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Doctoral School in Civil, Environmental and Mechanical Engineering

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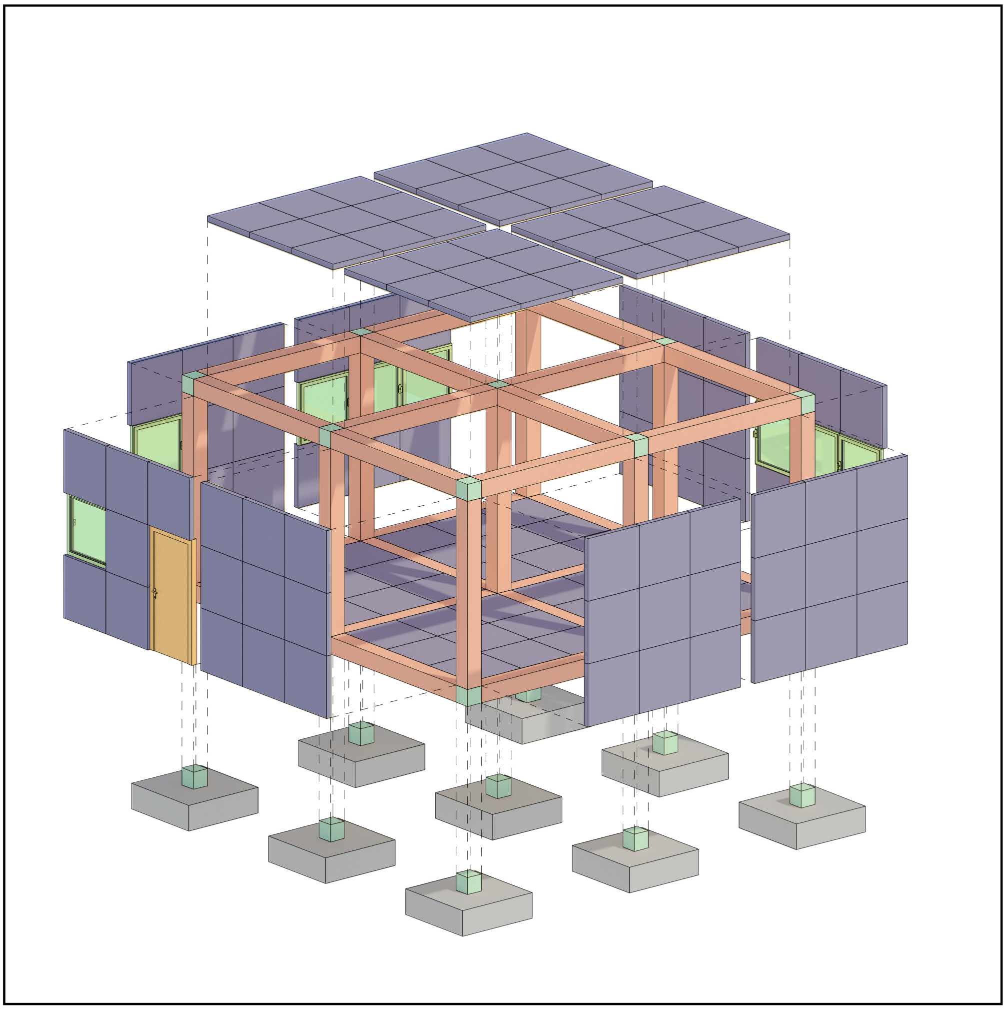
Emergency Modular Architecture

Study of applying of modular building technics to the house emergency field



2022 - Doctoral thesis

UNIVERSITÀ DI TRENTO

DOCTORAL SCHOOL IN CIVIL, ENVIRONMENTAL AND MECHANICAL ENGINEERING 33RD CYCLE OF DOCTORAL PROGRAM (2017-2020)

EMERGENCY MODULAR ARCHITECTURE

STUDY OF APPLYING OF MODULAR BUILDING TECHNICS TO THE HOUSE EMERGENCY FIELD

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Summary

1. INTRODUCTION

The present chapter illustrates firstly the issues and dimensions of *housing emergencies* worldwide, *disaster management* on a UN, EU and Italian scale, the detailed numbers of people in need of shelter each year and an overview of *shelter*.
The second part illustrates the aim of the thesis and the *research questions*.

1.1. GENERAL FRAMEWORK AND PRESENT CHALLENGES

In the last century, human evolution has been characterised by rapid changes beyond those of previous centuries. In particular, the industrial revolution has led to an exponential increase in general welfare, significantly raising the quality of life across the planet.

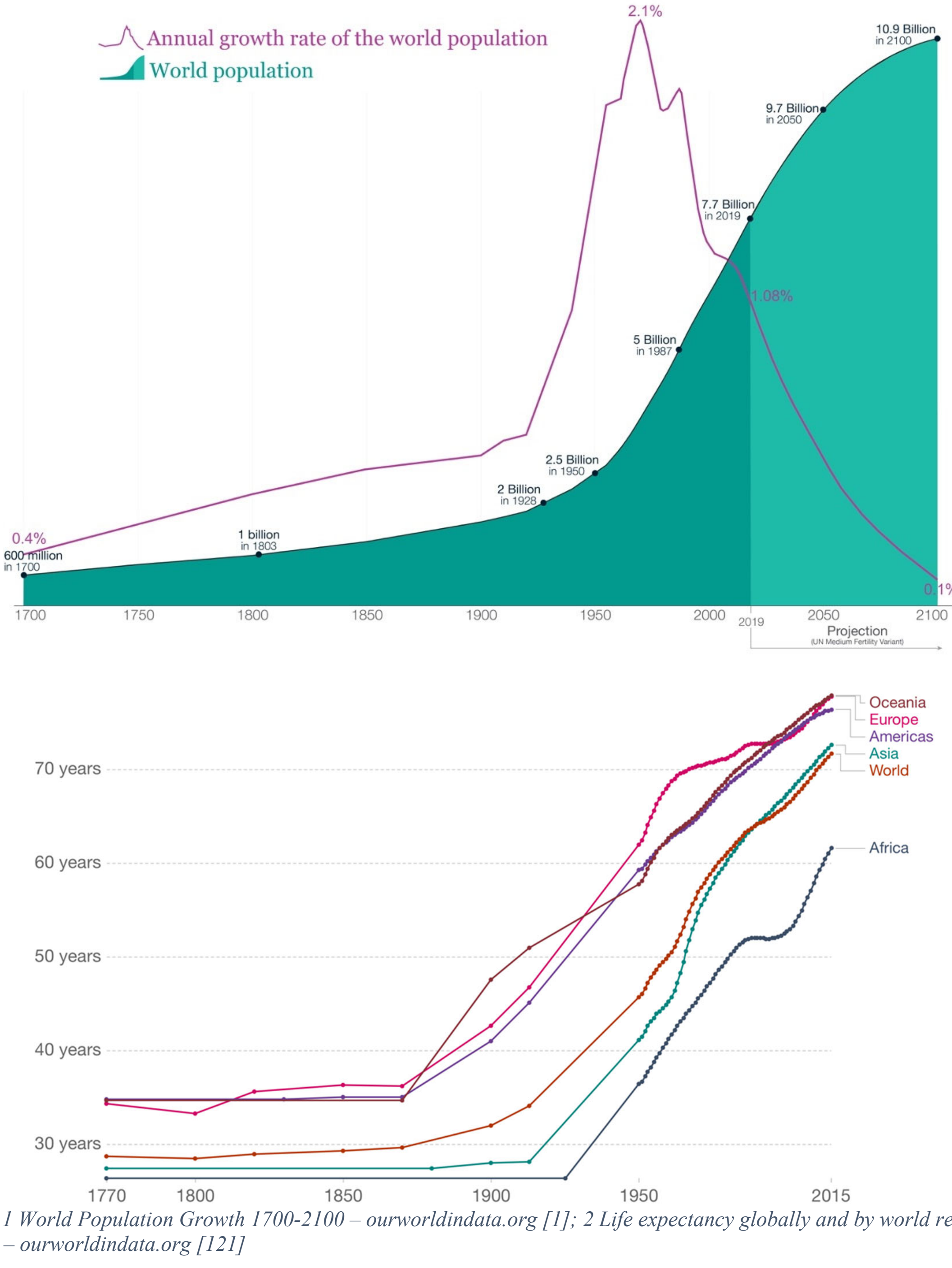

Figure 1 – 1 World Population Growth 1700-2100 – ourworldindata.org [1]; 2 Life expectancy globally and by world regions since 1770 – ourworldindata.org [121]

From the graphs presented in Fig. 1, it is noticeable that since the last 50 years of the last century, life expectancy has increased extraordinarily, and thus the general population has also risen as never before.
By analysing other demographic indices (infant mortality, GDP, democracy level, civil rights), it can be deduced that this demographic increase has been accompanied by an improvement in lifestyle and the needs of emerging countries for a better lifestyle.
Healthy housing is one of the most coveted indices to be achieved. [1]
On the one hand, the official credit for this phenomenon is attributable to science, through the discovery of antibiotics or vaccines; on the other hand, as Illich already pointed out [2], the improvement of environmental conditions of living and working places determined a significant lowering of mortality and morbidity rates even before the advent of specific treatments (for example TB was decreasing in England even before the discovery of streptomycin only because more "sunny" housing was offered) [3]. The incidence of rheumatic diseases even before the discovery of cortisone decreased by offering heated, non-humid housing. Therefore, the design of healthy places is one of the fundamental elements of a public and social health policy. [4]
Population growth with a relative need for increased prosperity has been enabled by an ever-increasing need for energy. This energy, mainly obtained from fossil fuels, is not inexhaustible and its derivatives or waste are beginning to create side effects or real damage to the environment and human health.
Moreover, the race to accumulate such energy sources has provoked and continues to provoke conflicts and wars on the international stage [5], with an explosion of migratory flows never seen before in human history and a consequent increase in demand for housing. This concern about energy is also reflected in the design of buildings, which are becoming even more energetically efficient, by making energy saving one of the main priorities of any project. This new element influences the history of design and the search for energy efficiency solutions as never before. [6]

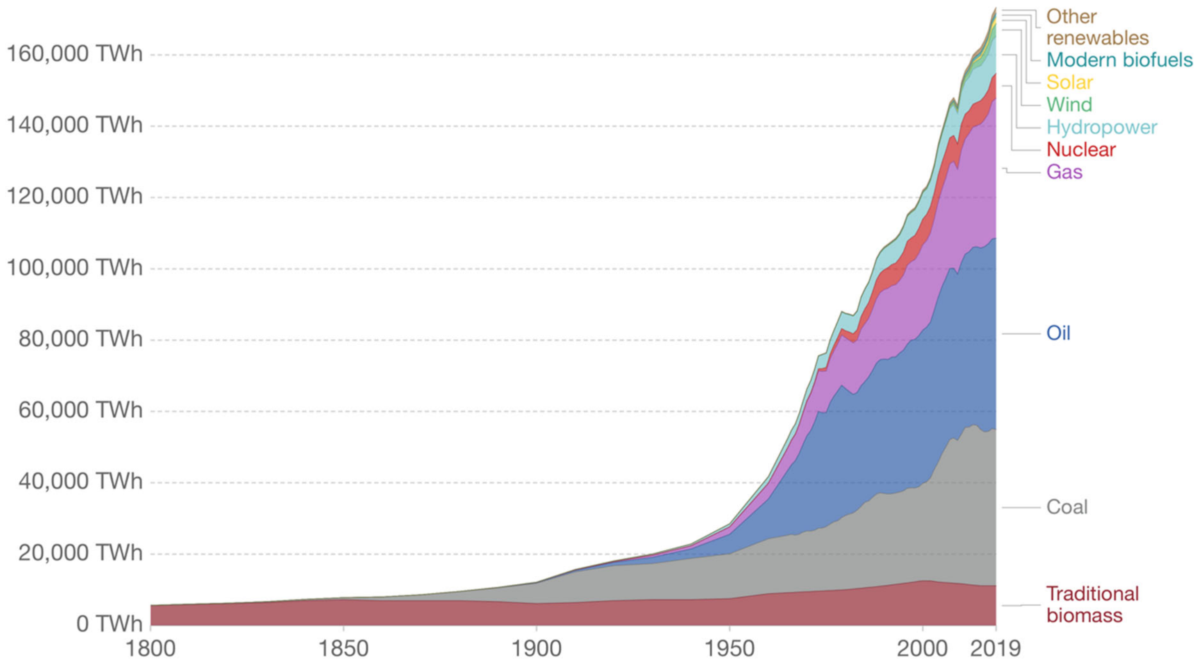

Figure 2 - Global energy consumption by source - ourworlddata.org [123]

A fossil fuel-dependent energy system leads to another consequence: an increase in air and land pollution with significant climatic effects, e.g., a rise in the average global temperature, melting ice and rising water, and an intensification of hurricanes and atmospheric phenomena of a devastating nature. [7] This causes suddenly and quickly to large numbers of people finding themselves in housing emergencies.
In addition, we should consider also all those living in "chronic housing emergency". That is, the millions of people living in *slums*. [8]
Given the general framework just illustrated, we may define an outline of the timing of the emergency; it corresponds to different modalities of analysis and approach:

- **Immediate** – the first week after the disaster: the main and basic functions to ensure people's survival must be guaranteed; including shelter from the weather, basic sanitary and food items, and personal safety.
- **Temporary** – first month: setting up the camps with the appropriate sanitation, food and organisational services.
- **Long-lasting** – from the first month onwards: setting up of temporary communities until reconstruction or relocation.

The present research, among the other, aims to develop buildings that can fulfil the housing needs of our days:

- **Rapidity**: a fast and widespread response to needs.
- **Quality**: comfortable buildings with low environmental impact**.**
- **Adaptability**: ability to fit in and change over time.

These three main requirements led to the idea of the thesis: to **develop modular housing for emergency housing situations**, which can be quickly set up and easily modified; characterized with comfort conditions appropriate to contemporary standards; with low environmental impact – both in terms of energy consumption and waste production; adaptable both in space – able to exploit the characteristics of the place where they are built - and time, as possibility of being modified over time.

Currently, about 1 billion people need housing. It means that 13% of the world's population does not have access to housing. This is alarming and highlights a key issue of our time. This issue is also becoming more relevant as the UN estimates that it will reach 40% of the population in the coming decades. [9]

The housing emergency does not only affect emerging countries, rather the whole world. The British Ministry of Housing, for example, estimates that 340,000 new homes are needed per year to meet the current demand for housing. [10]

Welfare and technological availability have facilitated mobility and annual migration counts several million people (258 million in 2017). [11] Migrants, of various kinds, contribute to the housing emergency.

The following data are helpful in providing an overview of what is generically referred to as the "housing or housing crisis":

- Slums: **1.033 million**
- Migrants: **258 million**
- Displaced people: **70,8 million**
- Homeless: **around 2 million**

Some of these numbers are common to several categories (e.g., displaced persons may also be migrants, etc.). However, they are truly relevant to understand the extent of the problem. In addition, we should consider the annual demand for new houses, which is physiological for every country.

In conclusion, the growth in housing emergency is due to multiple causes.

The present research focuses mainly on emergencies of a more circumstantial nature, partly excluding chronic and structured ones (e.g., slums). However, the used methodologies can also be applied to other situations and to housing emergencies in general. Indeed, the thesis will suggest a system characterized by extreme adaptability.

A general overview of what is intended as emergency will follow. Moreover, it will be presented how emergency is dealt with at various levels, as well as a selection of the state of the art. All this is necessary to identify the needs which the building system under research should fit.

1.2. Disaster management

In recent years, we are observing an increasing number of people in need of emergency accommodation because they have become displaced because of a natural disaster, conflict, starvation, or persecution. [12]

The rise of natural disasters [13] in recent decades has pushed nations around the world to focus more on this issue and specifically on emergency management: before, during and after a disaster.

"Disaster: a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts." [14]

Using this definition as a starting point, the general lines of risk management are outlined below. The declinations at different levels – UN, EU, and IT – are highlighted, with a particular focus on relief and shelter.

1.2.1. **United Nations**

"Recognizing the need to contribute to disaster response and recovery efforts, the United Nations established in 1971 its own mechanism to provide international assistance to governments when such governments elevate a request for humanitarian assistance." [15] Moreover, since 1971, with the December Assembly, the United Nations has enacted the figure of the Disaster Relief Coordinator (DRC), who acts in emergency situations in the name of the Secretary General, directing all the resources that the UN provides for that emergency. In the same document, the States concerned by the emergency are invited to collaborate with the coordinator; but above all, all States are invited to provide a plan for the prevention and management of emergencies, as well as laws and bodies prepared for such situations. [16]

Following this definition, the OCHA (Office for the Coordination of Humanitarian Affairs) mandate was issued in 1991, effectively superseding the DRC. [17]

"At the request of the government affected by a disaster, OCHA may dispatch a United Nations Disaster Assessment and Coordination team (UNDAC) to the country within 12 to 48 hours after a sudden-onset disaster to provide technical services, principally in tasks such as damage and needs assessment, on-site coordination and information management. UNDAC teams aim to facilitate close links between country-level, regional and international response efforts. When deemed appropriate, the United Nations may also set up an On-Site Operations Coordination Centre (OSOCC) to help local authorities in a disaster-affected country to coordinate international relief." [15]

The position of Emergency Relief Coordinator (ERC) is also defined: [17] "Who works with the Secretary-General and the Inter-Agency Standing Committee (IASC) in leading, coordinating and facilitating humanitarian assistance. OCHA is the office that provides support to the ERC and the Secretary-General to meet the leadership and coordination responsibilities charted in GA resolution 46/182". [15] [17]

OCHA is not an operational agency directly engaged in the delivery of humanitarian programs, and its added value is as an honest broker, facilitator, thought leader and global advocate, providing support to the humanitarian system. [15]

Together with the ERC, with the same deliberation, the phenomenon of IDPs (Internally Displaced Persons) is recognised, acknowledging them for all intents and purposes as persons in a state of emergency. From this moment until now IDPs are gaining more attention as they represent an important percentage of refugee persons (in 2018 IDPs are more than 41.3 million out of a total of 70.8). [12] [18]

OCHA and ERC are therefore the point of reference for people in a state of emergency. OCHA's strategy can be summarised through the following diagram taken from the Strategic Plan 2018-2021. [19]

"In addition, OCHA has established a structure of clusters as a way for UN agencies to work together with non-UN agencies (f. ex. NGOs) to deliver humanitarian assistance in a coordinated fashion. There are eleven different clusters, each one focusing on a specific set of tasks or functions. Each cluster is headed by one or two UN organizations or agencies. Both the UNDAC team and the OCHA clusters coordinate their efforts with the UN Resident Coordinator and the UN Humanitarian Coordinator in the country affected by the disaster. While most clusters operate during the response phase, the United Nations Development Programme **UNDP has established the Early Recovery cluster that focuses on the more long-term needs related to recovery.** Through this cluster, UNDP links humanitarian efforts with development work. The aim of this cluster is to gradually turn the dividends of humanitarian action into sustainable crisis recovery, resilience building and development opportunities." [15]

Figure 3 - OCHA Strategic Plan 2018-2021 [19]

