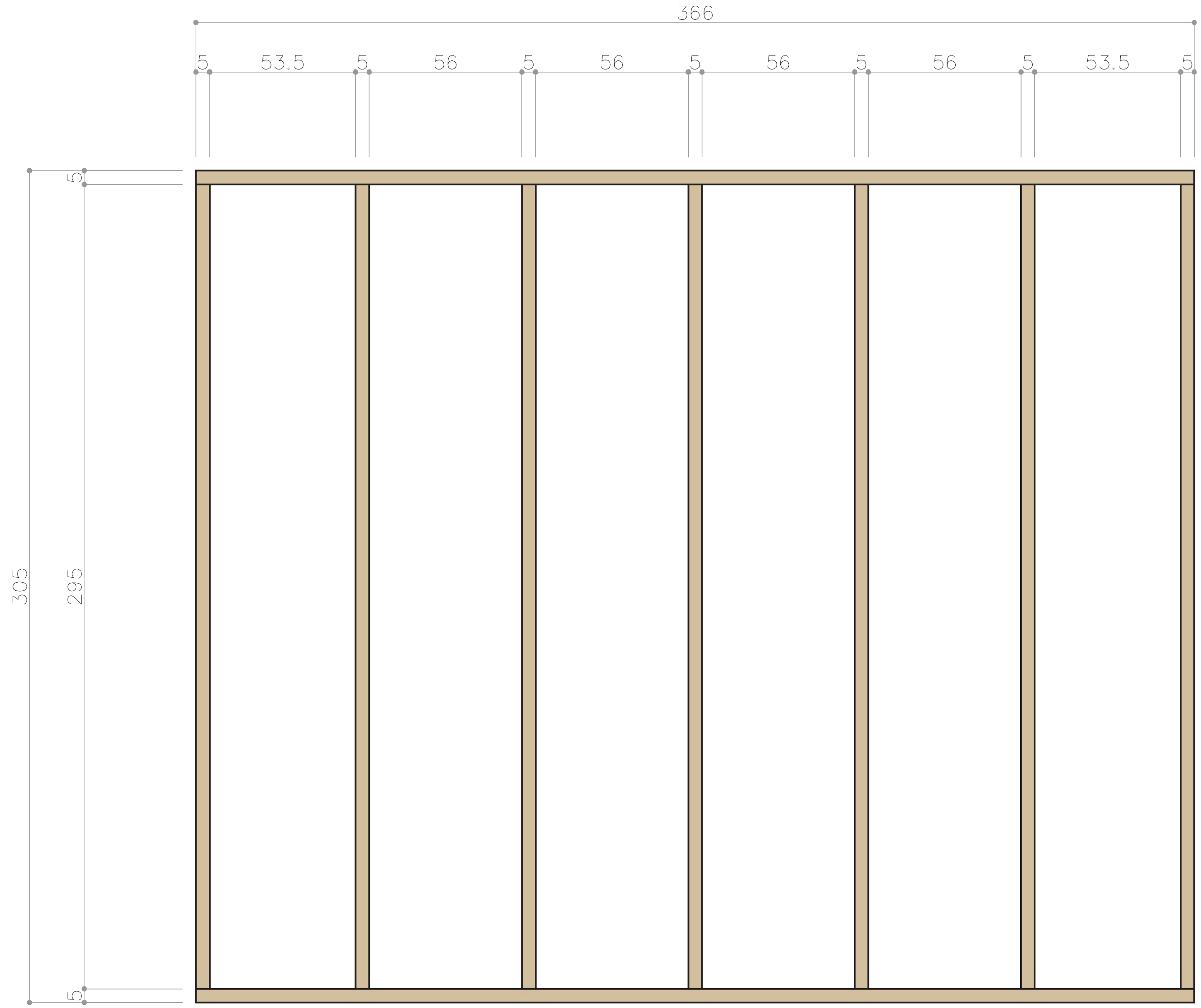
Drawing 22: floor frame 03



FLOOR FRAME BEDROOMS MODULE

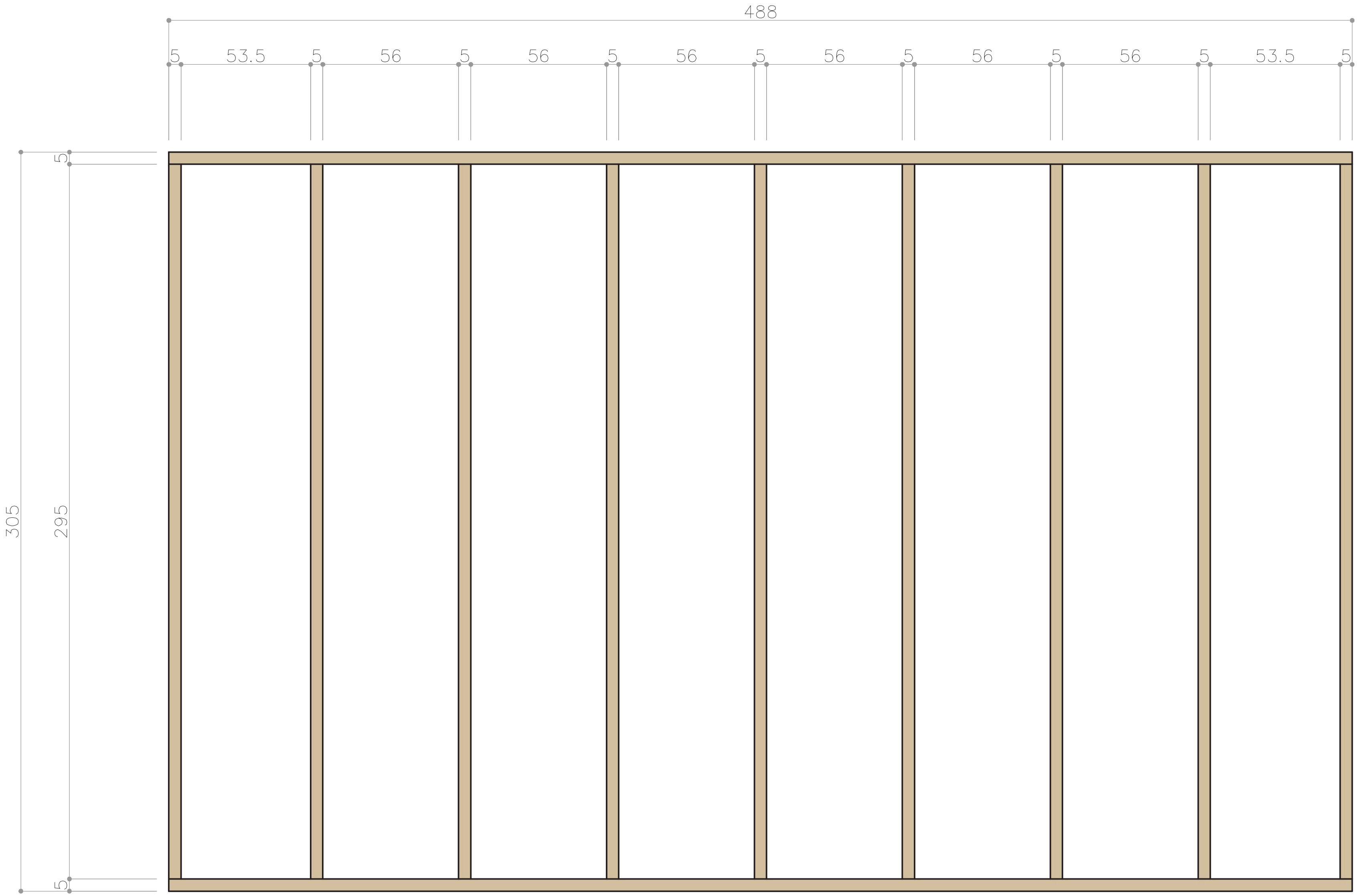
SCALE 1:75

Drawing 23: Ceiling frame 01



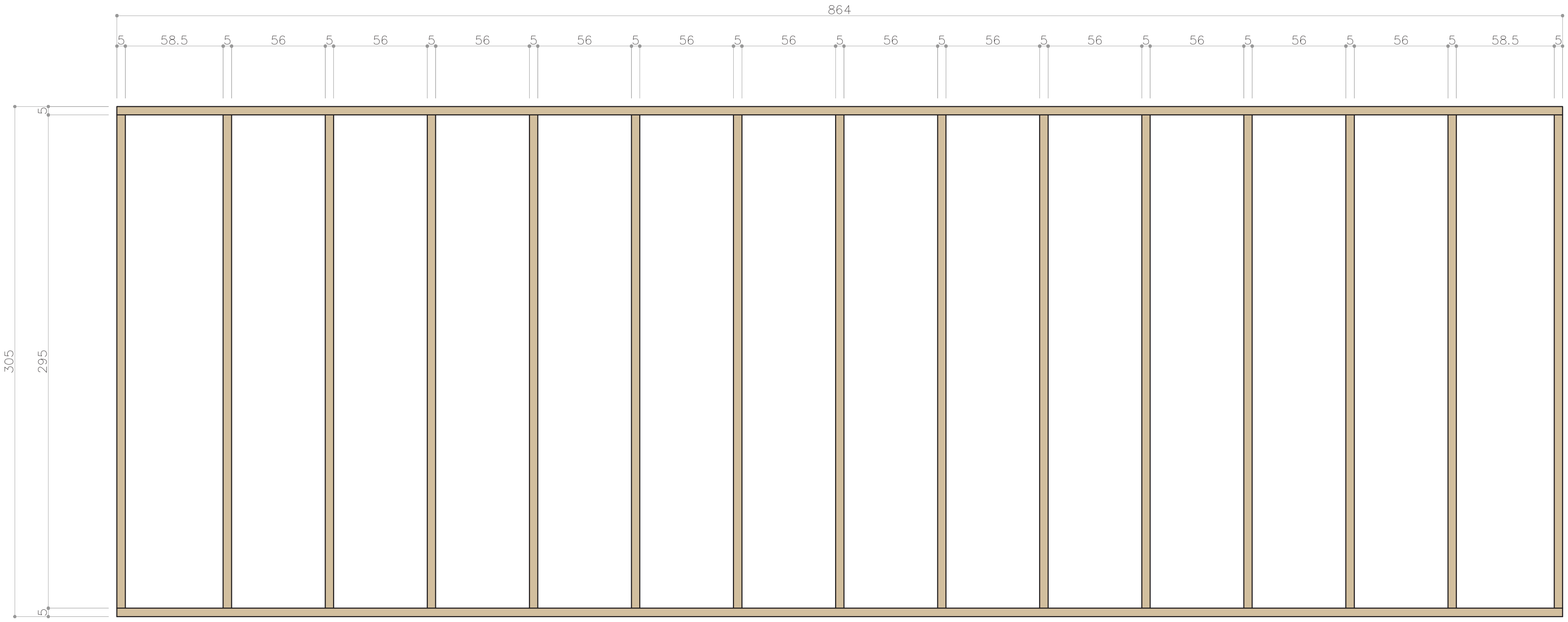
CEILING FRAME WET MODULE
SCALE 1:50

Drawing 24: Ceiling frame 02



CEILING FRAME SOCIAL MODULE
SCALE 1:50

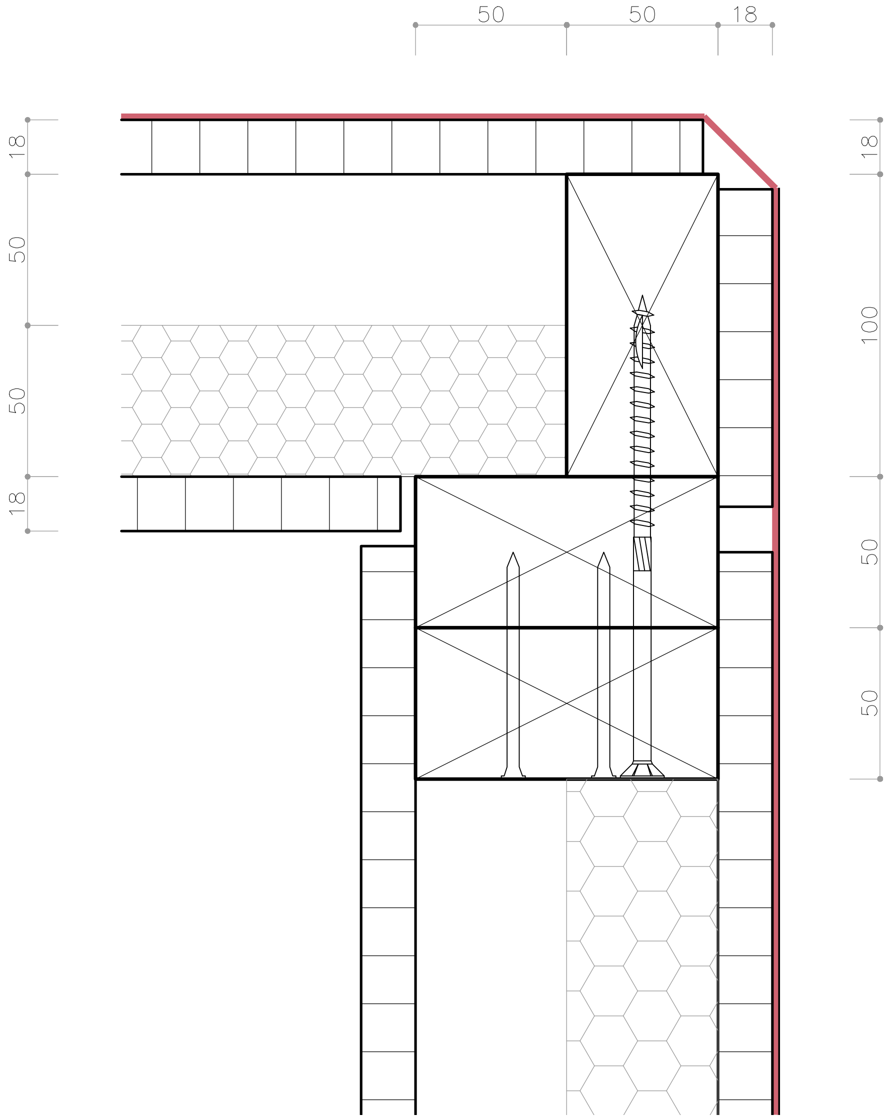
Drawing 25: Ceiling frame 03



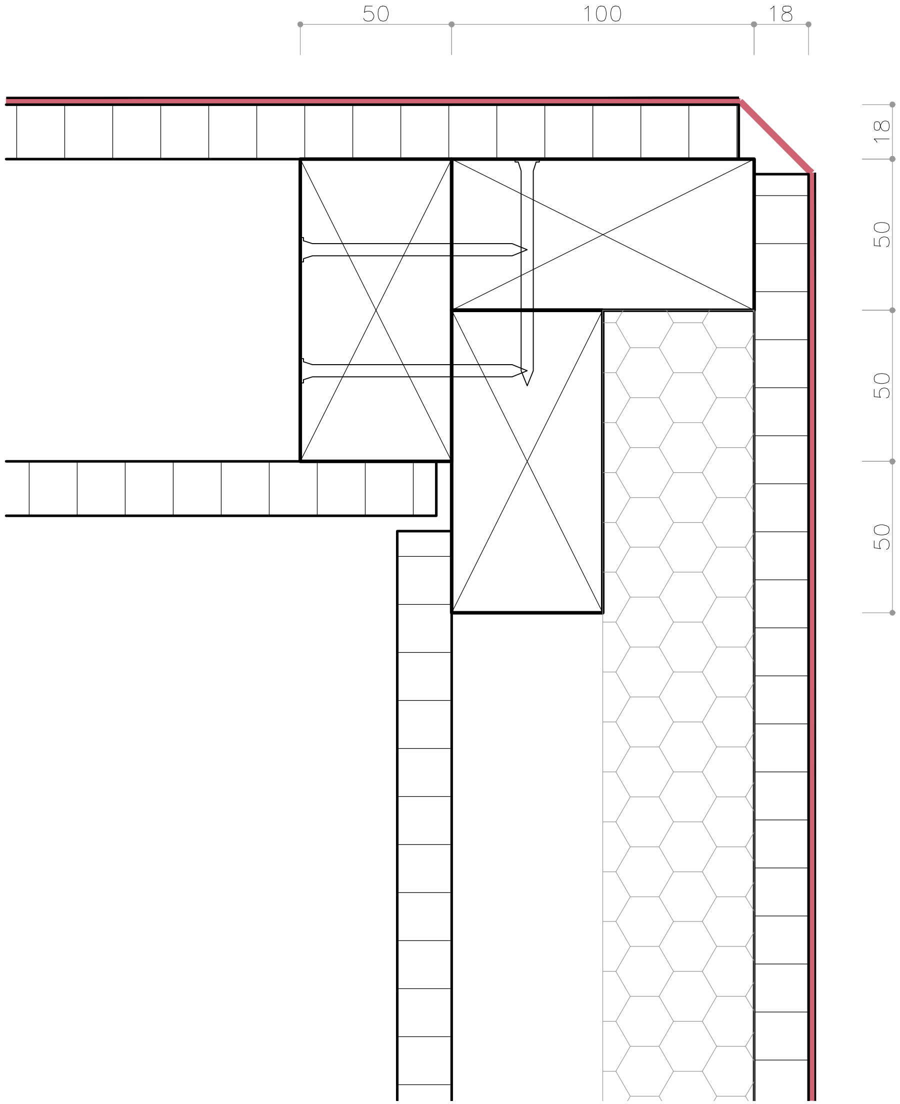
CEILING FRAME BEDROOM MODULE

SCALE 1:75

Drawing 26: Ceiling-wall connection
Drawing 27: Wall-wall connection

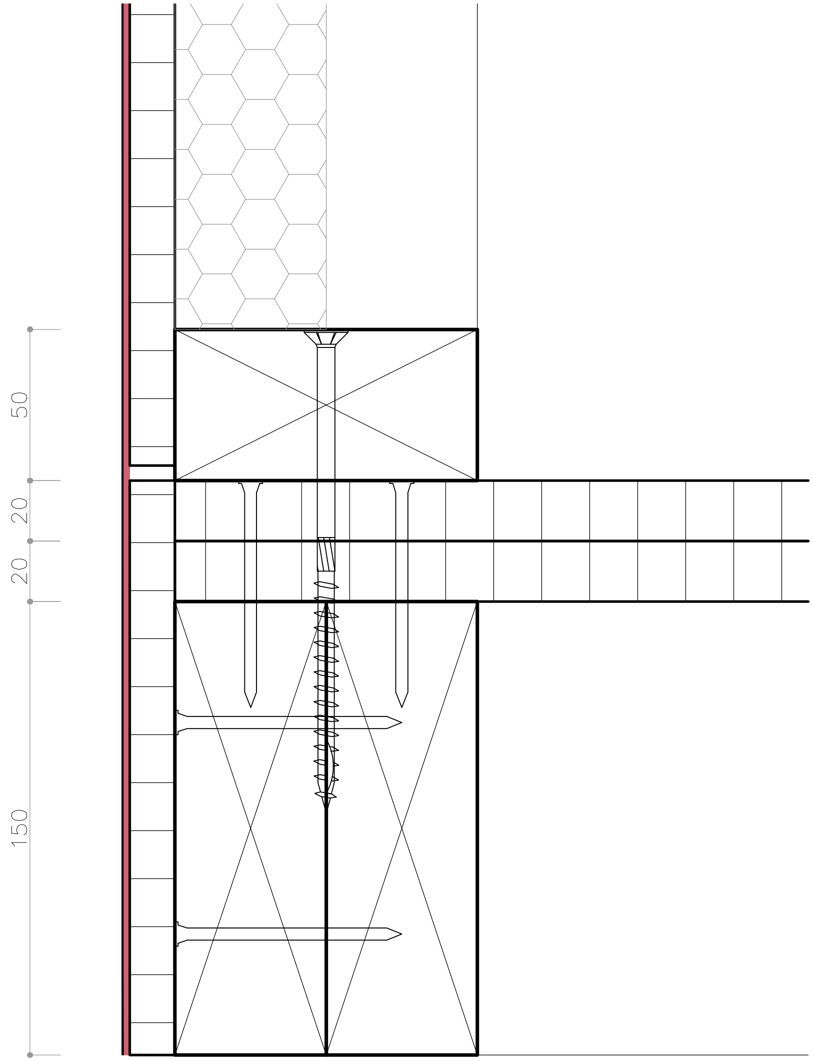


CEILING-WALL CONNECTION
SCALE 1:2.5

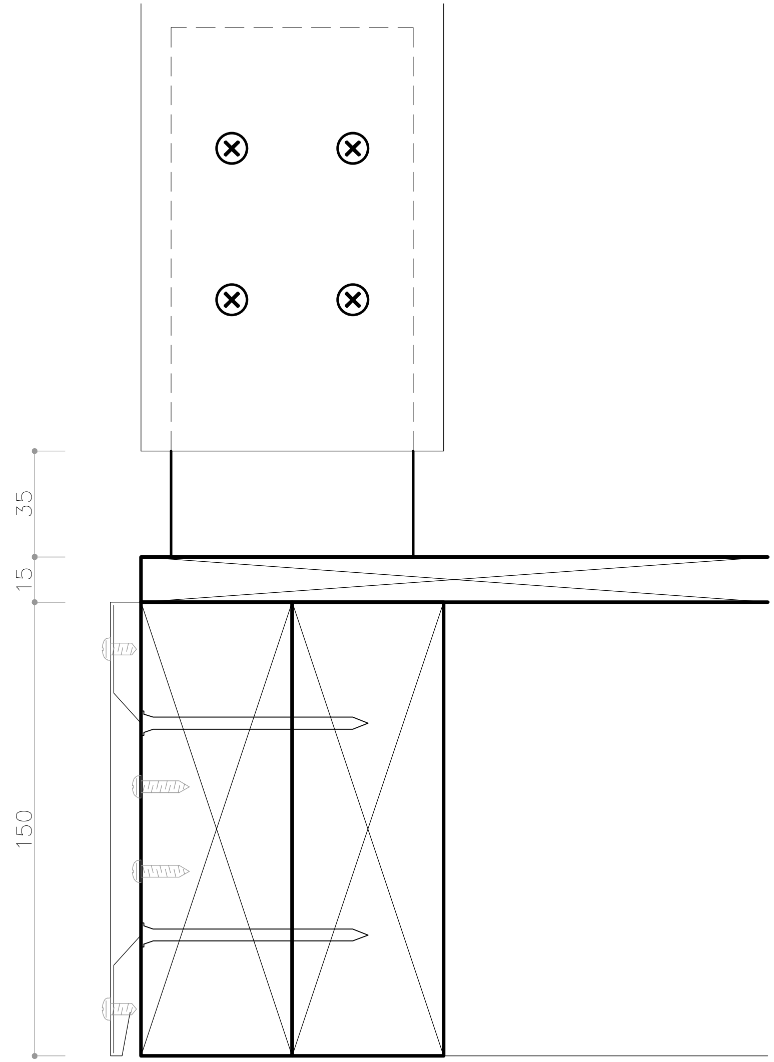


WALL-WALL CONNECTION
SCALE 1:2.5

Drawing 28: Floor-wall connection
Drawing 29: Colimn detail



FLOOR-WALL CONNECTION
SCALE 1:2.5



COLUMN DETAIL
SCALE 1:2.5

6.2 Transport

Transporting the modules is a delicate step in the construction process. For frame-type prefabricated buildings, it is clear that transporting the finished modules reduces the work that will be realized on site and this logistics brings benefits of time reduction, execution control, greater precision and, in standardized works, reduces costs. Brazil is a country where cargo transport is largely concentrated in the road system. With the exception of port areas that have a supply rail network, the vast majority of Brazilian regions can only be accessed by highways. In fact, there are some regions of Brazil that are difficult to access, either because of the low infrastructure of these roads, or for reasons of relief, vegetation and water bodies. However, for this work, the ideal hypothetical option was considered, where it is intended to concentrate the maximum number of on shop processes. Therefore, road transport of the assembled module is being considered for this work. [14]

Taking into account the transport of the modules, it is very important to plan how they will be lifted, from the factory to truck loading and from the truck to on-site assembly. To connect the crane or the munck truck there are two most common ways.

The first one is the pick points. Pick points are designed by an engineer to ensure that the lifting points coincide with

Figure 59: Panel lifting

Figure 60: Model lifting

the distribution of weight of the element. This is critical so the element will stay stable during craning and will be able to be placed square, or on a level plane. The pick points are hooks fixed to the structure, which will later be lifted by these points.

The second way is the process that will be used in this case study, which is lifting the modules with the wraparound belt strap. This way of lifting the structure is more usual for wooden structures, which can suffer damage if using the pick point method. To perform this process correctly, it is first necessary to pay attention to the extension of the module, to know how many belts will be used to distribute the weight of the structure and the not break at the midspan. Second point is to prevent the belt from crushing the module laterally. To avoid this damage, it is necessary to use the spreader bar, which opens the belt laterally, creating a horizontal reaction force in it when loaded with the weight of the modules.