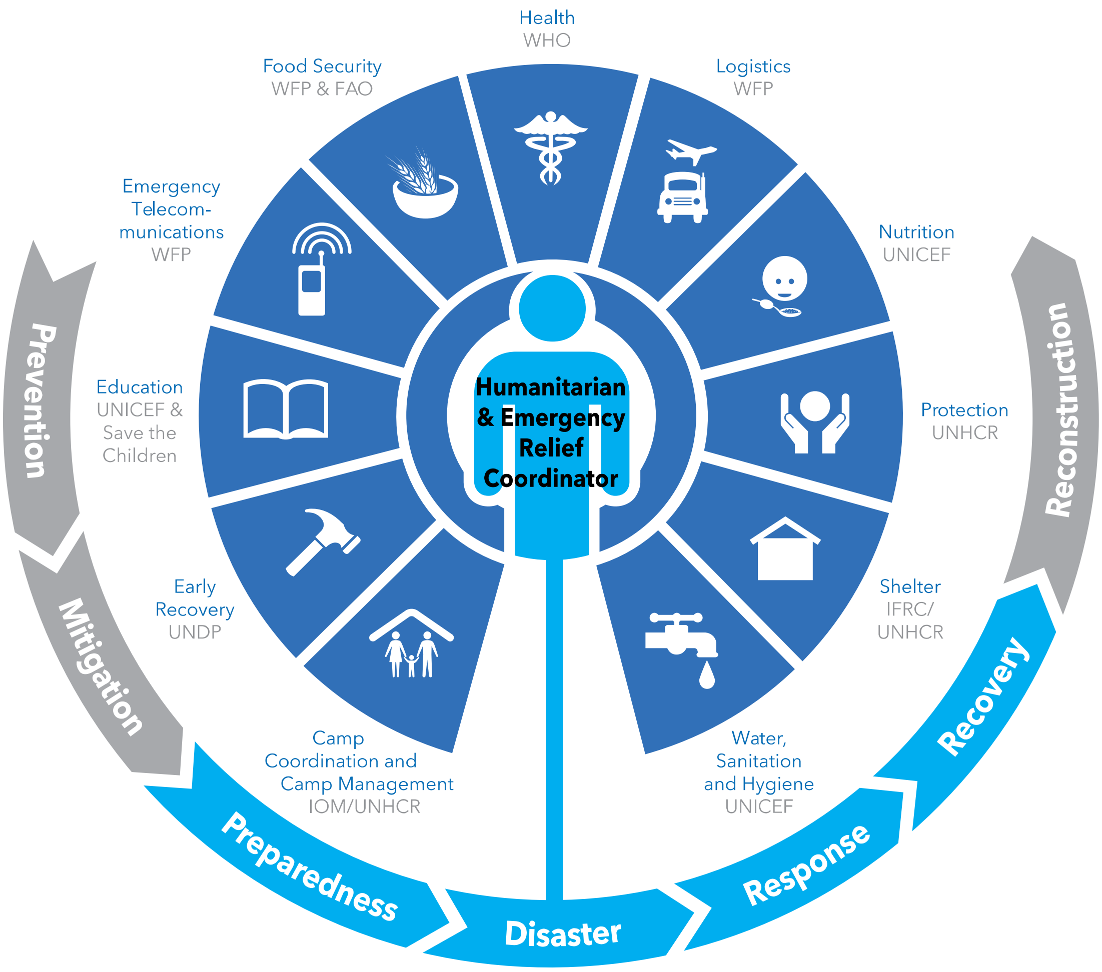

Figure 4 - The Cluster Coordination Reference Module [124]

Figure 4 illustrates the areas of influence of the various UN organisations: [20]

- Agriculture/**FAO**
- Camp Coordination and Camp Management/**UNHCR** for conflict IDPs and **IOM** for disaster situations
- Early Recovery/**UNDP**
- Education/**UNICEF** and **Save the Children**
- Emergency Shelter/**UNHCR** and **IFRC**
- Emergency Telecommunications/**WFP**
- Health/**WHO**
- Logistics/**WFP**
- Nutrition/**UNICEF**
- Protection/**UNHCR** for conflict IDPs and **UNHCR/OHCHR/UNICEF** for disasters and civilians affected by conflict other than IDPs.

Since 1990, the UN has paid increasing attention to the matter of risk management and especially to prevention. Some of the steps towards a more conscious management – before, during and after a "disaster" – are listed below:

- 1990-1999: The International Decade for Natural Disaster Reduction (IDNDR) [21]
- 2005-2015: Hyogo Framework for Action (HFA) [22]
- 2015-2030: the Sendai Framework for disaster risk reduction [23]
- 2006: established the United Nations Platform for Space-based Information Disaster Management and Emergency Response (UN-SPIDER) [24]

All these important steps contribute to the continuous search for a better management of Risk and Disaster, to reduce damage to people and property.

1.2.2. **European Union**

Starting with UN emergency management and risk management, we briefly review the EU's approach to these issues.
As mentioned above, in the 1990s attention and awareness were given to emergency management issues. This period was thus the basis for the important steps taken during the first decade of the 2000s and its influence is also evident in the EU. Consequently, in 2009 the Commission published an important communication in this direction [25] as a response both to the suggestions generated by the UN and to the internal thrusts of the various bodies and states of the Community. [26] [27] [28] The communication identifies the problem of natural disasters, which are drastically increasing mainly due to climate change [13], and highlights the need for a Community plan for the prevention and management of emergencies, to minimise the impact of such events. In this document there are clear references to the Risk Management actions of the above-mentioned UN.
The proposal broadly covers three points:
- to develop prevention policies based on the knowledge available at all administrative levels.
- to bring together the many actors and policies involved throughout the disaster management cycle.
- to improve the effectiveness of the policy instruments available for prevention.

The document outlines the strategies needed to achieve prevention policies.
It stresses the importance of a shared approach by the Member States, as well as greater knowledge of the matter. The creation of an "inventory of good practices" and "risk/danger mapping" is encouraged. [25]
Prevention and international cooperation are also encouraged. According to the Treaty of Lisbon of the end of 2007, the European Union becomes a "legal personality" [29] and thus adheres to the Council of Europe's International Charter of Human Rights. [30] The treaty highlights the need to strengthen the EU's capacity to deal with natural disasters.
In particular, the EU can implement measures concerning:
- risk prevention,
- the preparation of civil protection stakeholders,
- intervention in event of natural or human-caused disasters,
- international cooperation between national civil protection services,
- the coherence of actions undertaken at international level.

The same treaty reformed the main body of the European disaster response system abroad: the European Community Humanitarian Aid Office (ECHO). [31]
ECHO was founded in 1992 and was reformed in 2009 under the Lisbon Treaty. It was renamed Directorate-General for Humanitarian Aid and Civil Protection (DG ECHO).
Furthermore, Civil Protection was merged with ECHO to form a single body for disaster management and prevention, and to promote disaster management at Community and cooperation level.
The opening of the Emergency Response Coordination Centre (ERCC) was also determined [32], which is a civil protection "hub" that monitors disasters and improves the preparedness and resilience of disaster-prone countries,
Through the Lisbon Treaty, the UE fully adopts the humanitarian principles of humanity:
Humanity means to face human suffering wherever it occurs, paying particular attention to the most vulnerable.
Neutrality means to provide humanitarian aid without favouring any party in an armed conflict or other dispute.
Impartiality means to provide humanitarian aid solely because of need without discrimination.
Independence means the autonomy of humanitarian objectives from political, economic, military, or other objectives. [30] [33] [34] [35]

1.2.3. **Italy**

As already pointed out, the 1990s represented an important turning point in the awareness and enrichment of the theme of "emergencies". In effect, it was in this time that, all over the world, firstly in the UN, a feeling of necessity began to spread concerning the organisation and systematisation of emergency situations. Italy as well is proceeding in this direction.

It was in 1992 that the law officially established the "*National Civil Protection service to protect the integrity of life, possessions, settlements and the environment from damage or the danger of damage resulting from natural disasters, catastrophes and other calamitous events*. [36] Article 2 of the law differentiates the events for which the Civil Protection is called upon:

- **Type A events**: natural or human-caused events that can be faced by interventions, implemented by individual competent bodies and administrations in the ordinary way.
- **Type B events**: natural or human-caused events which, by their nature and extent, require the coordinated intervention of several ordinarily competent bodies or administrations.
- **Type C events**: natural disasters, catastrophes, or other events which, due to their intensity and extent, must be tackled using extraordinary means and powers.

The Civil Protection Service has undergone changes over the years, most recently in 2018 [37], when its activities were reformed. Indeed, art. 2 of the Decree contains a substantial difference from the law of '92: "*Civil protection activities are those aimed at forecasting, preventing, and mitigating risks, managing emergencies and overcoming them*".

Forecasting: "*set of activities, carried out also with the help of subjects with scientific, technical and administrative competence, aimed at identifying and studying, also dynamically, possible risk scenarios, for the needs of alerting the National Service, where possible, and civil protection planning*."

Prevention: "*set of activities of a structural and non-structural nature, also carried out in an integrated manner, aimed at avoiding or reducing the possibility of damage occurring as a result of calamitous events, also on the basis of knowledge acquired as a result of forecasting activities*."

Emergency management: "*an integrated and coordinated set of measures and interventions aimed at ensuring relief and assistance to the populations affected by calamitous events and to animals and the reduction of their impact, also through the implementation of non-deferrable and urgent interventions and the use of simplified procedures, and the related activity of informing the population*."

Overcoming the emergency: "*coordinated implementation of measures aimed at removing obstacles to the resumption of normal living and working conditions, to restore essential services and to reduce the residual risk in the areas affected by the calamitous events, as well as the recognition of the needs for the restoration of public and private structures and infrastructures damaged, and of the damage suffered by economic and productive activities, cultural assets and the building heritage and the start of the implementation of the consequent initial measures to deal with them.*" [37]

The activities of Civil Protection can therefore be distinguished into ordinary and emergency.

Ordinary: the ordinary activity consists of forecasting and implementing risk prevention and mitigation measures.

Emergency: emergency: when an event hits a territory, the Mayor - Civil Protection Authority within the National Service - must provide first aid to the population, according to the municipal emergency plans (Type A events). If the resources available to the municipality are insufficient, the Province, Prefecture and Region intervene (Type B events). In the most critical situations, upon request from the Regional Government, the national level takes over, with the declaration of a state of emergency (Event type C). In such case, the entire National Service is deployed with all its structures, coordinated by the President of the Council of Ministers, through the Civil Protection Department. [38]

The components of the National Service are: "*the State, the Regions and the Autonomous Provinces of Trento and Bolzano and the local authorities are components of the National Service and are responsible for implementing the activities referred to in Article 2, in accordance with their respective regulations and competences"*. [37]

Over the years, responsibility for civil protection has gradually shifted from the State to regional governments and local authorities. The main stages of this process were the legislative decree no. 112 of 1998 and the amendment of Title V of the Italian Constitution with the constitutional law no. 3 of 18 October 2001. The latter made civil protection a matter of concurrent legislation, which means that, except for the determination of fundamental principles, legislative power lies with the regional governments. Therefore, ach Region has organised its own civil protection system.

The civil protection bodies, at the various levels, have the task to deepen their knowledge of the risks and to identify useful actions, aiming to reduce the probability of disastrous events occurring or to limit the possible damages. Among these actions, informing the population and indicating the behaviour to adopt in relation to the risks of a given territory is fundamental. [39]

1.3. Housing Emergency

1.3.1. Displaced

The number of people forced to migrate is constantly increasing. [12]

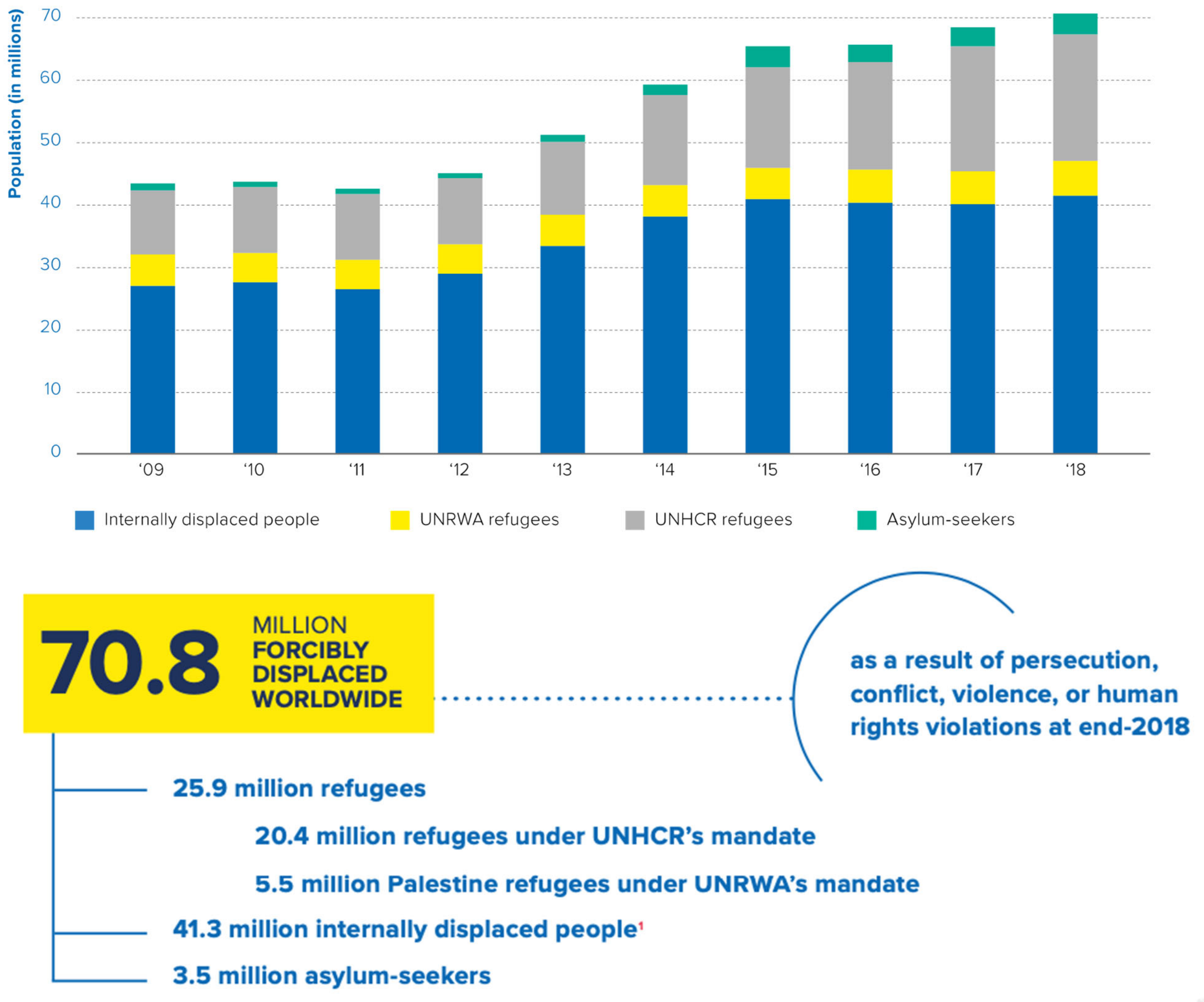

Figure 5 – Global forced displaced 2009-2018 and typology of displaced – source UNHCR [12]

These 70.8 million are divided into **refugees**, **IDPs** and **asylum seekers**.

- **Refugees**: Starting from Art. 14 of the International Declaration of Human Rights [33] of 1948, UNHCR issues the Convention (1951) and Protocol (1967) Relating to the Status of Refugees. Article no. 1A defines "refugee" as someone who is "outside *his or her country of nationality or habitual residence; has a well-founded fear of persecution because of his/her race, religion, nationality, membership in a particular social group or political opinion; and is unable or unwilling to avail himself/herself of the protection of that country, or to return there, for fear of persecution*." [40]
- **Internal Displaced Person (IDPs)**: "*Like refugees, they had to leave their homes because of conflicts or persecutions. However, unlike refugees, they have not crossed a recognised international border to find safety*". [41]
- **Asylum seekers**: "*This category includes those who, having left their country of origin and applied for asylum, are still waiting for a decision from the authorities of the host country on their refugee status.*" [42]

Of the nearly 71 million people, only 2.9 million (including 593,800 refugees) return to their country or area of origin. [12]

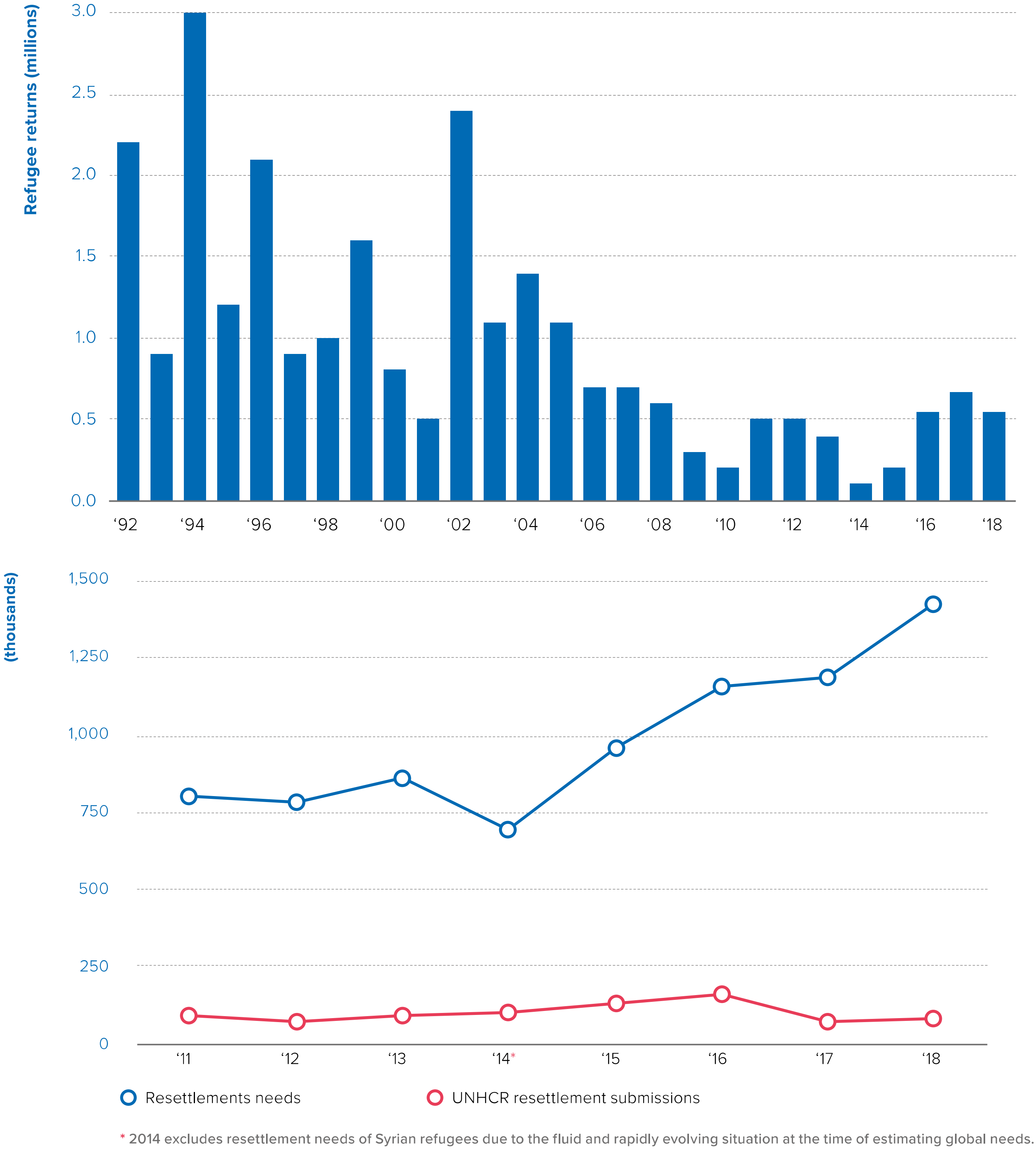

Figure 6 - Refugee returns 1992-2018 and gap between resettlement need and UNHCR's annual submissions 2011/18 - source UNHCR [12]

Consequently, we may understand the fact that in 2018 around 68 million people remained "displaced".
Moreover, in 2018 UNHCR estimates only 81,300 people resettled in host countries. From the graph it is evident how many people should be resettled each year. [12]
The UNHCR Secretary General encourages Nations to "integrate refugees into national development plans"; this concept is also clearly expressed in the document "Global Trend Forced". [43] The indication by the UN is a straight suggestion of reflection regarding the future of the management of migratory phenomena, especially those due to violent causes.