Figure 61: Model transport with munk truck

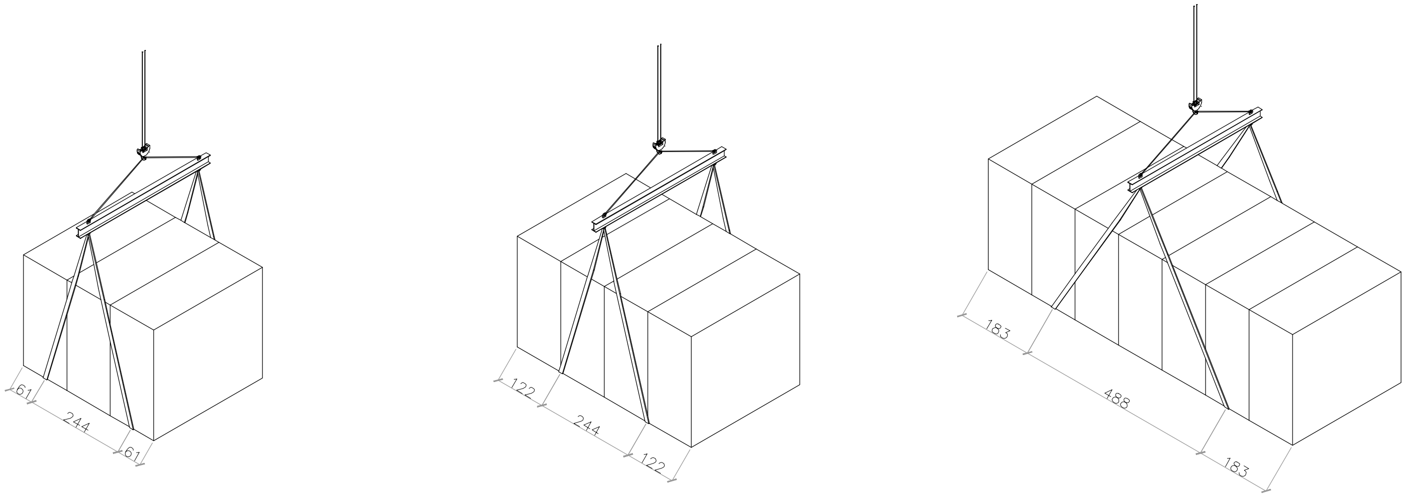


Figure 62: Model lifting with the wraparound belt strap

6.3 Assembly

The installation of the modules on site consists of connecting the structure to the foundation and the electrical and hydraulic pipework to the local inputs and outputs. In other words, with regard to the wooden structure, it is necessary to have the foundations already made. Foundations are structural concrete bodies that receive the load from the building and transmit it to the ground. In the case of a prefab wooden construction, the foundations also have the function of raising the building from the ground, so that it does not suffer from humidity.

Two types of foundations that can be used for modular one for regular topography and other for regions where there are flood periods. Both foundations were design to reduce the volume of concrete used, for economic and sustainable reasons. Modular construction can be designed to distribute load to vertical structure at corners alleviating the need for full-engaged stem wall bearing at the perimeter of the module. However, wood modules generally place distributed loads on foundations as they distribute loads similar to a bearing wall condition. In addition, there is the punctual load of the timber roof structure [14]

With this concept in mind, the foundations were designed in order to receive the loads of the module and the roof that will be made on site. As the foundation is a step that must be done in advance, it is a service that can be done by the local workforce.

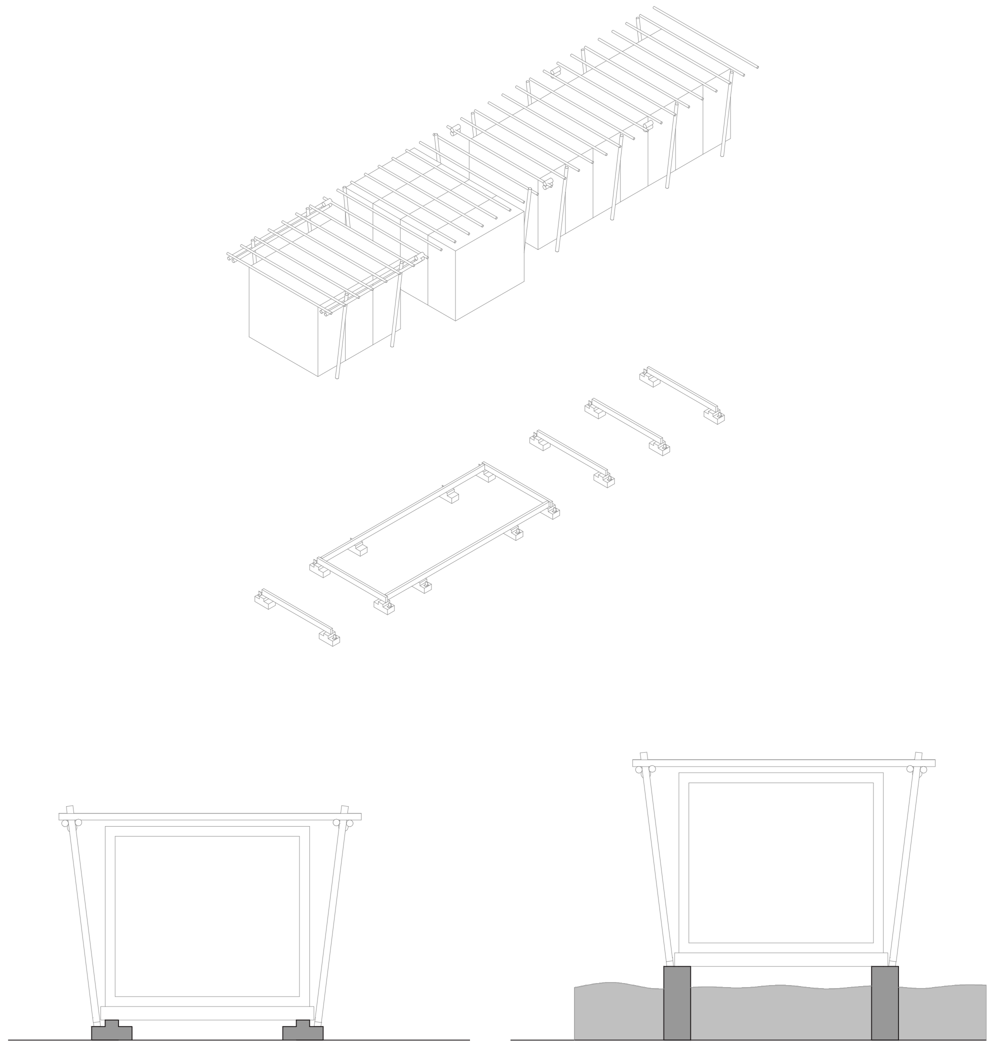
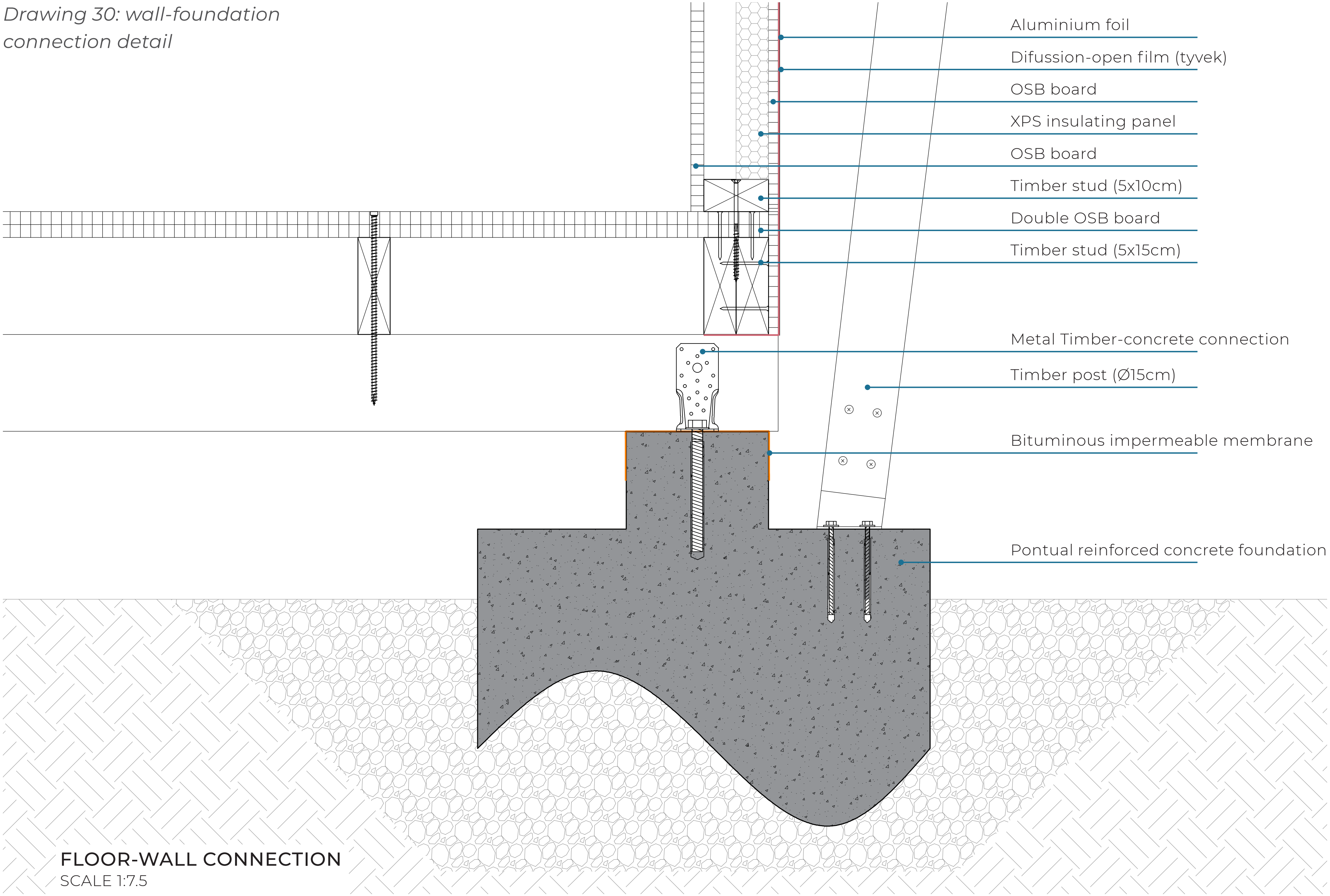


Figure 63: Isometric model foundation; Figure 64: section short foundation; Figure 65: section long foundation

Figure 66: Palafita houses

Drawing 30: wall-foundation connection detail



FLOOR-WALL CONNECTION
SCALE 1:7.5

6.4 In loco services: roof

After installing the module in place, there are a few more work to do in the house, two of which are the installation of the last layer of the facade and the roof. Given the design choices, these two components would not run as efficiently in the factory. That's why they were designed to be executed by local labor with local materials as well. The reason for this decision is economic. If, on the one hand, it was important to concentrate many stages of construction in the factory for all the efficiency of this process that has already been exposed, concentrating the money in large centers is not beneficial for a country like Brazil. It is necessary to decentralize this collection. That's why these steps were designed to be executed by locals.