The aim is to consider these tragic events as opportunities for development. The example is taken from Uganda: indeed, for years it has not only been welcoming refugees from neighbouring countries (particularly from South Sudan), but also offering them stable and safe accommodation within its borders, considering them a precious resource. This is an exemplary and replicable model. Migration flows can be an important opportunity for development and growth for host countries and areas, especially if they are carefully and rationally managed, and from an environmental and social point of view.

1.3.2. **Migrants**

Despite the general increase in the standard of living, there are still pronounced differences between the various areas of the planet. The distribution of wealth on the planet is not homogeneous.

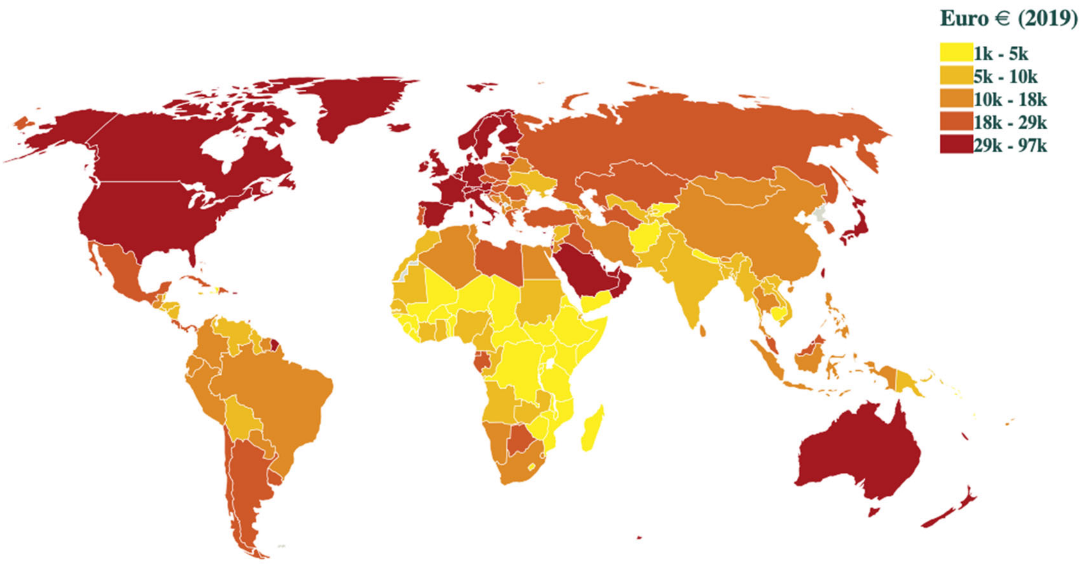

Figure 7 - Average national income - source: wid.world [125]

Inequity inevitably generates migration whose flow is almost entirely directed from the poorest to the richest. [44] However, the phenomenon of migration is overly complex and cannot easily be reduced to merely a movement towards wealth or an escape from poverty.
Migrants can be of various natures:

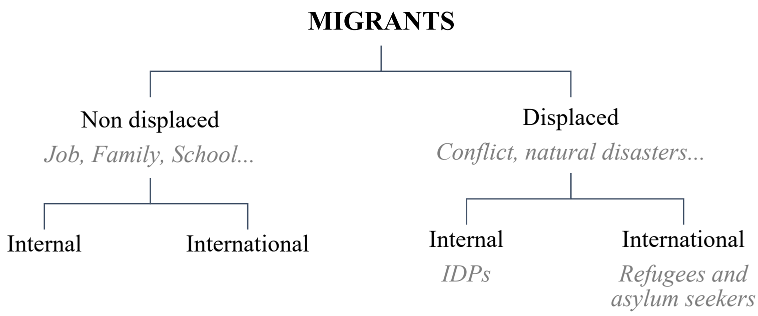

Figure 8 - Migrant's classifications – source: Pew Research Centre [45]

Asylum seekers are "*those who, having left their country of origin and applied for asylum, are still waiting for a decision from the authorities of the host country on their refugee status.*" [46]
The refugee is someone who "*owing to a well-founded fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group or political opinion, is outside the country of his nationality and is unable or, owing to such fear, is unwilling to avail himself of the protection of that country; or who, not having a nationality and being outside the country of his former habitual residence as a result of such events, is unable or, owing to such fear, is unwilling to return to it*". [Article no. 1A of 1951 Geneva Convention on the Status of Refugees]". [47] [48]

Migration flows, thus, can be divided into two streams: voluntary and involuntary. Every year millions of people move around the world, contributing to the need for housing.

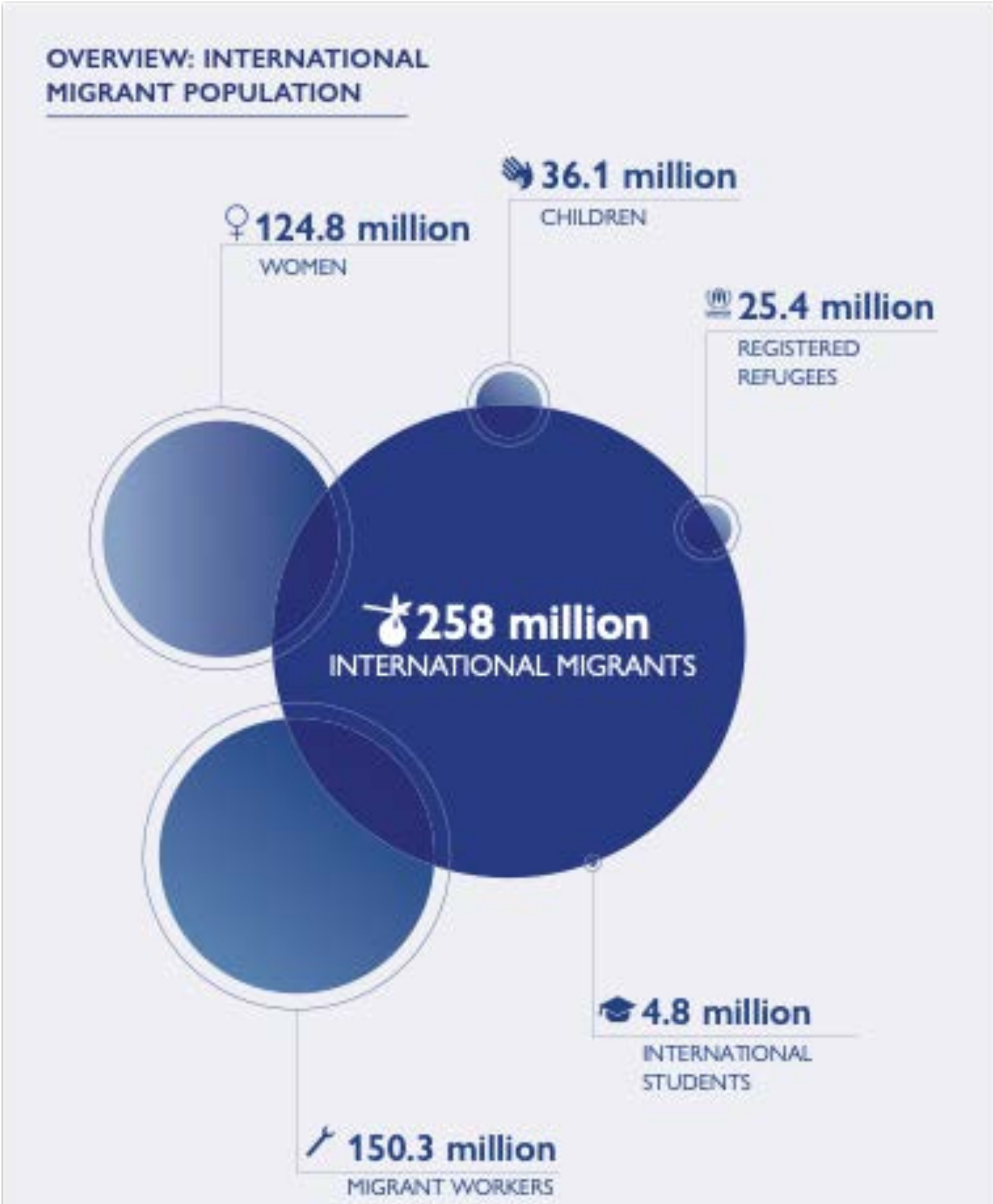

Figure 9 - Global international migrants 2017 - source: UN DESA 2018, UNHCR 2018, ILO 2013, UNESCO 2017 [126]

1.3.3.**Slums**

Between 2000 and 2014, the urban population living in slums decreased by 20% (from 28% to 23%). However, that trend has recently reversed, rising to 23.5% in 2018. The number of people living in slums or informal settlements is 1033 million: East and Southeast Asia 370 million, sub-Saharan Africa 238 million, Central and Southern Asia 227 million and remaining part of the world 199 million. It is estimated that by 2030, 3 billion people will require adequate and affordable housing.
"The growing number of slum dwellers is the result of both urbanization and population growth that are outpacing the construction of new affordable homes. Adequate housing is a human right, and the absence of it negatively affects urban equity and inclusion, health and safety, and livelihood opportunities. Renewed policy attention and increased investments are needed to ensure affordable and adequate housing for all by 2030". [8]

<u>In conclusion, it is evident that the equivalent of an entire continent (Europe plus the USA) currently requires a house.</u>

1.3.4.**Shelter**

A displaced person has automatically a need for a shelter. A shelter is a temporary accommodation that can at least shelter people from the weather outside and provide them with a place that temporarily acts as a "home". "*Shelter is a vital survival mechanism in times of crisis or displacement. It is also key to restoring personal security, self-sufficiency and dignity.".* [49]

These definitions are overly broad and potentially embrace an endless range of circumstances. Each of these cases is unique, and it is not possible to imagine a single solution that would respond to all the infinite facets of the issue.

As mentioned, OCHA has identified clusters that represent the macro areas of intervention in the field of humanitarian aid. [15] The shelter is responsibility of UNHCR. The Global Shelter Cluster (GSC) is a "*coordination mechanism that supports people affected by natural disasters and internally displaced persons in conflict with the means to live in a safe, dignified and adequate shelter. The GSC enables better coordination between all actors in the shelter sector, including local and national governments, so that people in need of shelter assistance get help more quickly and receive the right kind of support."* [50]

The GSC is a public platform chaired by the IFRC and UNHCR at the global level and has 45 partners who regularly participate in it. The IFRC is the convener of the Shelter Cluster in cases of natural disasters, while UNHCR leads the Shelter Cluster in conflict situations. [50]

In 1997, as a result of the growing attention on humanitarian aid issues and the increasing needs in this field, SPHERE was founded. The aim of the movement is to provide standards for humanitarian aid. It is organised into four macro areas: **Water, Food, Shelter** and **Health**. For each of these areas, minimum standards are provided to help and coordinate all actors involved in humanitarian aid. [51]

The main reference document is the Handbook. In this document all the indications for the corresponding areas are expressed. As far as shelter is concerned, an attentive approach to the characteristics and needs of the place of work is encouraged, as well as a focus on a "fluid" approach rather than a sectoral and rigid attitude.

In the Handbook, the chapter dedicated to the shelter is divided into:

1. **Planning**: the section addresses the issue of planning for the many levels and actors involved in emergencies. Particularly, a careful analysis of the situation is encouraged, especially in the pre-emergency phase. Furthermore, an intensive vertical and horizontal collaboration of all authors is recommended. Guidance is also given on the important steps to be taken following a crisis in order to optimise time and resources in providing the greatest assistance to affected populations and places.
2. **Location and settlement planning**: this section focuses on the technical planning of shelter locations. "*Location and settlement planning should promote safe, acceptable and accessible living spaces that offer access to basic services, livelihoods and opportunities to connect to a broader network*."
   The steps needed to achieve that goal are specified, still promoting cooperation and integration with local contexts and a broad vision looking towards the development of the context. The dimension of the refugee lot is also suggested: "*A ratio of shelter footprint to plot size of 1:2 or 1:3 is recommended, to allow sufficient space for the most essential outdoor activities of the households. However, a ratio closer to 1:4 or 1:5 is preferable. The ratio should consider cultural and social norms and practical space availability*."
3. **Living spaces**: the conformation of the accommodation and of the spaces for people are described, to guarantee adequate internal space to allow people to carry out the basic physiological functions of living; an external space necessary to guarantee people's health, social and physiological activities; use of construction materials and techniques that are as culturally, socially and environmentally sustainable as possible. It the continues to provide the dimensions:
   a. minimum 3.5 square metres of living space per person, excluding cooking space, bathing area and sanitation facility.
   b. 4.5-5.5 square metres of living space per person in cold climates or urban settings where internal cooking space and bathing and/or sanitation facilities are included.
   c. Internal floor-to-ceiling height of at least 2 metres (2.6 metres in hot climates) at the highest point.
   d. Set up internal separations while trying to respect the cultures and traditions of the people living in the accommodation.
   e. Provide the accommodation with adequate exits to the outside and ensure that staff know how to report any fears of domestic violence.
   f. Adopt a design of spaces that encourages social life.

g. In hot-humid climates maximize natural ventilation and minimize direct solar gains. Sunscreens can also help with rainfall (beware of climates with strong winds). Suggested materials are "light" materials with high thermal insulation performance. Raised floors.
h. In hot and arid climates, the use of heavy materials is encouraged to take advantage of thermal mass. Alternatively, very thermally insulating materials should be used. Screening and ventilation are desirable. If tents are available, the use of two sheets on the roof separated by a layer of air is recommended to reduce direct heat gain. Positioning doors in the direction of hot winds is discouraged. Continuity between walls and floor is recommended to prevent the entry of dust and disease vectors.
i. In cold climates, low ceilings are recommended to reduce the heated volume. Intelligent use of materials is recommended to take advantage of daily solar gains and provide thermal insulation at night. Minimize air leakage but ensure adequate ventilation in kitchen areas or where stoves are present.
j. Encourage natural ventilation to contribute to indoor air quality and the reduction of mold and smoke in cases of indoor combustion.
k. Pay attention to the proliferation and transmission of diseases.

4. **Household items**: it relates to everyday objects and equipment necessary for the conduct of human life. These items must be suitable for carrying out daily activities in safety and considering different needs according to age, gender, disability, social, cultural and family habits. Proper maintenance must also be ensured, as well as consideration of important factors such as the availability of such items and/or their fuel.
5. **Technical assistance**: technical assistance is an essential part of the aid and must therefore be easily accessible. Consequently, it is necessary to:
   a. Understand pre-crisis planning and construction practices, available materials, skills and capacities.
   b. Involve and support affected people, local government and local professionals in the construction process.
   c. Promote safer building practices to meet current shelter needs and reduce future risks.
   d. Ensure people access to adequate technical assistance, considering the need for specific technical specialists and paying attention to people with disabilities or special needs.
   e. Establish appropriate management of materials, finances, manpower, technical assistance and processes for obtaining regulatory approval requirements to ensure quality outcomes.
6. **Security of tenure**: it means the security for people to live in their homes without fear of being forcibly evicted. It can be achieved by having a thorough understanding of the local legal system, considering the consequences of tenure on "at risk" groups, increasing shelter programmes that encourage the possibility of "ownership", and protecting against the possibility of forced eviction.
7. **Environmental sustainability**: "*Environmental sustainability addresses responsible programming that meets the needs of the present without compromising the ability of future generations to meet their own needs.*"
   a. Integrate environmental impact assessment and management into all housing and settlement planning.
   b. Select the most sustainable materials and techniques from possible options.
   c. Recover and reuse, recycle or re-use available materials, including debris.
   d. Manage solid waste in a safe, timely, culturally sensitive and environmentally sustainable manner in all settlements.
   e. Establish, restore and promote safe, reliable, affordable and environmentally sustainable energy supply systems.
   f. Protect, restore and enhance the ecological value of operational sites (such as temporary settlements) during and after use.

The shelter chapter concludes with appendices schematically summarizing the addressed issues. The Handbook is a valuable tool for people approaching the risk management as it provides both general guidance on strategies and minimum standards, as well as helping to understand how needs and directions change over time. As example, an interesting point to notice: in the 2004, 2011 and 2018 versions of the Handbook (the latest one published) environmental issues and encouragement towards the creation of sustainable and local developmental solutions are dealt with increasing focus. [52] [53] [54]

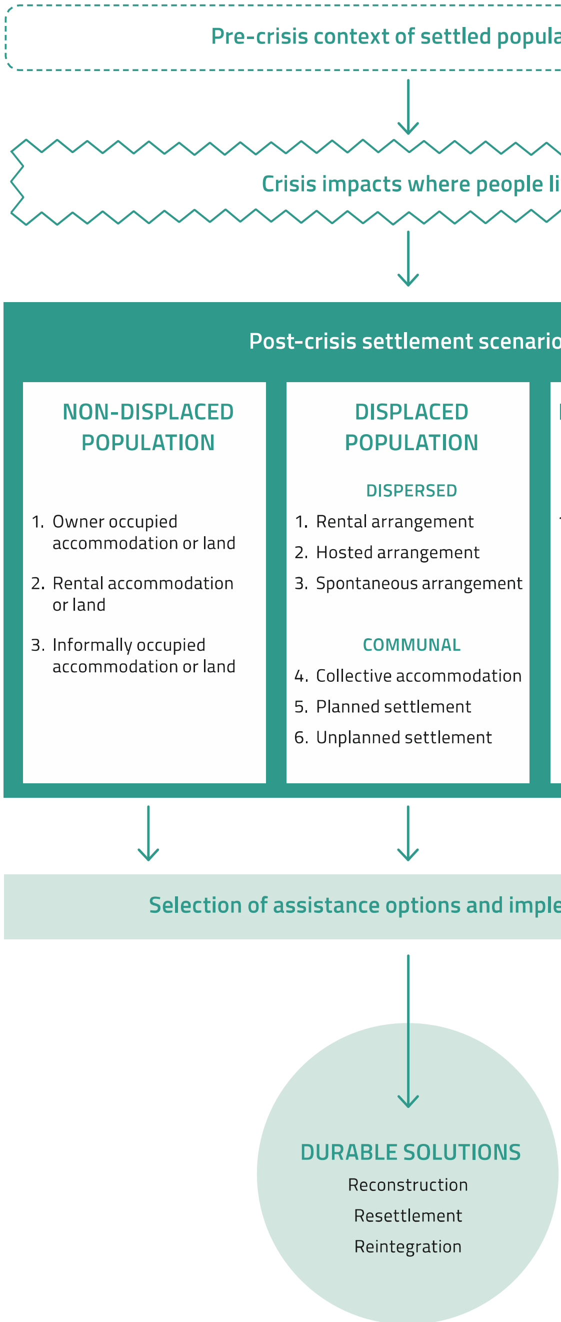

Figure 10 – Post-crisis settlement scenarios - source: Sphere Handbook 2018 [54]

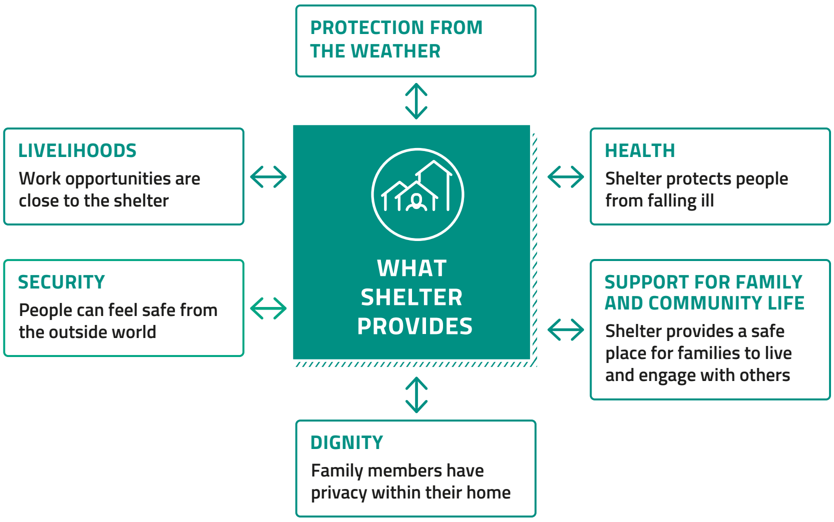

Figure 11 - "What shelter provides" - Some of the functions of appropriate emergency shelter. Shelter programs should support families to meet these needs - source: Sphere Handbook 2018 [56]

In January 2016 UNHCR published the "Shelter Design Catalogue". The purpose of the catalogue is to "*present applied examples of shelter designs in a harmonised manner to allow for quick reference, comparative analysis and contextual evaluation*.". These examples are divided into 3 types: **emergency shelter** designs, **transitional** designs and **durable** designs. [55]

1.4. Field of Application

As highlighted, emergency housing is a widespread and complex issue. One of the main aims of this research is to suggest methodologies for approaching the design, with a particular focus on emergency situations. Therefore, the scope of this work can be extended to the whole wide range of emergency situations. Indeed, the suggested methodology aims to identify ways to standardize as much as possible the components, the design and construction variables, but without reducing the possibilities of technical and compositional choice of the designer. In this way we want to propose a standardization of the quality of living (to make it higher and more widespread), while maintaining the possibility to customize as much as possible according to cultural, social, environmental, and economic needs of each case.

1.5. Aim of the Thesis

The research thesis therefore aims to explore the issues of housing emergencies, with a particular focus on post-disaster and generally unexpected contingency situations. The idea is to apply the opportunities and advantages provided by modern off-site and modular construction technologies to such emergencies, which are to be meant in both construction and design terms. The application of these methodologies can represent an excellent opportunity to approach a problem as widespread and complex as the housing emergency.
The industrial production process is characterized by a strong standardization, which guarantees knowledge and clearness in terms of costs, time, quality and safety standards of the whole production process. Therefore, in such a wide, varied and often unpredictable context, having the possibility to produce several high-quality items in a short time generates an additional value.
As opposed to the traditional construction sector, which suffered a severe setback following the 2008 economic crisis, the manufacturing sector continues to grow. Trends and experts affirm that the only solution for the construction sector to recover and survive is to convert to methods closer to the industrial sector. Off-site construction is taking further steps in this direction every year, with important results both in terms of quantity (production, earnings and extension) and quality (level of product quality and the possibility of precision and finishing).
However, it is diffusely believed that the design part is the current weak point of the whole off-site construction system: indeed, the latter is very advanced and constantly improving from the point of view of production, machinery, technologies and materials in use; while it is still too often anchored to a design approach linked to a traditional building system.

As highlighted in the present chapter, the housing emergency is widespread and is not only concentrated on specific areas, but it affects the whole world, albeit in different ways and with different intensity. The main issues in this matter are certainly time and size. Therefore, the answer to these problems will have both to be able to cover large numbers and, at the same time, to do it quickly. Moreover, it is precisely due to large numbers that, until now, the priority has always been to provide shelter in the shortest time and at minimum costs. The comfort and healthiness of these elements are rarely taken into consideration. It is fair, if the discussion is linked to a truly short deadlines; however, it becomes unacceptable if, as frequently happens, timing is extended until temporary solutions become permanent: the *slums*.

Very often, indeed, it happens that a temporary refugee camp ends up remaining active for years until it turns into an informal settlement and finally into a real city, i.e., a slum.
Taking all these considerations into account, the research will attempt to respond to the questions outlined above. It aims to:
study and design a building system that can respond to these questions quickly and effectively, through artefacts that are: highly transportable; easy to assemble and dismantle; as possible adaptable to different climatic and social situations; comfortable and economically sustainable.

1.6. RESEARCH QUESTIONS

Considering the goal to be achieved, the important aspects to be resolved are:

- **Rapidity** – the *system* should be: easily and instantly designed (ideally also accessible to "non-designers"); produced in a short time and without waste; easy to find and ship; practical to transport to multiple areas worldwide; assembled in a short time, in safety and through as possible participatory process with the local population.
- **Resilient** – the accommodation should be safe and durable.
- **Comfortable** – it should provide the minimum standards of comfort required.
- **Adaptable** – it should adapt to different cultures and climates, and ideally serve functions other than residential.
- **Modifiability** – adaptability is not considered only in spatial terms, rather also temporal: the possibility of modifying and dismantling an accommodation contributes to greatly increasing the resilience, an indispensable prerequisite in a changing world.
- **Sustainability** – it is meant in the generic and broad sense of sustainable development: environmental, economic and social. This issue is particularly important and is expected to pervade every project or action for the future.

All these objectives are fulfilled by the *modular system* which allows it to be scaled up and composed according to needs. The scalability is the main basis for the extreme adaptability, which is needed for such a broad topic as *emergency housing*.
Therefore, it is suggested to find the optimal dimensions of the unitary element, the *module*, to allow the greatest possible flexibility and adaptability of the complete system.
As the behaviour of the single *module* is known and defined, when external and contest conditions vary, the behaviour of more complex architectural systems composed of several *modules* may be composed.

2. STATE OF THE ART

Based on the classification made in the Shelter Design Catalogue, a series of examples for each of these types will follow.

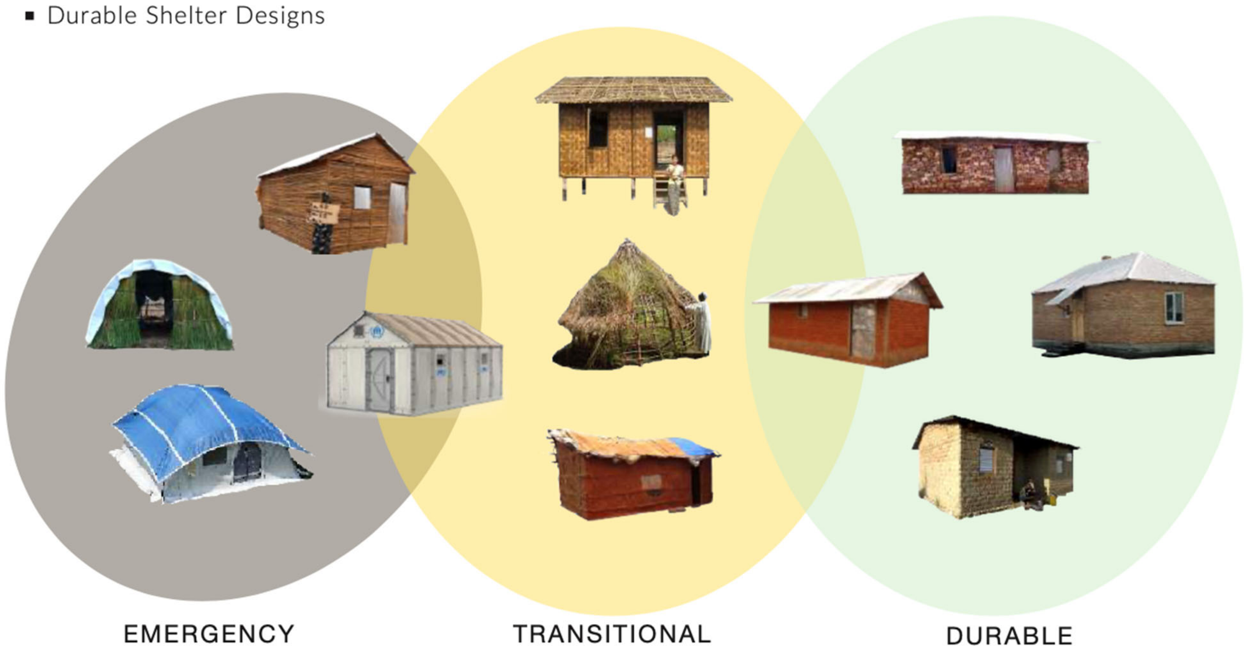

Figure 12 - Classification of shelter - source: Shelter Design Catalogue 2016 by UNHCR [55]

2.1. EMERGENCY

The emergency shelters are the most immediate repairs to create, but they are also the least durable in terms of use and in terms of lifetime of the object itself.

2.1.1.**Tents:**

Tents are the most widely used and popular shelter as they are extremely versatile, practical, and economical. They vary in size and weight and can be manufactured and/or shipped to a large part of the world. They are waterproof and provide limited thermal protection. [56]
The market offers therefore several models, with different prices and possible uses. The main differences between the various models are:
Size: depending on the number of people to be accommodated, tent "sizes" are identified: < 10 m^2, 15 m^2, 25 m^2, 35 m^2, 60 m^2, 100 m^2, 120 m^2, > 120 m^2.
Type: there are not only housing tents, rather also tents for functions such as health, logistics and education.
Storage space: how many units can be crammed into the transport unit: pallet and container. This element is particularly important as it also determines the transport "cost" of the tent itself. Indeed, the weight and space occupied by a single tent also determines how many of them can be taken on a trip. The range varies from a few units per pallet to up to 15 units, from a few dozen to several hundred per container (depending on the size of the container). Weight is also important when considering air transport.
Cost: the cost per unit varies from a few hundred euros (around 150 € is the lowest price observed) to tens of thousands of euros (for the tent single supply it can be up to 20,000 € for particularly large and developed models, such as hospital modules).
Climate: depending on the additional equipment (winter kit, etc.) and the materials used, the range of temperatures and climatic conditions can be quite wide. On this issue in particular, the actual ability of tents to withstand particularly adverse weather conditions are not widely test by studies. On the contrary, the few studies that have been carried out show a low capacity to provide adequate standards of comfort. Generally, tents have a greater ability to withstand cold climates than vice versa.
Equipment: consists of the possibility of customising the basic tent according to requirements. The most common equipment consists of the possibility of adding layers that improve the thermal performance or

fireproof reinforcements for the areas to be used as fireplaces (for cooking and/or heating). Other types of equipment can be used to transform the same tent into a different function: e.g., a dormitory tent can become an intensive care unit, etc. Lastly, there are also specific facilities for certain extremely specific situations. As example, the possibility of treating patients and situations in which it is necessary to guarantee no air contamination between the various environments (e.g., Ebola).
Generally, tents are the easiest, quickest, cheapest, and most practical means of responding to emergency situations. However, it is precisely because of their versatility and "lightness" that they are not suited to more permanent or even stable situations. This is not a remote occurrence, rather on the contrary, it is unfortunately very often an established reality. Indeed, entire communities worldwide are living in tented camps, which started out as temporary and emergency camps and have then become stable.
While always bearing in mind the importance of remedying the difficult situation of a huge number of people requiring immediate and urgent assistance, it is also necessary to draw attention to a problem that is now evident. That is the management of situations that started out as temporary and end up becoming consolidated and stable for many people. There is no reliable data on how many people are currently living in refugee camps, but the number of people living in "insufficient" conditions is around one billion. [8]

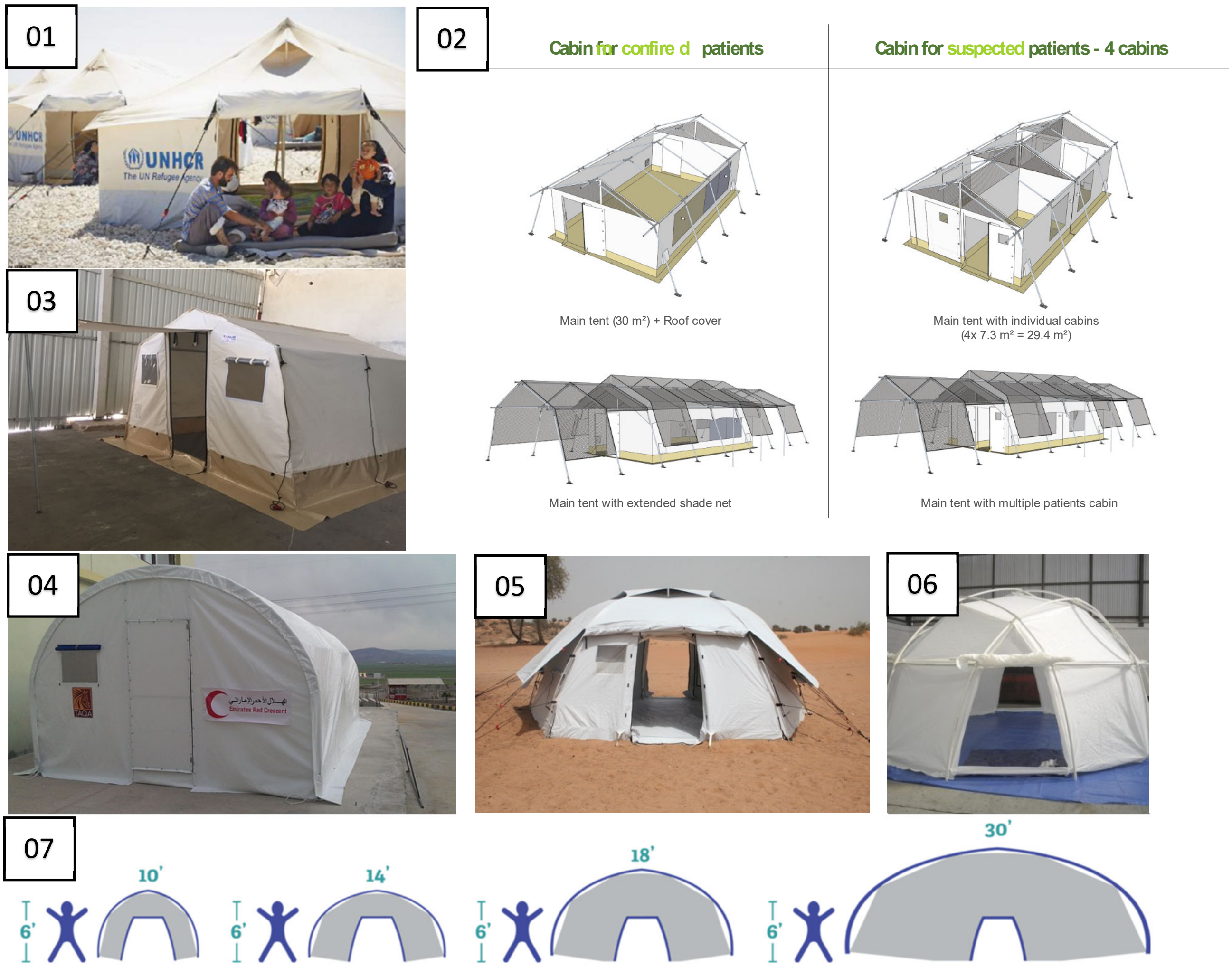

Figure 13 – 01 – UNHCR tent – source: Shelter Design Catalogue 2016 [55]; 02 – NRSRelief LegendMEDI tent. Medical structure with treatment rooms for contagious patients, including hemorrhagic fevers (also COVID19) – source: NRSRelief catalogue [127]; 03-04 – Tanus: Type RT 7 (03) and RT 9 (04) – source: Tanus catalogue [128]; 05 – Alpinter Blue tent – source: Alpinter catalogue [129]; 06-07 – Relief Tents: Model 14' (06) and all model dimensions (07) – source: Relief Tents catalogue [130]

2.1.2.**Solid shelter**

In the emergency category, there are accommodation types that are slightly more structured than tents, with a solid structure and greater shelter possibilities. They generally have a square base and a pitched roof.
As they are robust and therefore have a defined "shape", they also differ from tents in terms of type. In addition to the materials chosen, there are also different types depending on the social and environmental context in which they are to be constructed.
Better Shelter, the shelter developed by IKEA and UNHCR, is a modular lightweight prefabricated element constituted of sections that can be put together in series according to space requirements. The roof and walls are made of polyolefin foam panels treated with UV protection. The structural frame is made of galvanized steel. The door, windows and ventilation hatches are made of UV-stabilized polymeric plastic. [57]
UNHCR has also developed a series of shelters with various finishing and shapes but based on a common basic concept that can be adapted to different contexts, depending on the availability and characteristics of the place (such as materials). The shapes can be the typical pitched structure about 2.5 m high, a "solid" reworking of the Tuareg tent and the typical type of hut with a circular base and conical roof. Starting from these bases, variations are then proposed with different dimensions and above all materials, which can vary from fabrics and panels supplied by UNHCR (in synthetic material), to straw or raw earth, etc. [55]

Figure 14 – 01 – UNHCR Emergency shelter: left top Model I, left down Model II, right top-down Model III, IV and V – source UNHCR Shelter Design Catalogue 2016 [55]; 02 – Better Shelter – source: https://bettershelter.org [57]