The roof that we are going to present here is type 1, which is more suitable for hot climate regions with directed dominant winds. This roof typology is composed of a single slope roof, which is located above the modules and is supported by an independent wooden structure and sub-structure made with rebars. The material is local wood, with a round section of the same dimension for pillars and beams.

The wooden parts of the pillars and beams are of round section and have the same dimension for pillars and beams (10cm diameter). The pillars are connected to the concrete foundation by a T-blade metallic connection. The beams are double and are screwed to the pillars and then the two pieces of wood of circular section are screwed to the double beam to give greater stability to the structure and to join the beams, which have a limited size. This is the main structure of the roof.

To reduce the weight of this roof, it was necessary to use a light material, such as corrugated metal tiles, which are very common in Brazil. This tile is, in most cases, applied incorrectly, as it is a material that conducts a lot of heat and when used as a boundary of the thermal zone, it will overheat the environment a lot. That's why the roof was pulled away, to allow ventilation between the tiles and the ceiling. To transmit a sense of architectural lightness between the contrast of the wooden module and the roof, a metal structure was designed,

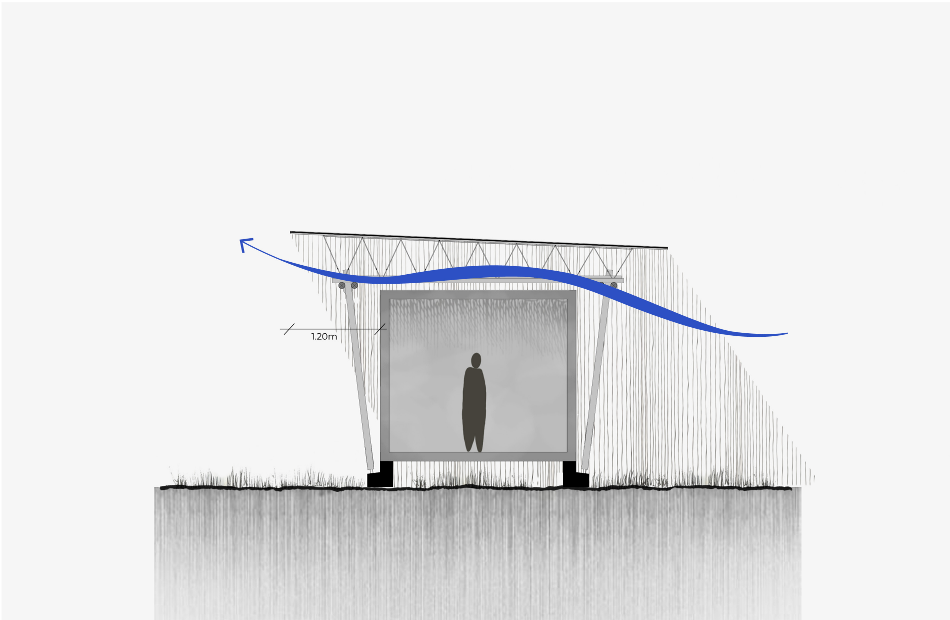
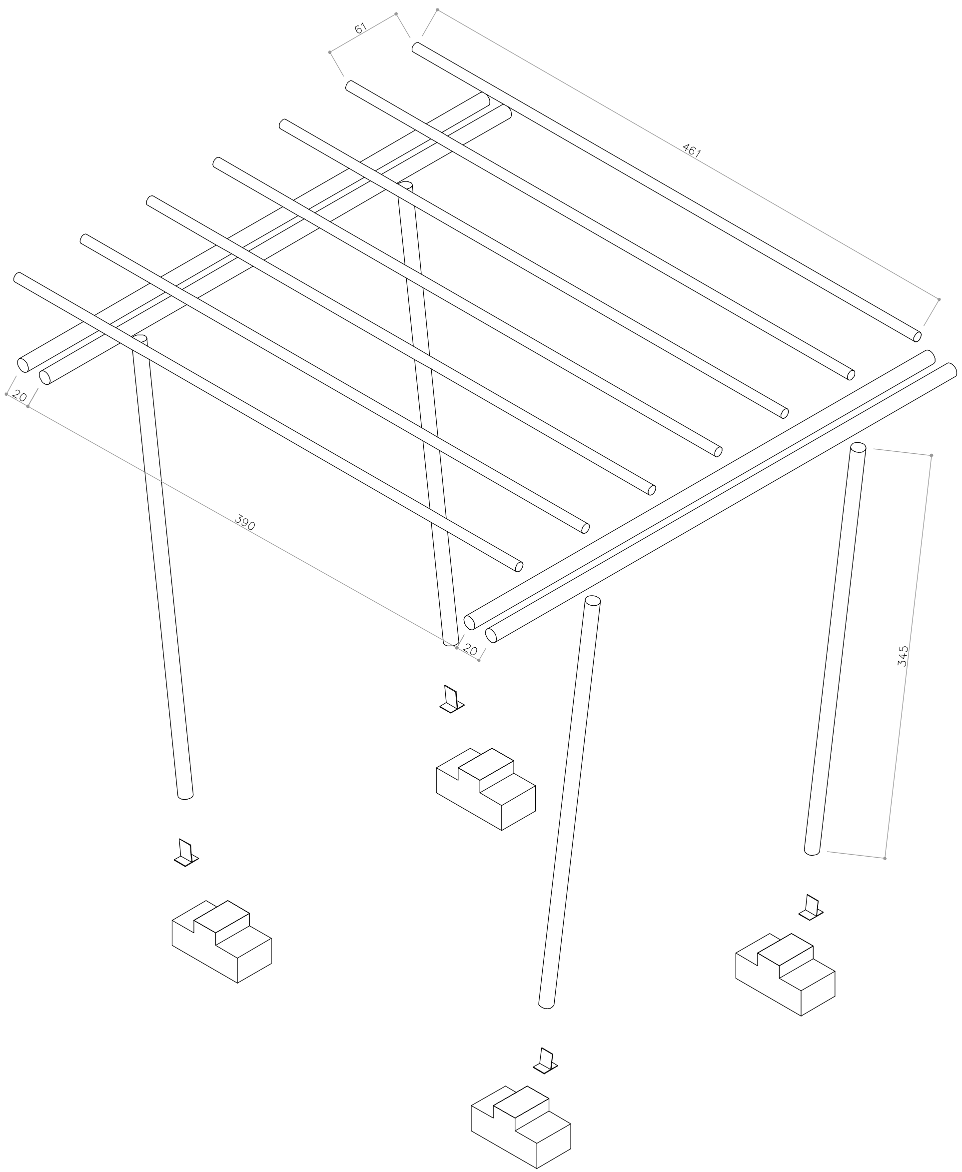


Figure 67: Roof type A

inspired by the designs of the 2022 Pritzker Prize winner Diébédo Francis Kéré. For some of his projects, such as the Primary School in Gando, Kéré designs a structure made with rebars to support a corrugated metal tile. The experience of this solution was used to design the roof of this typology of this case study.

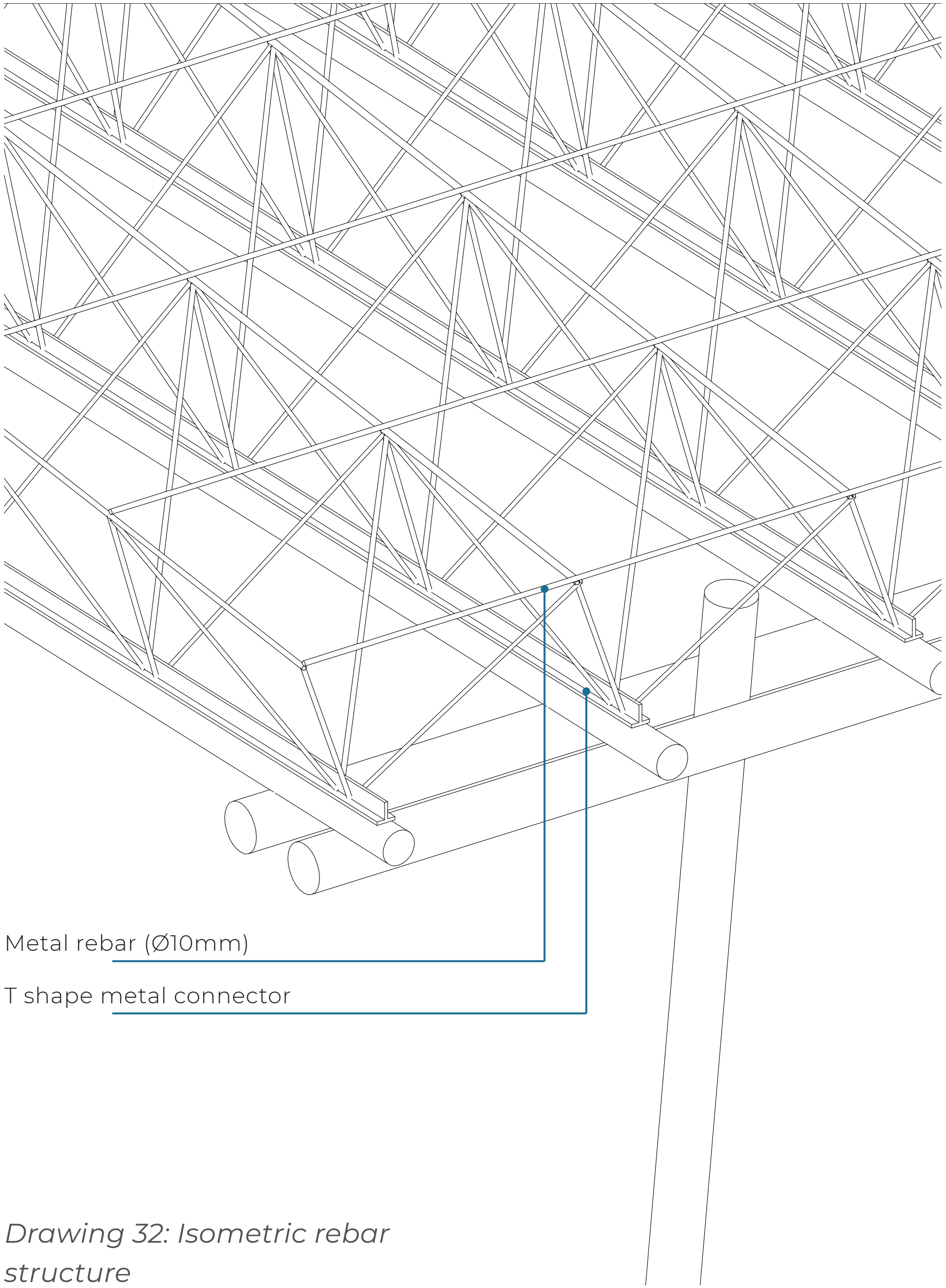
In the case of this project, there are fewer support points to support the rebar structure with the wooden structure. Thus, some transverse bars were used that are supported on



Drawing 31: Isometric timber roof structure

Figure 68: Gando primary school Diébédo Francis Kéré

Figure 69: Roof of Gando primary school Diébédo Francis Kéré



Drawing 32: Isometric rebar structure

the V-shaped structure of the rebars and that will structure the roof in a more continuous way.

6.5 In loco services: facade

The facade is a simpler component than the roof and has the dual function of being a mechanical protection for the wooden structure and the waterproof blanket, and creating a ventilated facade. Using this type of facade has the following advantages: energy efficiency, the flexibility of design decisions, noise protection and simplicity in installation at building's construction and reconstruction. The main purpose of the gap is to provide a thermal protection of the building, playing the role of the air buffer, reducing heat loss. [15]

This type of solution is very well suited to the work flow of this work, because it is a constructive element that can be installed with the modules made, without having any interference in the previous steps. For the installation, it is necessary to make a grid of timber studs fixed to the module's frame structure. This grid of wooden pieces with a 3x3cm section will create the 6cm gap that we need for a good result of the ventilated facade. If the preset thickness of the gap is excessive, the facade will buzz and whistle because of the impact of wind flow. Otherwise, in case of deficient air gap, the convective flow will be reduced, the moisture removal will be impossible; the insulation will damp and collapse eventually. In this situation the function of the air gap is reduced to zero.

[15]

The material that will be used on the facade is totally up to the user, according to personal taste and local availability. The possibilities are the most varied, ranging from coverings made of natural materials, such as wood, fiber (sapê), to industrialized materials such as cement board, marine plywood, metal tile, etc.

Figure 70: Strategraphy

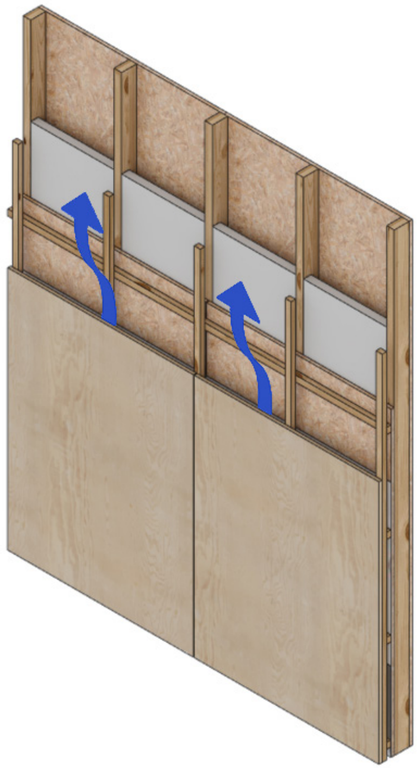


Figure 71: Ventilated façade

6.6 Services

The daily use of a residence is related to some equipment that provide comfort to carry out routine activities. Among these basic services are the availability of electricity, hot water supply and artificial temperature and humidity air conditioners.

As was seen throughout the development of this work, the increase in thermal comfort was an objective pursued to be achieved in all seasons of the year. However, in extreme hot or cold weather, this goal is impossible to achieve with passive strategies only.

In the case of Brazilian climates, the northern regions of the country have a very hot climate throughout the year and as an estimate, it is very likely that at certain times of the day in some months of the year it would be necessary to use the air conditioning to bring the temperature down to a comfort zone. To more accurately estimate the need for climate control, a dynamic simulation of the model in the climate and with the correct implementation would have to be done. As the work is nationwide, this simulation would have to be done specifically for the implementation of one of the houses.

In addition, taking into account the social and economic context in which these dwellings are being considered, thinking about artificial air conditioning would be incoherent with the development of the work so far. Therefore, the use of artificial air conditioners in houses will not be considered. A more economical solution, which also has a good relationship with passive solutions to allow continuous ventilation of houses in hot and humid climates, is the use of a mechanical fan to move the air in the environment and increase the user's feeling of comfort.

To calculate the amount of photovoltaic panels that will be needed, the energy demand of a house was estimated to have the value of the total daily demand. The second step is

Figure 71: Integration of the services

to know the solar radiation available in the region. To access this value, the CRESESB database was used, with the average value of global horizontal radiation. As the inclination of the panel installed in this typology is 2°, the value of the horizontal radiation is very reliable. Finally, the total power is calculated, and having the nominal power of the panel, we can access the amount of panels needed.

$$Pmax = \frac{Pd}{E \times \eta}$$

	Power (W)	Time (h)	Daily energy demand (kWh)
Lamp	7	26,6	0,19
Fridge	-	-	0,79
TV	48	7,5	0,36
Notebook	45	14,0	0,63
Ventilator	5	52,0	0,28

Total daily energy demand (kWh/day)	2,33
Average horizontal radiation (kWh/m²*day)	4,69
Efficiency	0,80
Max. Power (kW)	0,40
PV nominal potential (W)	260
Number of panels	**1,53**

Tabela 17 and 18: Calculation of PV panels

$$Panels = 2$$

To calculate the number of solar heater plates, we calculate the volume of hot water needed per day, based on an estimate of consumption and hot and cold water temperatures. Thus, with the values of radiation and efficiency of the plates, we can access the amount of plates.