A good example of a shelter, which has been developed privately, is "Hexayurt": it is an idea of Vinay Gupta from 2002. It is defined a Light Weight Emergency Tent (LWET) and, indeed, it is an alternative to a tent. It consists of 6 rectangular panels (for the walls) and 6 triangular panels (for the roof) made of cardboard lined with a sheet of reflective material (usually aluminium). The composition ensures a moderate level of insulation and at the same time reflects the sun rays. The panels are fixed together with a strong adhesive tape. They are fixed to the ground by means of tie rods. The panels can be made and combined in different ways according to requirements. This example of accommodation can therefore also be considered "transitional" or "durable", depending on the material the panels are made of and the size of the housing. [58]
In his career, Architect Shigeru Ban has dealt with the issue of emergency housing several times. Particular attention should be paid to the Paper Long House experiment, developed for the 1995 Kobe earthquake. It consists of single-family emergency accommodation built mainly out of cardboard. The foundation consists

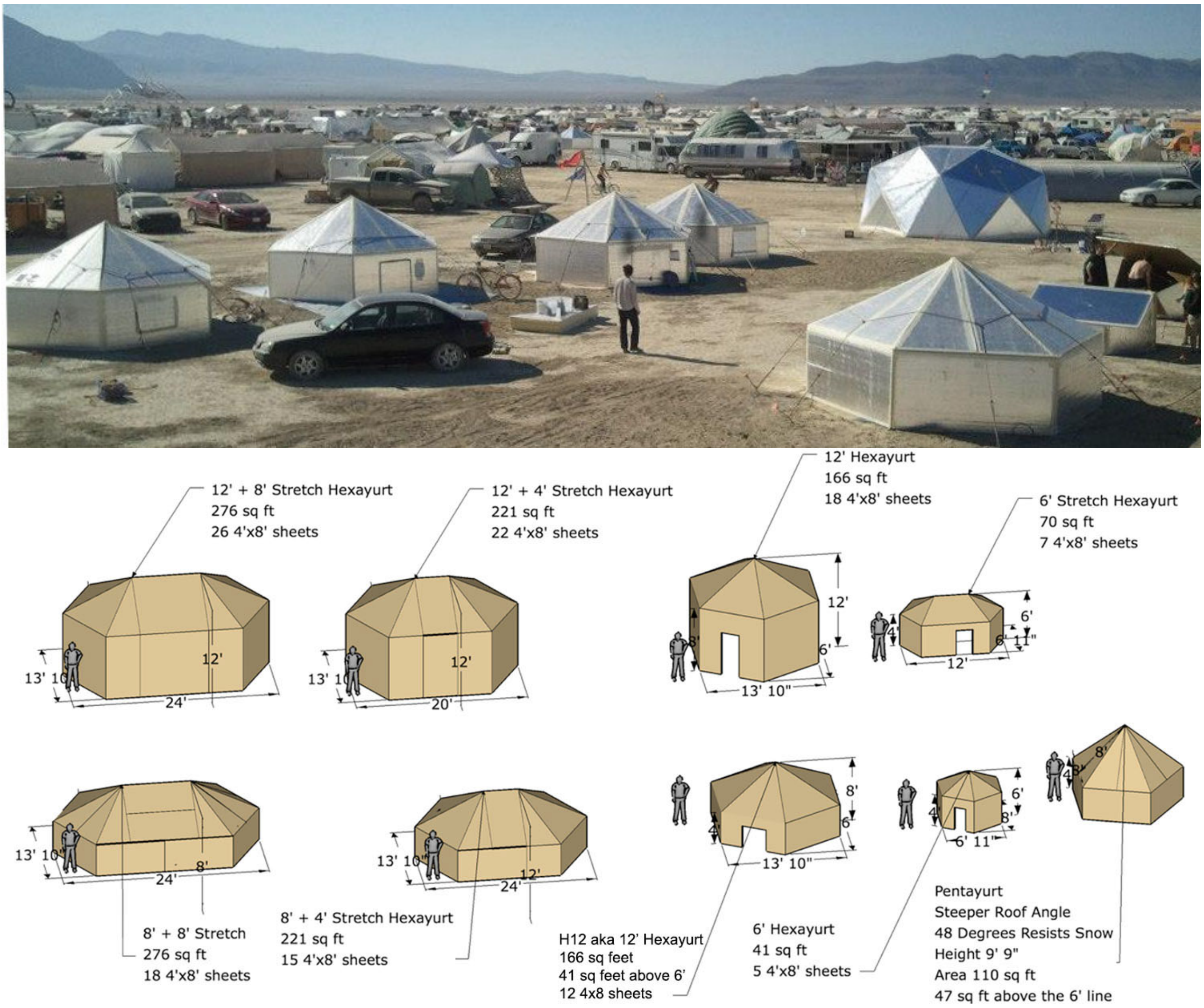

Figure 15 - Hexayurt - source: hexayurt.com [58]

of beer crates loaded with sandbags. The walls are made of paper tubes with a diameter of 106 mm and a thickness of 4 mm. Tent tarpaulins are used for the roof. The 1.8 m space between the houses was used as a common area. A waterproof sponge tape was inserted between the paper tubes of the walls. The unit is easy to dismantle, and the materials are easily disposed of or recycled. Starting from the Paper Long House used in Japan, variants were developed for other countries, such as India, for the 2001 Gujarat earthquake. In particular, the roof was changed in a barrel vault with a bamboo structure and woven bamboo and plastic mats. Also, the foundations were modified, for which the rubble of destroyed buildings was used, topped with a traditional mud floor.
A different variant was used for Kenya (still under development). Three models have been developed: Type A is the one developed from the basic Paper Long House model. It has the same features as the basic model, except for the roof, which has two sloping sheet metal pitches on a cardboard tube truss structure. A tent tarpaulin is however applied under the sheet metal.
They were used also in Turkey in 2000, changing both the roof insulation (in fiberglass) and the insulation in the walls: shredded wastepaper was inserted in the tubes instead.
In 2013 in Daanbantayan, Cebu, Philippines, following the Haiyan typhoon, another variant of the Paper House was tested. The construction methods of previous Paper House projects (in Kobe, Turkey and India) were overly complicated and time-consuming to build in large volumes. In the Philippines project, the Paper Partition System (developed for the construction of partition walls inside evacuation centres) was incorporated; it simplified construction and shortened the construction time. The foundations were made of beer crates filled with sandbags, and the floor panels of coconut wood and plywood. A sheet of bamboo was applied to the paper tube frame, and Nypa palm leaves laid on plastic tarpaulins on the roof. The construction was carried out in collaboration with students from the University of San Carlos in Cebu.

The same model was used for the 2016 earthquake in Ecuador.
A similar idea to the Paper House is the prototype shelter designed in 1994 in collaboration with UNHCR for the Rwanda crisis. In 2010 it was used for the earthquake in Haiti. In this case, the Studio worked with the Universidad Iberoamericana and the Pontificia Universidad Catòlica Madre y Maestra of the Dominican Republic to build 50 shelters out of paper tubes and local materials. The idea is to make a slightly more solid tent: a rigid structure with cardboard tubes, covered with a technical cloth. [59]

Figure 16 – Shigeru Ban Architects, Paper House – source: www.shigerubanarchitects.com [59]

The project, created by Jasmine Mariani and Madison Setiawan, as a response to the refugee crisis displaced after the July 2018 earthquake in Lombok, Indonesia has a similar nature. The accommodation consists of a wooden pole structure covered with straw mats. Each house can be equipped with electrical wiring, a rainwater harvesting system, a water collection tank, a water filter and an easy-to-clean floor covering. “Should this first phase of The Shelter Project in Lombok be successful, the team hopes to continue building countless more homes for those in need on a much more global scale.” [60]

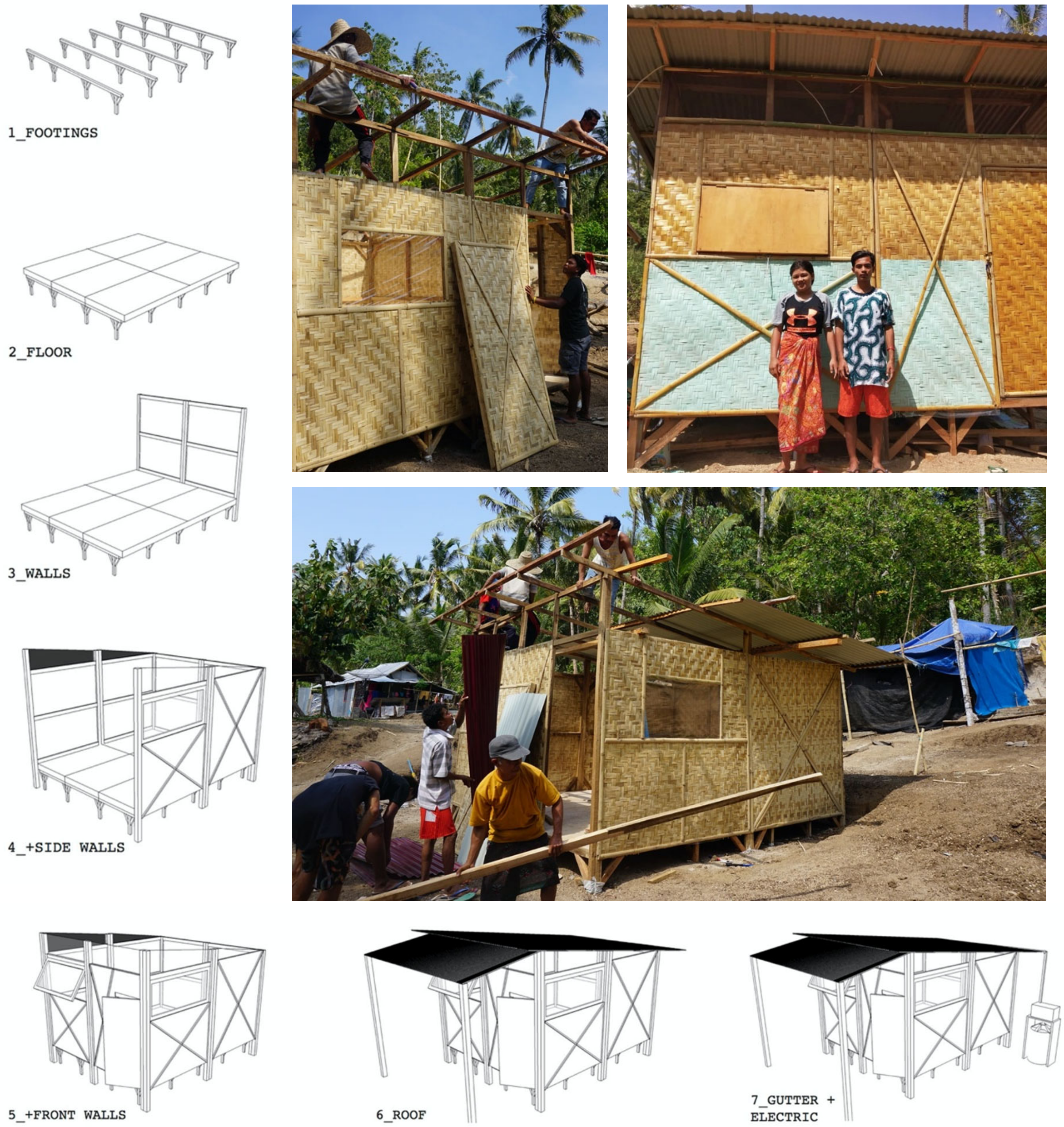

Figure 17 – Jasmine Mariani & Madison Setiawan, The Shelter Project – source: www.theshelterproject.net [60]

The above-mentioned shelters can range from a few hundred Euros to a few thousand.
Generally, there is a lack of documentation and scientific literature regarding the thermal and comfort capacities of emergency "shelters". The information available is provided by the many manufacturers and designers and focuses mainly on the possibilities of storage (and consequently of transport), dimensions, assembly and general ranges of extreme use (e.g., minimum and maximum operating temperature). It is evident that the nature of the choice regarding these issues is clearly political and economic, and that comfort takes a back seat. This is a very understandable approach if applied to circumstantial and emergencies situations with strictly timeframes. However, it may become questionable when the situation becomes more stable over time. Many steps need therefore to be taken in this direction: first, it is necessary to investigate the issue of the comfort of these shelters, and consequently to work on the human living conditions in the camps and informal settlements of which the world is full.

2.2. Transitional

The shelters presented in this paragraph are those used in transitional phases. They are more structured than the emergency shelters, but they still have temporary nature. They are also used in refugee camps, when budgets allow, for areas that have been there for the longest time. In this sense, while the most recent and emergency areas are dealt with using emergency shelters, those that have been there since before use transitional shelters.[1]

UNHCR provides, also in this case, several models for various needs. Due to their structure, they can achieve better performance. Thus, the number of models is reduced: indeed, both the complication of development and use, and the possibilities they may provide, reduce the need for their variety. The basic model is approximately 24 m^2 with a rectangular floor plan and a pitched roof. The materials used, as well as the ground connection, depend on the location.

UNHCR classifies these shelters as transitional, but in relation to what presented above, they could also fall into the "emergency" category. This is because, clearly, this classification is more functional than typological, and it is therefore used here mainly to get a general idea of the state of the art.

T-Shelter: interlocking steel structure, designed to maximize privacy and protect against adverse weather conditions. T-Shelters provide protection against strong winds, dust and extreme weather changes.

Bamboo Shelter: it has a compact eucalyptus cladding with a split bamboo beam and pillar structure and a corrugated iron roof. The shelter has an internal partition, two lockable windows and a door that can be locked from both the inside and outside for added security. The structure is well ventilated and provides adequate protection from rain. Both refugees and many workers in the hosting community have benefited from the project. Indeed, through participation in the construction process, training and prefabrication of the shelters, the project itself has acted as an incentive. It also provided them with livelihood opportunities through the employment generated by the project.

Twin Elevated Shelter: in Myanmar, provided shelter for IDPs until a durable solution could be reached. The dimensions of the elevated shelter are 6.70 m by 5.50 m, two family units of approximately 18 m^2 per unit. The shelter has a wooden frame structure, bamboo mat walls and floors (with wooden support) and a corrugated galvanized iron roof. The materials used are locally produced and adequate to the climate. The construction technique used is based on traditional methods, making it easier for users to maintain and repair. More job opportunities have been created, as people have committed to making the bamboo mats for walls and floors and preparing the straw panels.

Once again, it does not exceed the maximum cost of € 5,000. [55]

Figure 18 – Top: T-Shelter; middle: Bamboo Shelter; down: Twin Elevated Shelter [55]

[1] *Information obtained through dialogue with INTERSOS during 2019-2020. Specifically looking into the case study of refugee camps in Nigeria.*

2.2.1.**Container**

Containers are the main mean of storing and transporting goods in use nowadays. Consequently, all means of transporting goods are also designed and dimensioned based on spaces and units of measurement designed to accommodate containers. The same applies to the production system, which is obviously already well established and optimized.
The weak points in applying this type of artefacts as accommodation are follow described: the transport, which consists in moving an object that has been entirely pre-built and therefore occupies a lot of “empty” volume; the limited possibility of customization in terms of both space and morphology; the expensive cycle in terms of resources and technology required to produce them.
Also in this case, it is possible to consider containers as transitional but also as durable, depending on the circumstances and the level of finish.
The examples currently on the market present mainly the same characteristics and their final prices depend mainly on the level of finishing and the quality of the envelope, as well as the technological equipment (installations, glazing, etc.). The price per m^2 can range from around 250 €/m^2 to just under 1,000 €/m^2. That is, from about €10,000 per unit (14 m^2) to about €50,000 (60 m^2). The modules can be combined to create more complex and spacious buildings. The finishing and quality of the objects can vary greatly (and consequently the price). Many architectural firms have taken up the design challenge of using containers as design modules for emergency and other situations. A particularly good example in this direction is Shigeru Ban’s intervention on the occasion of the earthquake and tsunami in Onagawa (Miyagi prefecture) in 2011. The peculiarity of that intervention is that, in addition to the general quality of the accommodation, a multi-storey system was used for a transitional emergency situation. Indeed, all emergency and transitional shelters have only one floor. In this case, however, the possibility of stacking containers (in this case 20’ containers: 6,058 mm; 2,438 mm; 2,591 mm) was exploited. The result was the possibility of creating multi-storey buildings in line with even open parts (loggias) up to 3 floors. The flats are of 3 types: one consisting of 2 modules (approx. 29.5 m^2) and two variants of 3 modules (approx. 88.6 m^2). [59]

Figure 19 - Shigeru Ban Architects, Onagawa, Miyagi, 2011 recovery plan after earthquake. Floorplan of the three typology of apartments – source: shigerubanarchitects.com [59]

The use of containers presents particular advantages. Indeed, and the example of Onagawa is a demonstration, it is possible to develop extremely comfortable accommodations suitable for an extended period of use. Furthermore, they are in line with the standards of international and worldwide transport.
However, containers even have criticalities: firstly, in terms of thermal comfort and energy consumption, the continuous metal structure is a fragile element; the rigid and pre-established structure does not allow adaptability and customization of spaces; then, the production cycle requires the use of specific resources that are not easily available in all areas of the world, as well as the technology necessary for its construction; from the point of view of transport, the container is a fixed, pre-assembled quadrangular shell, and therefore a large part of the volume that is transported is empty; lastly, the life cycle is rather onerous in terms of impact on the environmental. [2]

2.3. DURABLE

The durable shelter is the closest to the traditional accommodation. They are permanent and can be considered as houses. Even if reduced to a minimum, this accommodation comprises all the elements necessary in a permanent house for a family or individuals. They are generally used in situations where the circumstantial emergency has been absorbed and overcome, or for “chronic” emergency situations such as slums. They are not necessarily of a strictly permanent nature, more precisely it may be said that they do not have a “duration”. That is, they can be kept in place for as long as is deemed appropriate. At this end, it is therefore necessary the comfort of such housing to ensure a dignified survival of its inhabitants for a long time. [61] [62]

2.3.1. **Temporary**

They are the permanent type of accommodation that can still be dismantled. An example is the “MAP” (Moduli Abitativi Provvisori - *Temporary housing modules*), which were used, among the others, following the 2008 L’Aquila earthquake. These dwellings are, to all intents and purposes, minimum homes that were used to host part of the population of L’Aquila and the surrounding areas, while waiting for the city to be restored and fit for habitation. They are served by all the basic infrastructures such as sewers and the energy network. The project envisaged three sizes of accommodation: 40 m^2 - 1 person; 50 m^2 - 2-3 people; 70 m^2 - 4-6 people.
Each winning company had to provide transport to the areas indicated by the administrations, assembly and fixing of the structure, and the necessary connections to water, sewage, electricity and telephone networks. It also had to collect, transport and unload excess materials. The structures were made of wood and were delivered finished and ready for use: they included all the fittings and connections to the electricity and sewage networks. They were placed on concrete slabs. The cost was 760 €/ m^2 for the object itself, also adding the costs of primary urbanization, for a total of 1,700 €/ m^2.
The MAPs represent a fairly successful experiment, appreciated both by the scientific and technical communities and by the local population. However, it is necessary to highlight that these accommodations have encountered criticalities, mainly of two types: the need for serious maintenance following prolonged use (some modules are still inhabited since 2008); and the difficulty of dismantling them when decommissioned. The latter point is particularly important for a building system that calls itself “provisional”. Moreover, assembly and storage are particularly costly in terms of time (more than a month to be assembled) and space (difficulties in storing and transporting such large elements). [63]

Figure 20 - M.A.P. realization and finished - source - Cosimo Colizia and Paolo Marronaro [63]

[2] *Information learned during verbal interviews with: WFP, INTERSOS and UN-HABITAT*

2.3.2. **Durable**

They are those dwellings created based on the idea of staying. An example is the C.A.S.E. project (*Complessi Antisismici Sostenibili Ecocompatibili* – Anti-seismic Sustainable Eco-friendly Complexes), also implemented for the post-earthquake situation in L'Aquila. Unlike the MAs, the C.A.S.E. housing was conceived with the idea of having a durable basic structure and more temporary components, which could be used over time as elements around which the new city of L'Aquila could develop. The C.A.S.E. was a virtuous example, from a strictly technical building point of view, of post-disaster intervention. In few months (23 April 2009 - announcement of the project; 29 September 2009 - assignment of the first 400 dwellings; 19 February 2010 - completion of the entire project) it was possible to design and build housing for about 16,000 people.
All the buildings of the C.A.S.E. are built on two anti-seismic plates (made of reinforced concrete with seismic dampers) measuring 21 m x 57 m, 50 cm thick and spaced 2.7 m apart, in order to accommodate parking spaces between the two plates. The plates are designed to support a 3-storey building of 600 m^2 per floor: 80/100 inhabitants. A total of 150 plates were built. The housing sizes are:

- Studio 36 m^2
- 2 people 54 m^2
- 3/4 people 72 m^2
- 4/5 people 104 m^2

The types of construction were freely chosen by the various companies, as long as dry assembly was guaranteed. The construction techniques used were:

- 50% wood (mainly X-Lam)
- 30% prefabricated concrete (frame)
- 20% steel (frame)

Moreover, the quality of the housing (MAP and C.A.S.E.) is perfectly comparable to traditional housing. The critical points of the post-earthquake interventions in L'Aquila remain in the town planning and territory management. On the other hand, from the technical building point of view, the critical elements can be found at the maintenance level; in fact, currently many of the building compartments of the C.A.S.E. project are in a rather advanced state of deterioration. This, however, is also due to the "transitory" nature of the interventions in examination, which were born with the idea of a city in the making that is taking a long time to be, or has not been at all. [63] [64]

Figure 21 - Progetto C.A.S.E. . Concrete slab, anti-seismic system and finished flat – source: Cosimo Colizia and Paolo Marronaro [63]

2.4. INSPIRATIONAL ELEMENTS

2.4.1. Temporary Architecture

This type of architecture merges with sculpture, differing from it only to the extent that it is possible to "enter" and experience it. Indeed, such architecture often ends up as monuments. Famous examples are the Crystal Palace and the Eiffel Tower. Born with the aim of celebrating the progress of time and intended to be a "performance" of the contemporary.
Such architectures can be useful and inspirational as they are often an expression of the most modern construction technologies, being a kind of celebration of them. Moreover, they were created with the idea of "change". That is, the possibility of being born in one way and varying their composition over time is considered in their nature. A contemporary example is the London 2012 Olympic Quarter. The temporary nature of the sporting event prompted the designers to imagine various phases in the life of the district, e.g., the sporting event. Each intervention was designed with both its use and function during the event and the

more lasting post-event phase in mind. In this way, each stadium, each hall and each swimming pool had structured and definitive elements, which were designed for life in the neighbourhood after the Olympics; and other elements, which were mobile and temporary to host the big event. This experience suggests a more "resilient" and mobile use of architecture that can absorb the variations and changes of time.
This is an increasingly necessary feature in a world that, as mentioned, is constantly and rapidly changing. [64] [65] [66] [67]

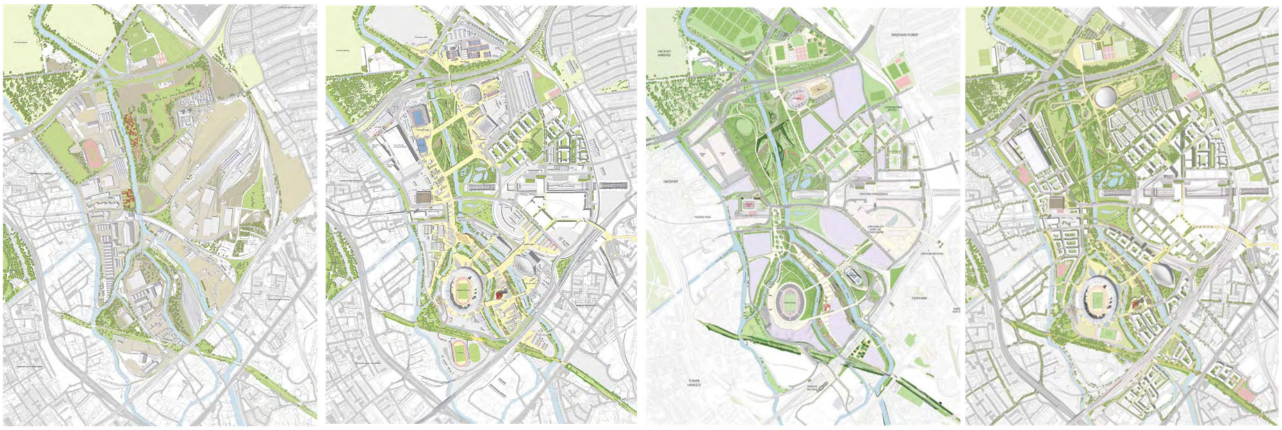

Figure 22 - Masterplan of the Queen Elisabeth Olympic park. From left: 2007, 2012 (Olympic game), transformation masterplan, Olympic Game Legacy masterplan – source: "A walk around Queen Elisabeth Olympic park" MLA+ and London Legacy Development Corporation [131]

Figure 23 - Zaha Hadid Architects, Queen Elisabeth Olympic park Aquatic center (during Olympic game and after) – source: Zaha Hadid Architects

2.4.2. **Mobile Architecture**

The term mobile or transportable architecture defines those buildings that merge with transport. Somehow, a boat can be understood as mobile architecture. During history, there have been many examples of "mobile homes". Most of these examples come from nomadic cultures. The modern and contemporary history of North America is also particularly dense with such examples. Certainly, one of the most identifying examples of this type of accommodation or "building" is the caravan and camper/caravan. They fully embody the mobile nature of architecture (as a place to live). [64] [65]

2.4.3. **Modular Architecture**

Modular architecture is a branch of prefabricated construction (off-Site). "*The term off-site construction refers to processes and work carried out in a controlled environment, away from construction sites or carried out in dedicated spaces close to the construction site* [...]". [68] Simplifying, it is the transposition of the construction world into the manufacturing world. This process, which started in the 19th century, has taken a major turn in the last decade. Thanks to modern mechanical and computer technologies, especially in the field of parameterization, the off-site industry has significantly increased the production and sale of prefabricated buildings, especially in Anglo-Saxon countries.
Following the 2008 crisis, the construction industry suffered a huge decline. Many industry experts, including McKinsey, have identified off-site as an opportunity for the construction industry to recover. Specifically, towards the modular. [69]
The world of prefabricated construction (off-site) has been divided into 7 macro-areas. This subdivision derives from the United Kingdom and has been accepted by other countries, including Italy.
Classification of Off-site construction:

- **Category 1 - Three-dimensional systems**: it is a technological system based on the production of volumetric elements that form three-dimensional units manufactured under controlled conditions for the purpose of subsequent positioning/assembly on site.
- **Category 2 - Two-dimensional systems**: it is a technological system based on the use of flat panels for the conformation of building elements such as floors, vertical walls and roofs.
- **Category 3 - Structural Elements**: it foresees the use of prefabricated structural elements of the framed or massive type produced through engineering processes of wood, hot-rolled or cold-rolled steel and precast concrete.
- **Category 4 - Additive manufacturing**: it is a system of "printing" on site, near site or off site and made from different materials.
- **Category 5 - Off-site**: it brings together different approaches to prefabrication which include the use of single building elements (infill, roofing portions) or assemblies which do not perform a structural function.
- **Category 6 - Traditional system**: it is composed by large single (individual) building products, pre-cut and/or to be assembled in a simple way through joints.
- **Category 7 - Process optimization**: it aims to collect approaches that use innovative techniques applied to work on site and that result in an improvement of the work processes on site.

These categories also correspond to different levels of prefabrication. They are summarized by an index, the PMV (pre-manufactured value) and it "*represents an indicator of manufacturing intensity and measures the value created by the execution of non-site work, out of the total job costs, and is therefore estimated as a percentage of the total costs*".

$$\text{PMV} = \frac{\text{costs of the project} - \text{costs of the construction site} - \text{costs of the work on the construction site}}{\text{costs of the project}}$$

Modular construction is a part of the macro set of off-site construction. It can fit into any of the above-described categories and can take place at various levels. Generally, "modular" is used to describe a process that involves the identification of one or more unitary elements (minimized as much as possible in terms of both quantity and quality) that can be replicated in series. Consequently, due to in-depth knowledge of all the elements composing the module, it is possible to obtain an efficient production, reducing inefficiencies and costs. As matter of facts, such production is repeated and therefore predictable.
The module can then be aggregated with other modules to form a complex system. Modular construction, therefore, reduces inefficiencies in the entire process, resulting less expensive and less time consuming.
McKinsey's 2019 report "Modular construction: From projects to products" indicates the potential of modular construction for the construction industry: $130 billion in potential gains; $22 billion in savings; $1,600 billion productivity gap compared to 2017. These are just some of the numbers highlighted in the report.
Working on modularity and prefabrication would therefore make it possible to have mass production of modules that can be aggregated at will and according to requirements. It would guarantee qualitative and productive standardization, without sacrificing customization of spaces and finishing. [68] [70] [71] [72] [73] [74] [75]

2.4.4. **Sustainable Architecture**

As consequence to the various energy crises, the awareness on the need for more energy-efficient architecture has increased. [76] Generally, energy consumption goes parallel with indoor comfort. Indeed, the increased energy use of buildings is functional to modify and maintain indoor environmental conditions.
The latest news about the state of the planet's environmental health has further increased research and efforts towards an economic, productive, social and general living system free from the current slavery to environmental pollution. [77] The field of building design is increasingly developing buildings with an extremely low environmental impact. Great contribution comes from the study of past methodologies of microclimatic regulation, dating back to times when it was necessary to make maximum use of the characteristics and opportunities of the place to improve human living conditions. [78] [79] [80]
The process of awareness-raising and systematization of local knowledge in construction began in the 1960s. One of the fathers of this process, and of sustainable architecture in general, is Victor Olgyay. His studies, in particular his book "Design with climate" (1963), are still a valuable source of knowledge about techniques and strategies of bioclimatic architecture.

There studies in this direction are copious, both in terms of design techniques and of technical and technological possibilities.
Broadly, this process has led to the possibility of creating buildings with high standards of comfort and with zero or even passive energy consumption (they produce energy instead).
The main assumption of sustainable architecture is the concept of making maximum use of the characteristics of the place where you are building. For instance, whenever artificial interventions are made to change the environmental conditions, energy must be used. To achieve this point, a constant exchange between building and environment is therefore necessary.
Each contemporary and future building must necessarily turn in this direction. Consequently, sustainability is one of the main requirements of the system this research aims to analyse.
Even in the field of emergencies, such an approach is increasingly required, as the environmental crisis has become more and more widespread and therefore pressing for all fields.
Every part of the world has specific microclimatic conditions. They are subject to continuous changes: seasonal, daily and instantaneous. However, trends, which are identifiable that have served to catalogue them. Cataloguing is needed to highlight certain characteristics. External and microclimatic conditions have always conditioned the architectural choices and techniques of all peoples.
For ease of reference, it was decided to limit this variety to 4 macro areas, characteristic of different climatic types: temperate, cold, hot dry and hot humid. These 4 differentiations (also adopted by Olgyay) provide a sufficiently complete picture of the global behaviour. [81]
As a result of the energy crises of the 1970s and the consequent growing attention to environmental and energy-saving matters, from the late 1980s to the 1990s important scientific and political steps were taken towards the definition of solid strategies and regulations for energy saving and environmental protection. Below a brief timeline of the steps taken in this direction is provided:

- **1987 – Brundtland Report** – "Our Common Future": United Nations report named after Gro Harlem Brundtland, president of the WCED (World Commission on Environment and Development), established in 1983. The report clearly identifies a disparity between the 'developed" world and the remaining emerging world, including in terms of production and consumption. The disparity, according to the report, is the basis of an inequality that contributes, among other elements, to environmental deterioration. It was in this context that the definition of "sustainable development" was born, and still forms the basis for development and strategies to curb environmental pollution. This impetus gave rise to UNCED (United Nations Conference on Environment and Development).
- **1992 – UNCED of Rio** – United Nations Conference on Environmental and Development at Rio de Janeiro. 172 countries met to discuss the issues of poverty, growing inequality between countries, and difficulties in the social, economic and environmental spheres. The conference resulted in three non-binding agreements (Agenda 21, Rio Declaration and Declaration on Sustainable Forest Management) and two binding conventions (Framework Convention on Climate Change, Conversion of Biological Diversity).
    - **Agenda 21**: global action program towards sustainable development on four points: economic and social, intelligent resource management, strengthening the role of social forces and implementation instruments. [82]
    - **Rio de Janeiro Declaration on Environment and Development**: it establishes 27 rights and obligations of nations; it gives a fundamental role to the principles of causality and prevention and defines the basic preconditions for sustainable development [83]
    - **Declaration of Principles for the Sustainable Management of Forests**: it defines the responsible use of forests [83]
    - **Framework Convention on Climate Change**: it limits the production of greenhouse gases, not endangering the future of the planet [84]
    - **Convention on Biological Diversity**: it highlights the importance of protecting biodiversity [85]
- **1995 – COP 1: Conference of the Parties** – First Conference of the Parties on Climate Change (COP 1) in Berlin, Germany. Not particularly significant except as for being the first in a long series. At the conference, concerns were raised about the viability of the restraint measures expressed at the Rio Conference and a two-year *Analytical and Assessment Phase* (AAP) was agreed.
- **1997 – COP 3: Kyoto Climate Change Conference** – the first binding international treaty committing signatory states to reduce greenhouse gas emissions. Specifically, it requires a reduction

in greenhouse gases of no less than 8.65% compared to 1990 emissions in the period 2008-2012. Furthermore, the Kyoto Protocol allows signatory countries to convert their emissions into “credits” [86]

- Clean Development Mechanism (CDM): allows companies from more industrialized countries with emission constraints to carry out projects in developing countries, without emission limits. These projects must focus on reducing greenhouse gases in these countries, on economic development and social development. These “credits” are called CERs - Certified Emission Reduction. 1 CER = 1 tCO_2eq. [87]
- Joint Implementation (JI): allows companies from the most industrialized countries to implement projects within the same group (i.e., between industrialized countries) aiming at reducing greenhouse gas emissions, operating without an emissions constraint. Credits from these operations can be used by both countries: the project country (host country) and the country operating the project. [88]
- Emissions Trading (ET): allows the “trading” of CERs. A country that has a surplus of emission credits can trade these credits with a country that has a deficit. [89]

- **2015 – COP 21: Paris Agreement on Climate Change** – treaty signed by 196 countries that commit to adopt drastic measures to contain global warming within the limits of 1.5°C and well below 2°C. These limits are derived from the IPCC report [7]. The EU has committed to a reduction of at least 40% in emissions by 2030 compared to 1990 levels. The EU’s commitment to reducing greenhouse gases and energy consumption is described in the *2030 climate & energy framework* proposed in September 2020 as part of the *European Green Deal*. [90] [91] [92]
- **2015 – Agenda 2030: Transforming our world** – the agreement defines the general strategies for action for the 2020-2030 decade. These strategies are aimed at achieving a more sustainable and equitable world. In paragraph 52 of 92, 17 *Goals* are identified, which will become known as Sustainable Development Goals (SDGs) and which represent goals to be achieved to achieve a “better and sustainable future”. The 17 *Goals* are: [93]
  - **Goal 1 - No Poverty**: End poverty in all its forms everywhere
  - **Goal 2 - Zero Hunger**: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
  - **Goal 3 - Good Health and Well-Being**: Ensure healthy lives and promote well-being for all at all ages
  - **Goal 4 - Quality Education**: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
  - **Goal 5 - Gender Equality**: Achieve gender equality and empower all women and girls
  - **Goal 6 - Clean Water and Sanitation**: Ensure availability and sustainable management of water and sanitation for all
  - **Goal 7 - Affordable and Clean Energy**: Ensure access to affordable, reliable, sustainable and modern energy for all
  - **Goal 8 - Decent Work and Economic Growth**: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
  - **Goal 9 - Industry, Innovation and Infrastructure**: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
  - **Goal 10 - Reduced Inequalities**: Reduce inequality within and among countries
  - **Goal 11 - Sustainable Cities and Communities**: Make cities and human settlements inclusive, safe, resilient and sustainable
  - **Goal 12 - Responsible Consumption and Production**: Ensure sustainable consumption and production patterns
  - **Goal 13 - Climate Action**: Take urgent action to combat climate change and its impacts[3]

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[3] Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.

- **Goal 14 - Life Below Water**: Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- **Goal 15 - Life on Land**: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
- **Goal 16 - Peace, Justice and Strong Institutions**: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
- **Goal 17 - Partnership for the Goals**: Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

2.5. Conclusions

The current offer for emergency shelter presents a wide variety of proposals. An overview of these proposals has been proposed in this chapter. It is evident from this overview that this issue is very important and of common interest.

Drawing a conclusion about what is currently on the market and the strategies in the field, we can deduce that:

- the recurring theme of all interventions is the cost. A low cost is one of the main (perhaps the main itself), characteristic that an emergency shelter must have.
- Speed of construction is certainly the second most important characteristic.
- Transport is also a very important consideration, especially in the case of "Emergency Shelter".

These elements highlight, however, two major gaps in the approach to emergencies: comfort and sustainability. These two factors are becoming increasingly important: as regards sustainability, it is obviously an increasingly widespread and unavoidable issue; as regards comfort, it is quite clear (as we have seen) that emergency situations or temporary accommodation in general very often end up becoming permanent or almost permanent. Therefore, the issue of comfort of accommodation is gaining significance and importance. The system being researched consequently aims to explore the possibility of identifying new buildings and design systems that can compensate for these deficiencies and at the same time satisfy the needs of emergency accommodation, primarily by exploiting the opportunities provided by off-site and modular construction, and a standardised design approach, in order to have industrial products with high quality standards and low production costs.

The system in question is mainly in the "transitional" range and upwards. Because of its rather defined structures and because of extremely contingent and fast-moving situations, it is difficult, at present, find something better than the tent (or similar).