$$Q = m \times c \times (Tf - Ti)$$

$$A = \frac{Q}{(l \times \eta)}$$

Temp. cold water (°C)	26
Temp. hot water (°C)	45
Temp. mix (°C)	38

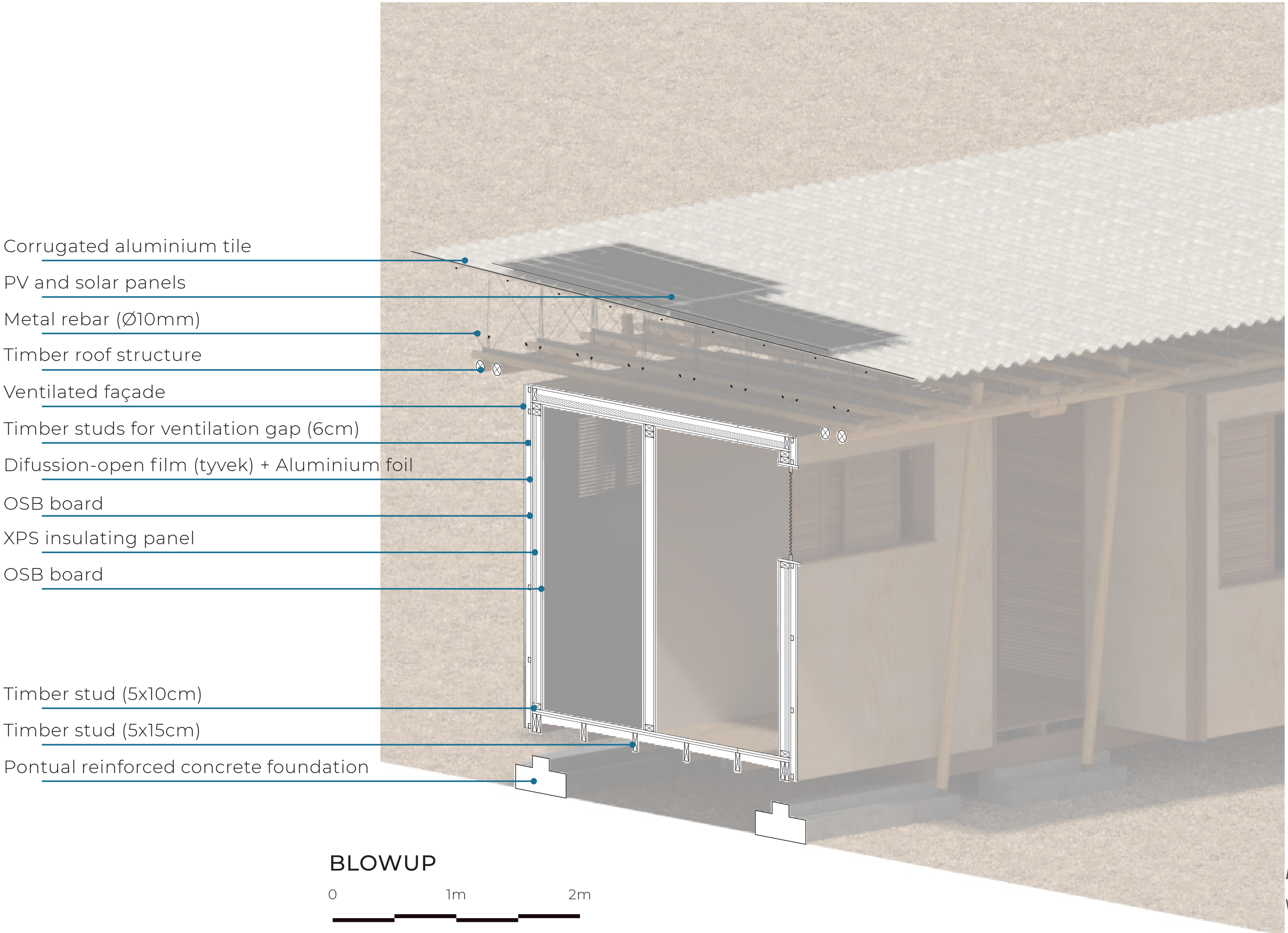
Total water volume (l)	135
Hot water volume (l/p)	85,26
Number of people	6
Total hot water volume (l/day)	511,58

Horizontal radiation (kcal/m²*day)	4689
Sensible heat needs (kcal/m²)	9720

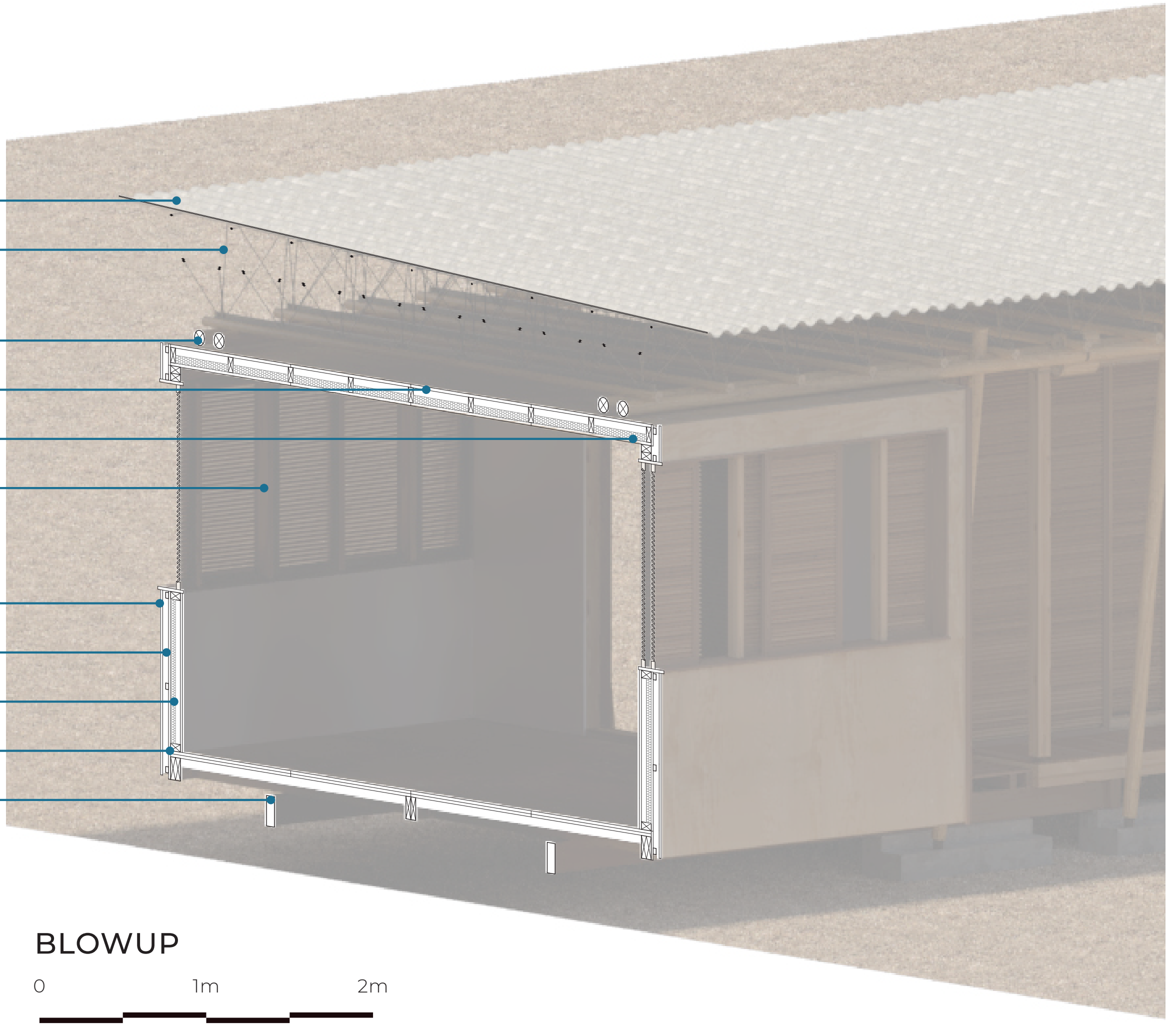
Efficiency	50%
Necessary area (m²)	4,15
Area panel (m²)	2
Number of panels	**3**