3. THEORETICAL MODEL

Based on what has emerged in the previous chapters, a widespread housing emergency is evident in current times. The number of people without access to housing, for a wide variety of reasons, is increasing from year to year. Housing and buildings are intricately linked to human life, and it is therefore necessary to investigate how these elements can respond to the challenges of the times. This research aims to explore the different approaches to the theme of housing and buildings in general, with attention to situations of "emergency". Emergency that, as we have seen, can be a very wide term that, all things considered, goes from post-disaster situations to *slums*, to migratory flows and city suburbs. Currently, the building, in its broadest and most generic meaning, is a rather static and "definitive" element and is ill-suited to a dynamic context such as modern living. Every year the world moves faster and faster. Resilience to change and adaptation become more and more necessary attributes to assist and support mankind in this increasingly "fluid" and ever-changing world [94].

Even figuratively, the monolithic residential blocks of the post-war period and of the '70s, result of a passed philosophy, do not fit well with an image of a "fluid" society. Therefore, the idea is to address the issue of living and building trying to set the goal of incorporating all the needs that emerged from the analysis carried out, laying the foundation for a debate and deeper research on the issue of contemporary living. The possibilities given by the new technologies applied to construction (off-site and modular) make it possible to transpose the efficiency of industry to the building sector [69]. This allows to respond to such a pressing and important demand, reducing inefficiencies, and to spread the product more widely.

Adaptability and sustainability represent a proper synthesis of the needs of such a building system that aims to respond to the complex problems mentioned above.

Such a problem deserves a multidisciplinary approach that concerns elements of sociology, engineering and architecture etc. This research intends to establish the basis of a methodology that can provide technical and design tools to the actors involved in the field of emergencies: guidelines that help to develop and produce solutions to such a complex and urgent issue.

Methodologically, the process has been divided into 4 parts:

- Problem identification (chapters 1 and 2)
- Identification of the ideal objectives: Theoretical Model (chapter 3)
- Transformation of the ideal theoretical model into an architectural project: Real Model (chapter 4)
- Application of the architectural project in a technical/realistic study (chapter 5).

Chapter 3 outlines the ideal declinations of the system: **adaptability** and **sustainability**.

3.1. ADAPTABILITY

Housing emergencies are extremely vast, and they impact the entire world, and it is difficult to imagine a one-size-fits-all solution. It is appropriate to look for systems that can adapt to various contexts. In general, adaptability in space and time exists. By *adaptability in space,* we mean the possibility of creating environments that are congenial to the most varied needs and that integrate, exploiting the characteristics, with the places where they arise. *Adaptability over time*, on the other hand, means the possibility of change, modifiability, according to needs and external environmental, social and economic conditions. Therefore, inflexible, static and slow systems are not only difficult to adapt to emergency situations but can also be an obstacle, if not a worsening element. The system being studied must therefore be able to adapt to a wide context and at the same time be quick both to realize itself and to be eventually modified.

Prefabrication of the building system is an excellent opportunity in this regard, as it allows for faster, larger and safer production than the traditional building system. The first category of the off-site classification is the three-dimensional system, as already exposed (Chapter n.2.4.3.), consists in the realization of three-dimensional elements as finished as possible, which are shipped and assembled on site. This type of element is certainly the one that allows the greatest exploitation of the potential of off-site construction and therefore of the industrial production system. However, it is hardly adaptable. In fact, once the element to be produced has been designed, it is no longer modifiable. This would imply a different project and product for each situation. This procedure would not fit what we have seen so far: we would have an innovative and industrial production system on a traditional "site specific" design and approach.

On the contrary, the need for adaptability is also understood in terms of design and personalization of spaces. Ideally, we would need a system capable of providing (high) quality standards for all, while, at the same time, being able to be elastically interpreted in terms of space, needs, and resources available to each individual or

community. In addition, the three-dimensional off-site system requires significant resources and high technical capabilities to be transported and mounted [95].
For these reasons, it was preferred to adopt the systems shown in categories 2 and 3: two-dimensional systems and structural elements, i.e., prefabrication of entire two-dimensional finite elements (walls, floors, roofs etc.) and single structural elements (columns, beams etc.). These elements, among other things, are easier to transport. Whole finished walls or floors, however, present the same rigidity problems seen for three-dimensional systems; they are, however, cumbersome, expensive and technically complex elements to realize. In order to overcome this problem, it was deemed appropriate to split the elements, reducing them to the minimum size and giving the possibility to add or remove elements as needed. The modular system well suits this approach. In fact, working on the module (unitary system) it is possible to obtain complex systems by aggregating multiple elements [96]. The more the unitary system – *the module* -, is minimized, the more the resulting complex systems can be customizable and adaptable. The size of the unit determines the accuracy of the composed object following that unit. That said, it becomes necessary to find the module that can vary in the three dimensions and minimizes the variations of the individual pieces.
Since ancient times, when trying to rationalize and optimize space and living spaces, man has often used orthogonal systems. It is probably an ancestral element that in its simplicity helps to find an order and a repeatability in more complex and vast systems. The quadrangle is therefore an element that has accompanied the history of human architecture since the beginning. Juxtaposing several squares in an orderly fashion creates a grid.
Consequently, if the right angle and the quadrangle have guided buildings, the grid has been the basis of development for many neighbourhoods and settlements [80] [97].
The square, in this perspective, is nothing more than a module; the grid is consequently the complex system derived from the juxtaposition of several modules. The grid was used in the Hellenistic age [98], as in the Roman castra [99].
Later, it dictated the basis for the development of large cities such as New York and Barcelona. Rem Koolhaas even claims that it was the grid that allowed for the resilient development of Manhattan [100].
Le Corbusier built the idea of the *Maison Dom-Ino* on the idea of the grid, as well as the *unitè d'habitation* [101] [102], which in this case is not only limited to the plan level but also to the elevation, bringing the idea of the module into three dimensions. In general, it can be argued that an important element of rationalist architecture comes from the study of the measure, of the module (in 1948 Le Corbusier published the *Modulor*) [103] [104].
The idea of modularity survived the end of the modern movement, giving rise to numerous post-war examples of large-scale modular architecture with buildings, prototypes and projects [65] [105] [106] [107].

Figure 12 - Manhattan grid - Delirious New York - Rem Koolhaas; Unité d'Habitation - Le Corbusier; Habitat 67 - Moshe Safdie; Nakagin Capsule Tower - Kishō Kurokawa

It was therefore decided to develop a system from categories 2 and 3 of the off-site construction (two-dimensional elements and structural elements) because they allow a modular approach of the right size to exploit the potential of prefabrication, but at the same time have adaptability and freedom of use. It was decided to use a structural frame system to have a grid that is always the same and repeatable, regardless of the internal divisions. For the size of the module, it is necessary to have the same dimensions in plan and in elevation. It has been chosen to use the length of 3,00 m in all directions: indeed, as a height it meets the minimum height standards for western residential buildings (2,70 m); and as a plan it is the minimum size of a single room (9 m^2). It is also particularly congenial for internal divisions: 0,90 m is the width of a door with disabled access, and 2,10 m is the minimum height of each door[4].

[4] *0,90 x 2,10 m are not 3 m modules. In the following chapters, this issue will be discussed in more detail.*

The *module* of 3,00 m (which is a multiple of 60 cm, the width of a person) is a synthesis that fit both in height and in plan. Later, we will see how this is a starting point that will be developed and modified according to the needs that arise.
In conclusion, the experimental base module is a cube with a side of 3,00 m. The *grid* is made up of the juxtaposition of 3,00 m squares interspersed with a 0,30 m thick structural mesh. Indifferently between elevation and plan.
By aggregating the 3,00 m module, it is possible to customise the height (choose the number of floors to be used) and plan (aggregate the number of rooms and in the wished position). To size rooms smaller than 3,00 m x 3,00 m a sub-module is 1,00 m can be used.

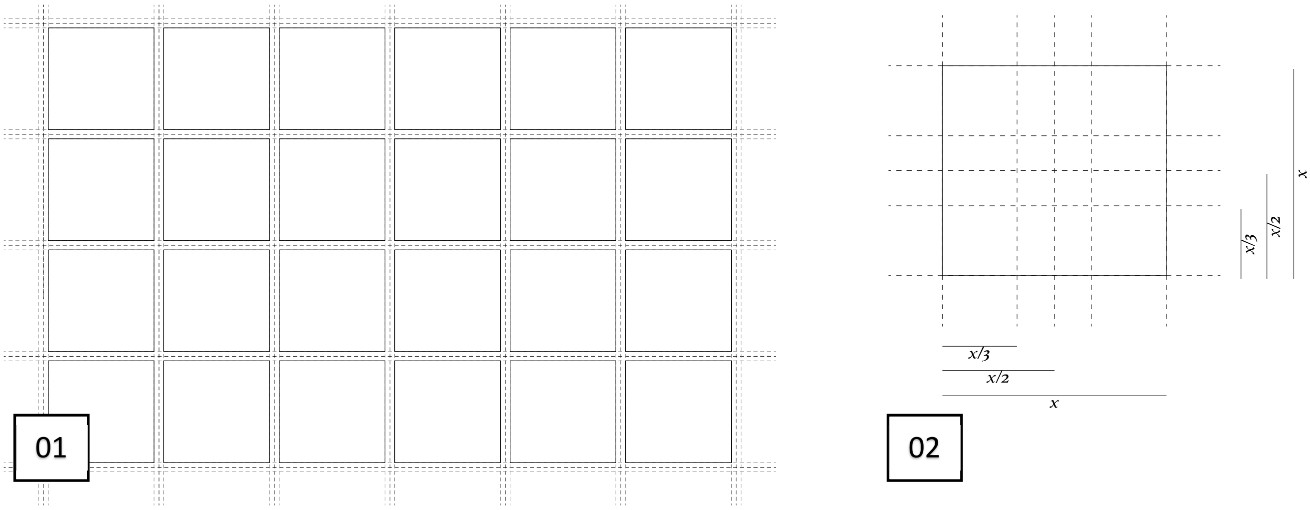


Figure 14 – 01- Module-grid (plant and elevation) 3,00 m x 3,00 m and structural grid 0,30 m. 02 - The module composition

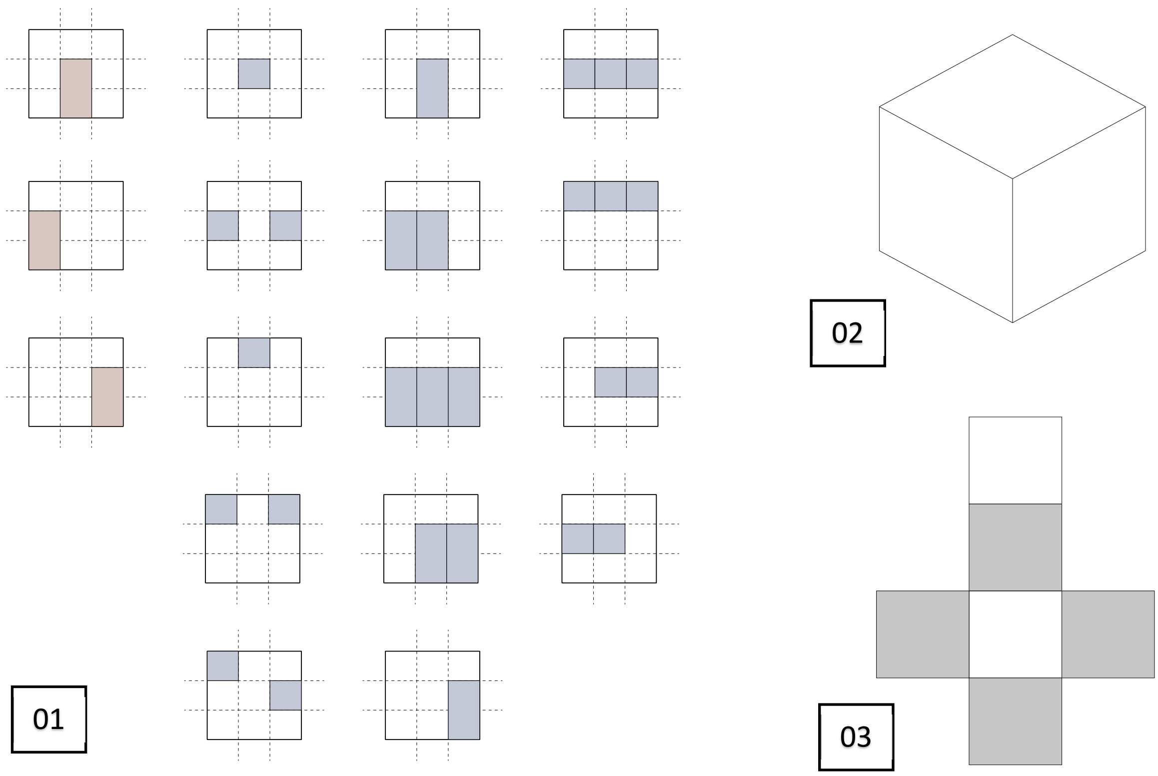


Figure 13 – 01 – Possible composition of the façade; 02 – The 3D module; 03 – Opened box of the module 3D

3.2. Sustainability

As far as the useful life of the structures and buildings is concerned, three temporal phases can be identified: **construction**, **use** and **decommissioning**. [108] [109]
The *use phase* will be analysed because the architectural design it is the most incisive, influential and that can be influenced.
As far as the phases of construction and decommissioning are concerned, we have limited ourselves to working on a building system that is as open as possible, i.e., that can be used with different technologies and materials. The choice of a specific material or production system necessarily implies a limitation of the action of the system itself. For example, a structural system made of steel would necessarily limit the use of the system to places and communities that have a supply chain capable of producing all the elements needed to make such a product, without the need for expensive (economic and environmental) transport costs. Not to mention the absence of the beneficial impact on communities affected by the emergence of "0 km" production systems. Production sustainability is therefore to be sought not in products but in production systems and processes that can be exported to various contexts. For this matter, it was decided to design a process that can be applied to different construction systems and materials, precisely to encourage local production chains as much as possible.
The same applies to the issue of *disposal*. In fact, the possibility of using different materials is an issue that allows the possibility of considering the "cost" of decommissioning when designing and building these objects. A system conceived for just one material limits the possibilities of action in the decommissioning phase. On the contrary, an "open theoretical model" allows the system to be adapted each time according to the resources and possibilities of the place and situation.
As matter of fact, the proposed system is not intended to be closed and finished, to be dropped into a precise and static situation. On the contrary, it is meant to provide a series of "tools" and guidelines that can be used to provide a rapid response to a serious emergency situation such as that of "housing" and that can transform difficult situations into opportunities for development in extremely varied contexts.
The *use* of buildings, in terms of sustainability, is, according to this thesis, mainly represented by the comfort/energy demand ratio [110].
Buildings are "artificial environments" in which the conditions of well-being are best guaranteed. Today's technologies allow, much more than in the past, to intervene on these conditions and to make them as personalized as possible. It, of course, involves costs, primarily energy costs. The focus is on the comfort/need ratio, highlighting the optimal module configurations by studying it in four typical climatic ranges: temperate, cold, hot-dry and hot-humid [81].
The energy analyses were all carried out considering only one isolated *module* (the cube with 3,00 m edge). The applicability of the results of the study cannot be automatically "additive": i.e., the behaviour of the single element is not a sufficient condition to directly identify the behaviour of the sum of several elements of the same type from the bioclimatic and energy demand point of view. Such consideration may represent an important starting point for subsequent working hypotheses.

3.2.1. **Comfort**

Thermal comfort is currently defined by ASHRAE as "the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation" [111].
According to this definition, comfort would therefore be a completely subjective condition, impossible to measure; and therefore, by personalising the definition, it is impossible to create an object or an environment that is objectively judgable as comfortable for everyone. There have been various attempts to objectify the concept of comfort, and the most accredited is the "statistical" one (e.g., the concept of effective temperature gives a good idea of the reference group, since by varying the parameters of air speed, humidity and temperature, the majority of subjects obtain a sensation of well-being).
On the basis of these considerations, the temperature parameter was taken as the most influential indicator to define the degree of comfort of the *module*. Air speed and air humidity were not addressed directly, although, they are obviously indirectly influenced by the 5 parameters identified (Chapter 3.2.4.). About lighting, a comparative study was made based exclusively on natural daylight. The contribution of artificial light was considered generically as always satisfied. The study on the natural light of the *module*, varying the size and exposure of the transparent component of the envelope, has led to a specific scientific publication [paper awaiting publication - IHAS 2019], the results of which show guaranteed minimum values in all the configurations of the transparent surfaces studied.

The thermal element was therefore chosen as the main parameter. Conventionally, the thermal comfort zone is placed within the range 20° C - 26° C. Therefore, the simulation software was set with temperature values inside the *module* included in such minimum and maximum range. The period of analysis and study of the energy behaviour of the *module* was set at 52 weeks. A yearly analysis would limit the understanding of the variations due to the alternation of day and night. A daily information would have led to an excessive production of data, which would have been difficult to manage. The time range of 7 days allows to determine the influence of the differences between day and night with a more readable number of results.

3.2.2. **Needs**

Once the range of thermal comfort has been set (20° - 26° C), there are technologically various ways of achieving it (e.g., simple air conditioning systems). Since the industrial revolutions until recent times, the achievement of such objectives was mostly delegated to artificial systems, which can guarantee perfectly customisable conditions regardless of the context conditions. With the growing awareness of environmental issues, in particular energy saving, passive strategies (e.g., solar gains) have been increasingly studied. The environmental crisis is largely generated by the increasing need for energy, which is mainly used by buildings, with air conditioning being the main cause. [112]
Therefore, indoor climatic conditions are particularly important in terms of both quality of human life and energy consumption. A correct exploitation of the climatic conditions of the location and an adequate use of the building components can considerably vary the energy needs of the building. Design and technical choices, therefore, considerably influence the energy needs of buildings. Having chosen the thermal parameter as the main objective, the demand (represented by the thermal energy, expressed in thermal kWh, needed to modify the internal temperature of the module in order to keep it in the range of 20° C - 26° C) is the quantitative method of classifying efficiency.