Tabela 19: Calculation of solar panels

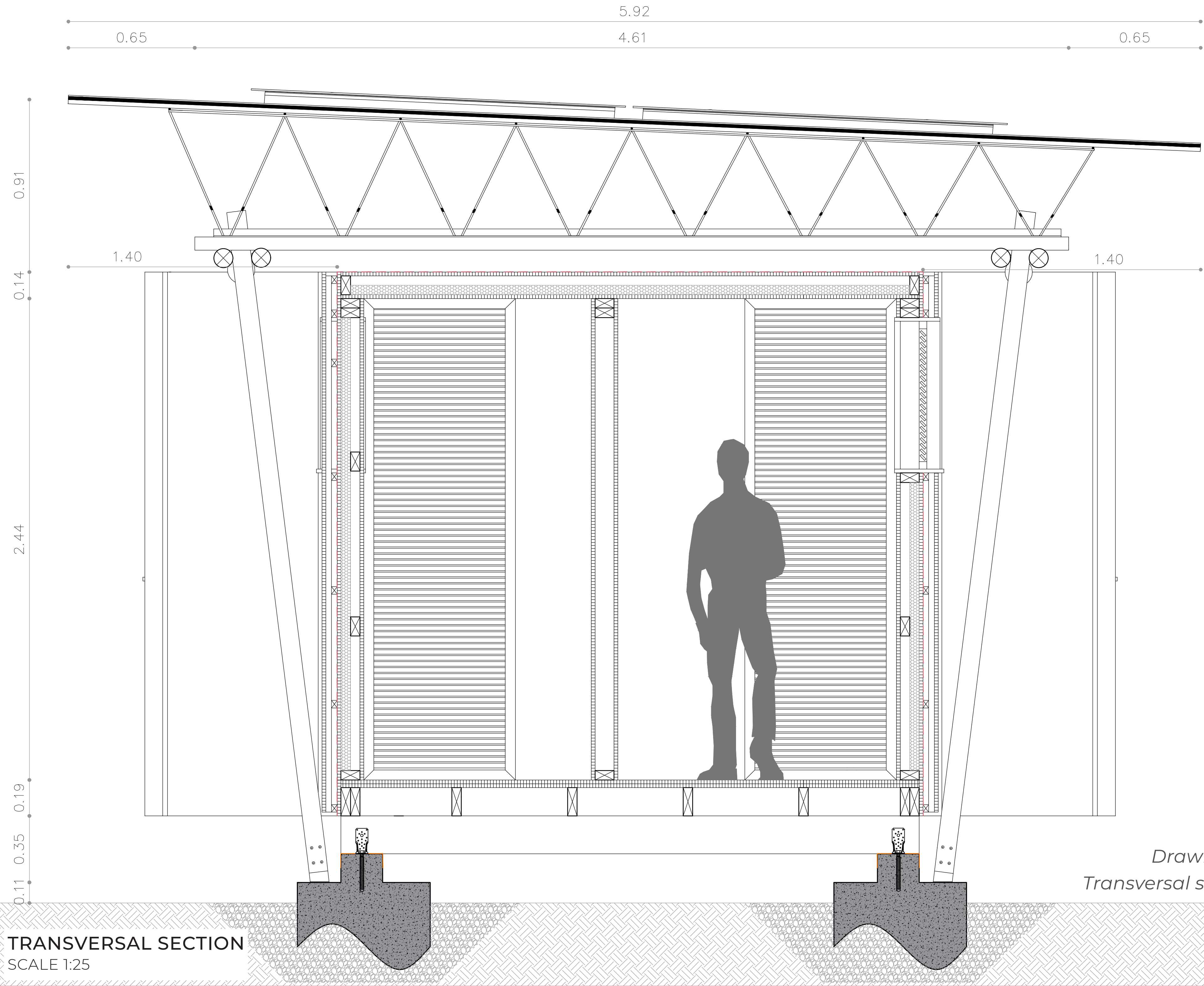
7. Constructive drawings



Drawing 33: Blowup wet module



Drawing 34: Blowup social module



Drawing 35:
Transversal section

TRANSVERSAL SECTION

SCALE 1:25

LONGITUDINAL SECTION
SCALE 1:25

Drawing 36: Longitudinal section

8. CONCLUSION

This work presented a case study for the problem of housing deficit in the Brazilian reality, understanding, redesigning and rethinking, from the main problems of the country on the subject, how a single solution could be proposed to serve the entire country. The work aimed to create a method to organize a project that was both standardized and adaptable, to achieve the objectives of constructive efficiency, open to different layouts, thermal comfort and energy efficiency. In addition, it was also thought how this method could work to try to soften the socio-economic imbalance between small cities and large centers in the South American country, organizing stages that could be executed in loco with local labor and materials. Also, it was calculated the energy demand, the domestic hot water consumption and the PV energy generation, in order to efficiently integrate architecture and services.

As it was presented in the work, the concept/method developed presents a resolution for each demand/problem analyzed during the study of the general picture. The project initially provides possibilities to adapt a standardized modular solution, creating an evolutionary layout that adapts to different family realities and different implementations. In the second step, the climate filter dictates which adaptations will occur in the house in the roof and envelope components. Such a resolution meets the initial expectations of proposing a standardized, but also adaptable house.

As it is a large project, without a specific site, without being limited to a single possibility, it was necessary to opt for a project proposal to be designed and detailed, in order to prove the effectiveness of the solution. Constructive technologies were presented in pursuit of affordable, efficient and sustainable construction. All construction logistics were planned to attend the assumptions of the method.

Thus, the case study presented in this work proved to be promising in presenting a coherent path to the problems raised. Energy and comfort simulations performed by software such as IES-VE would be very welcome to give more endorsement to the project, however, the study proposed to think about passive solutions and in a project of a small scale and of low complexity and, therefore, following the scientific literature on the subject is enough and provides the necessary technical and scientific support.

LIST OF FIGURES

LIST OF DRAWINGS

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BIBLIOGRAPHY

[1] Fundação 1 de Maio, "Defict habitacional reflete a desigualdade do país" [Online]. Available: https://www.fundacao1demaio.org.br/artigo/deficit-habitacional-reflete-a-desigualdade-do-pais/

[2] Climate Watch, "Historical GHG Emissions" [Online]. Available: https://www.climatewatchdata.org/ghg-emissions?breakBy=sector&calculation=ABSOLUTE_VALUE&chartType=line&end_year=2018&regions=ITA&sectors=bunker-fuels%2Cindustrial-processes%2Cwaste%2Cbuilding&start_year=1990

[3] Climate Watch, "Historical GHG Emissions" [Online]. Available: https://www.climatewatchdata.org/ghg-emissions?breakBy=sector&calculation=ABSOLUTE_VALUE&chartType=line&end_year=2018&regions=BRA&sectors=bunker-fuels%2Cindustrial-processes%2Cwaste%2Cbuilding&start_year=1990

[4] Instituto Brasileiro de Geografia e Estatística [Online]. Available: https://cidades.ibge.gov.br/brasil

[5] D. Barreto, G. Weimer, H. Medeiros, W. Holzer, A arquitetura popular do Brasil, (2010), Bom Texto.

[6] Britannica, "Köppen climate classification" [Online]. Available: https://www.britannica.com/science/Koppen-climate-classification

[7] F. Butera, Sustainable building design for tropical climates, 2014, UN-Habitat.

[8] Instituto Brasileiro de Geografia e Estatística, Pesquisa Nacional por Amostra de Domicílios Contínua, *Características Gerais dos Domicílios e dos Moradores 2019*, 2019.

[9] A. Zani, Arquitetura em madeira, 2010, Eduel.

[10] G. Weimar, Arquitetura popular brasileira, 2005, Wmfmartinsfontes.

[11] G. Utrabo, Palestra arquiteturas do sul global: Gustavo Utrabo, [Online]. Available: https://www.youtube.com/watch?v=9KvtbQMZs8o&t=1090s

[12] Archdaily, "Parem de construir casas para resolver a falta de moradia" [Online]. Available: https://www.archdaily.com.br/br/927662/parem-de-construir-casas-para-resolver-a-falta-de-moradia

[13] Projeteee, "Estratégias bioclimáticas: venilação natural" [Online]. Available: http://www.mme.gov.br/projeteee/estrategia/ventilacao-natural/

[14] R. Smith, Prefab Architecture A guide to modular design and construction, (2010), John Wiley & Sons, Inc.

[15] A. Barabash, E. Naumova, O. Zhuvak, D. Nemova, V. Olshevskiy , The Efficiency of the Ventilated Gap of the Double-Skin Facade Systems Using Fire Crosscuts, TPACEE, 2016

[16] Centro de Referência para as Energias Solar e Eólica Sérgio S. Brito, Valores de Radiação, [Online]. Available: http://

www.cresesb.cepel.br/

[17] R. Tubelo, L. Rodrigues, M. Gillott, A Comparative Study of the Brazilian Energy Labelling System and the Passivhaus Standard for Housing, Buildings, 2014.

[18] G. Salvalai, M. Sesana, D. Brutti, M. Imperadori, Design and Performance Analysis of a Lightweight Flexible nZEB, sustainability, 2020.

[19] Trata Brasil, "Esgoto", [Online]. Available: http://www.tratabrasil.org.br/saneamento/principais-estatisticas/no-brasil/esgoto

[20] Estadão, "Brasil é modelo em geração de energia limpa" [Online]. Available: https://economia.estadao.com.br/noticias/geral,brasil-e-modelo-em-geracao-de-energia-limpa,70003545423

[21] Associação Brasileira para Reciclagem de Resíduos da Construção Civil e Demolição, "Brasileiro produz por ano meia tonelada de resíduos de construção civil" [Online]. Available: https://abrecon.org.br/brasileiro-produz-por-ano-meia-tonelada-de-residuos-de-construcao-civil/

[22] SEEG Brasil, "Emissões por atividade econômica" [Online]. Available: http://plataforma.seeg.eco.br/economic_activity