3.2.3.**Schedule – internal functioning**

Given the definition of the geometric element (3x3 module), the target (20°C - 26°C), the quantitative method of classifying the effectiveness (thermal kWh) and the external conditions (the 4 climate bands) were identified and set within the software as internal reference conditions. The reason behind this choice was to create a rather plausible theoretical model. The sheet of the internal heat loads set for the *module* is represented below:

Table 1 - internal loads

Parameter	**Value**	**Schedule**
Infiltration	1,2 Vol/h	
Ventilation	1,8 Vol/h	
Lighting loads	12,0 W/m^2	06:00 – 13:00; 14:00 – 20:00
Sensible occupants load	10,0 W/m^2	06:00 – 13:00; 14:00 – 20:00
Latent occupants load	5,0 W/m^2	06:00 – 13:00; 14:00 – 20:00
Equipment loads	15,0 W/m^2	

3.2.4.**Parameters**

The face of the *module* (3x3) was spatially divided into 9 *sub-modules* of 1,00 m on each face (Figure 24). Each of these 9 squares can be technically composed in a different way. For example, it can be opaque or transparent, made of concrete or wood, etc. These choices determine the consequences both of the construction and of the installation. They have implications both in architectural, static and aesthetic terms, and in the quality of the interior environment. The size and position of a window can completely vary the perception and quality of the environment in which it is placed; variations also occur from a thermal point of view [113].
By combining the division of the module faces by 9 squares with the traditional architectural choices of form and function during the design phase, “parameters” were identified, representing different possible compositions and arrangements of the elements that make up the *module*. The parameters, listed below, are therefore the characteristics that each 1,00 m square can assume within the module, and which condition its thermal efficiency:

1. **Opaque envelope**: it is like a skin; its composition contributes significantly to the thermal exchange between inside and outside. The characteristics of this exchange can be divided into two macro-categories: a) thermal permeability (represented by the thermal insulation capacity) and b) delay/attenuation of the thermal passage (represented by the thermal capacity, which affects the capacity of a membrane between two environments to regulate thermal lag and damping). The value to be identified is the "quantity" of **Insulation** and **Thermal Mass**, i.e., the optimal value that the wall should have in terms of insulation capacity and thermal lag/damping capacity [114]. It was decided to set an unchanged envelope thickness of 40 cm (this is a rather standard thickness in use in the building industry and moreover a publication [115] has demonstrated a rather negligible variation on thermal perform in different walls with thicknesses greater than 40 cm). The composition, on the other hand, was varied by 10 cm for each simulation, giving a total of 5 results for this parameter. Opaque envelope of 0% Insulation (100% Thermal Mass), 25% Insulation corresponding to 10 cm (75% Mass - 30 cm) etc. up to 100% Insulation and 0% Thermal mass. A diagram of the thermal characteristics of the materials used as Insulation and Thermal Mass in the simulations is represented below:

   Table 2 - Material characteristic: Insulation and Mass

   "I" – Insulation:

Parameter	Value
Thermal conductivity	0,034 W/mK
Specific heat	1030,0 J/kgK
Density	80,0 kg/m^3

   "M" – Mass:

Parameter	Value
Thermal conductivity	2,25 W/mK
Specific heat	850,0 J/kgK
Density	2440,0 kg/m^3

2. **Transparency**: the percentage of a transparent facade's surface area has a significant influence on the thermal behavior of the interior. There are two main factors involved: the heat permeability of the glazed components (U-transmittance) and the radiative contribution of the sun's rays (g-factor):

   Table 3 - windows characteristics

Parameter	Value
Trasmittance U	1,2 W/m^{2}K
G-Value	0,61
Visible trasmittance	0,80

   As the module is a cube, it is not necessary to define an exposure. However, if an element of discontinuity is inserted into a facade, such as a window, it becomes necessary to identify the cardinal exposure of that facade. Therefore, in addition to a numerical size value, the exposure of the facade was also added for such parameter. A simulation was carried out for each window size on each exposure. In a facade consisting of 9 sub-modules, the percentage of transparent surface, consequently, can vary according to 9 magnitudes and the possible relative percentages will vary from 11% to 99%[5]. From the thermal point of view, the positioning of the transparent surface does not change the total heat input to the interior consistently (contrary to the light input [paper awaiting publication - IHAS 2019]). Therefore, it was decided to position it in the perfect centre of the facade in object and to vary only the size. Each case was tested on the 4 cardinal exposures.
3. **Shading**: the contribution of shading to opaque surfaces was also evaluated; however, considering that the variations were negligible, it was decided to consider only the shading of glazed components.

[5] *The software used does not consider 99% glazed facades. The maximum allowed is 94%. All values labelled 99% are therefore to be understood as values of 94% glazed area.*

The shading used was chosen in such a way that it does not interfere with the heat exchange due to "transmittance" on the behaviour of the building. A sliding curtain was used, placed at distances and made of materials that do not significantly interfere with the heat exchange due to thermal "transmittance". The screening percentages vary from 0% to 100% with intervals of 10%.

4. **Natural ventilation**: it influences humidity and temperature. This value entered in the software's "schedules" to vary according to reference values taken from the UNI 11300-1 technical standard [116]. It is expressed in vol/h and represents the number of air volumes changed in one hour. The values considered are: 0.5 vol/h; 1.0 vol/h; 4.0 vol/h and 10.0 vol/h.[6].
5. **Slope inclination**: it influences both the ability of rainwater to run off and the ability to absorb solar radiation. The angle of incidence between the surface and the heat ray determines the energy transmitted to the surface. The roof, represented by the face of the cube facing upwards, was made to vary between 0°, 15° and 30°. As for the transparent percentage, the variation of the inclination also determines a consequent exposure of the facade to the sun. Therefore, also in this case, each variation was tested on the 4 cardinal exposures.

The parameters listed above represent the main design and technical choices that normally make up a building. In the case of the *module* in question, they have been adapted according to the dimensions and needs of the module itself but can of course be used in more complex contexts.

3.2.5. **Simulations and parametric analysis**

To identify the best solution, from the point of view of thermal requirements, the amount of thermal energy required to achieve the set thermal comfort objective (20° C - 26° C) was analyzed.
The absolute value of each simulation is not useful as such, but by comparing the results a hierarchy of "better" or "worse" combinations can be established.
Initially, simulations were carried out by varying only one parameter at a time while keeping the other four fixed. This procedure, however, gave partial data as each parameter actually influences the behavior of the others and of the whole system. Therefore, it was decided to continue with simulations by combining the various parameters with each other with different relative values. A considerable number of combinations were produced, because:

1. **Enclosure** - 5 values of % Insulation - 5 cases
2. **Transparency** - 5 values of % transparent surfaces x 4 exposures - 20 cases
3. **Shading** - 6 values of % Shading - 6 cases
4. **Natural ventilation** - 4 values of air change volumes per hour - 4 cases
5. **Roof pitch** - 3 values of roof pitch x 4 exposures - 12 cases

In total: 5 x 20 x 6 x 4 x 12 = 28,800 combinations.
Each of these combinations was processed using the EnergyPlus® dynamic energy simulation software. Each simulation then gave a value of thermal kWh required by the combination in question to maintain the internal temperature in the comfort zone, considering the external conditions (climate band) and internal conditions (internal loads) to be the same for all combinations. In this way, the contribution of the individual element to the overall operation can be identified.
In order to evaluate the quality of the variations also in function of the day/night alternation, it was chosen to simulate each combination with an hourly step: i.e., one simulation for each hour of each of the 52 weeks. Thus: 52 weeks x 7 days = 364 days; 364 days x 24 hours = 8,736 hours.
So, for each climate band 28,800 combinations x 8,736 hours = about 250 million simulations, multiplied by 4 climate bands studied, this gives a total of about 1 billion results!
The result of each simulation is a value expressed in kWh. In order to make the values of each simulation more "readable" and usable, they have been grouped into annual and weekly blocks. Subsequently, only the combinations with the lowest heat demand values and all those with a maximum deviation of 15% have been highlighted. These values are divided into heating and cooling.
Using the EnergyPlus® engine, places were chosen (cities and state capitals) that presented the typical characteristics of the 4 microclimate ranges identified and already present in the software database.
Rome was chosen for the temperate climate; Riyadh for the hot-dry climate; Bangkok for the hot-humid climate; and Minsk for the cold climate.

[6] *The value of 10.0 vol/h is not present in the regulations but has been added to test a particularly high value.*

3.2.6. **Tools**

To carry out such a large number of simulations, the University of Trento's HPC (High Performance computing) system was used. The software equipment was:

- The combinations of geometries were modelled within the Grasshopper environment for Rhinoceros, managing, through an optimised script, the automations of the variations (e.g., varying the size of the window, etc.) and setting the energy calculation, through the Ladybug® and Honeeybee® add-ons (EnergyPlus® simulation engine), in a parameterised manner. The impossibility of managing the large number of simulations on a single local compiler led to the use of the HPC cluster.
- The 28,800 simulation models, exported from Grasshopper in .idf format, were loaded onto the HPC cluster (Linux environment), and simulated, using an R® script based on the "eplusr" library, with EnergyPlus®, previously installed on the machine in version 9.4.0.
- The output of the simulations (28,800 files in .csv format), and the relative results, were managed through a Python® script that collected the values in a format suitable for visualisation, subdividing them as described previously (by weeks and by year), then associating, with each simulation, a schematic image of the 3D model representing the parametric combination under examination.
- The visualisation of the results was entrusted to the online application Design Explorer, an open-source tool created by CORE Studio. A more detailed exploration of the raw data was carried out using classic spreadsheets.

3.3. Results

The values for each of the four environments analyzed are presented below.

3.3.1. **Rome - Temperate**

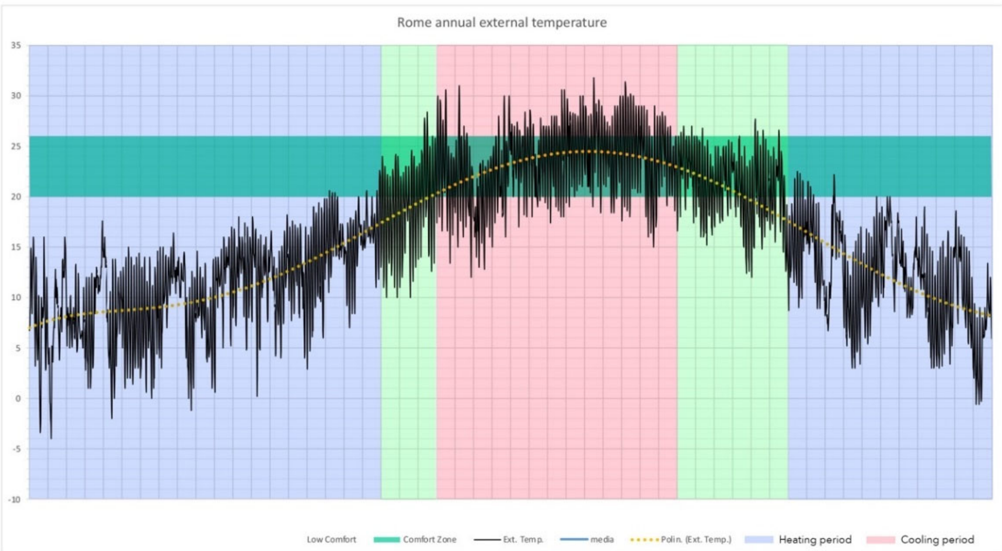


Figure 15 - Rome hourly temperature of one year and comfort zone

The results of the simulations on an annual basis for the temperate climate zone – Rome are presented below.

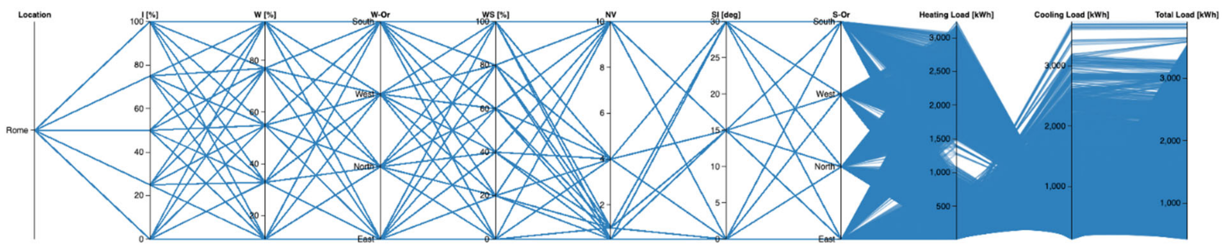


Figure 16 - Best case: Heating, Cooling, Total – Graph plot with Designexplorer.com

The graph shows all the simulated combinations:

The columns represent the parameters, the rows the parameter values. In order:

- **I** = Insulation - 0%; 25%; 50%; 75%; 100%.
- **W** = Window % - 11%; 33%; 55%; 77%; 99%.
- **W-Or** = Window Orientation - South; West; North; East
- **WS** = Window Shading - 0%; 20%; 40%; 60%; 80%; 100%.
- **NV** = Natural Ventilation - 0,5 vol/h; 1,0 vol/h; 4,0 vol/h; 10,0 vol/h
- **Sl** = Slope - 0°; 15°; 30°.
- **S-Or** = Slope orientation - South; West; North; East

The last three columns represent the values of Heating, Cooling and the sum of the two totals (expressed in kWh).
Through this display it is possible to consider both the best combinations and to understand which parameters influence the demand more.
The three best combinations in terms of demand are reported below: the combination with the lowest heating, cooling and the sum of the two.

Best Heating:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
75%	11%	South	0%	0,5 Vol/h	0°	//

Best Cooling:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
50%	95%	East	100%	10,0 Vol/h	30°	West

Best Total:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
75%	33%	North	100%	1,0 Vol/h	0°	//

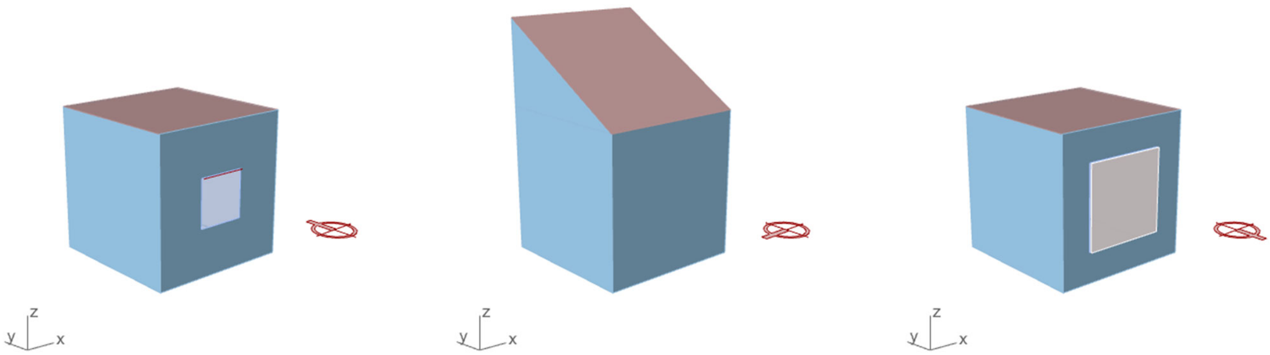


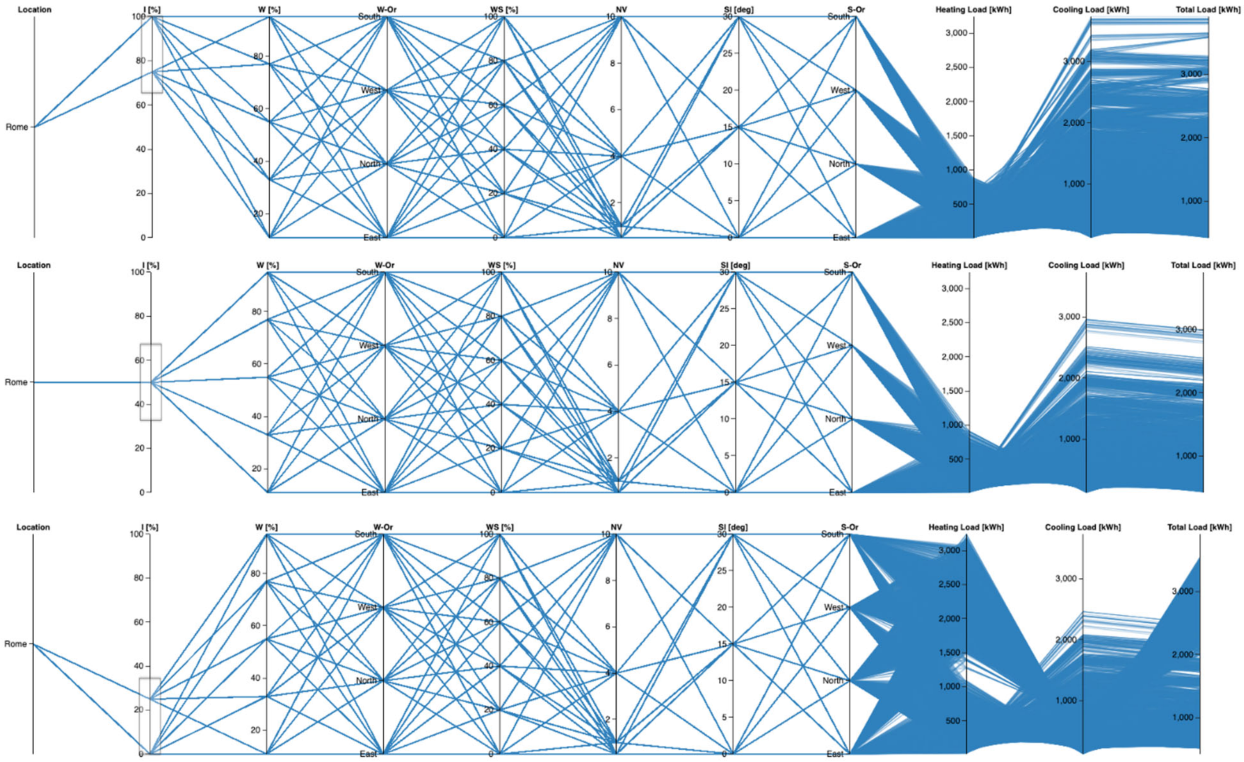
Figure 29 - Scheme of the combinations: Best Heating, Cooling and Total

These values are useful to identify the best configurations in absolute terms. They are a first indication, but for more precise information, further analysis is needed:

3.3.1.1. Annual value:

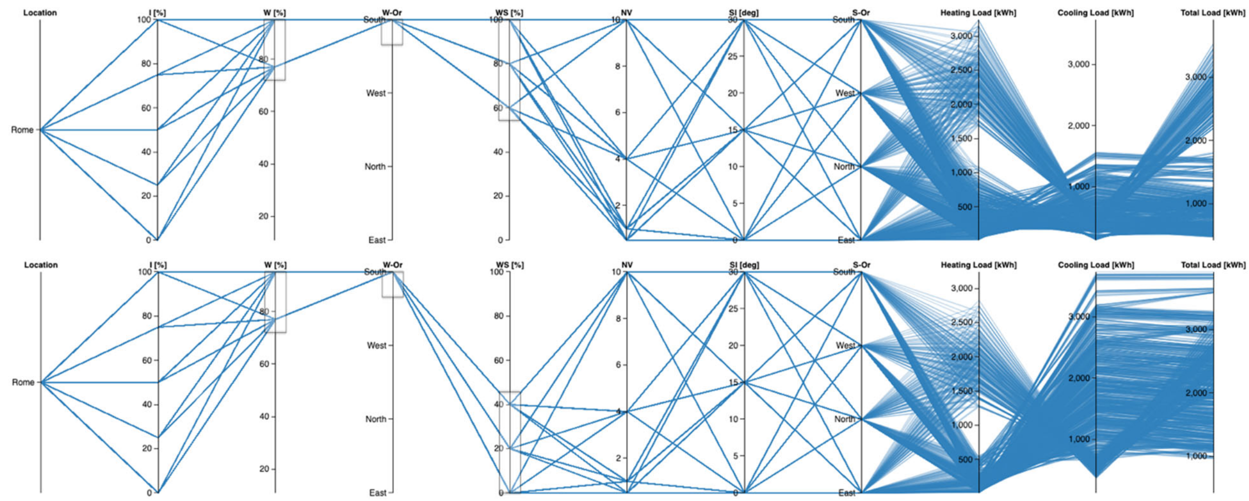
The graphs of the influence of each parameter on annual requirements are represented as follows:

1. **Insulation**:

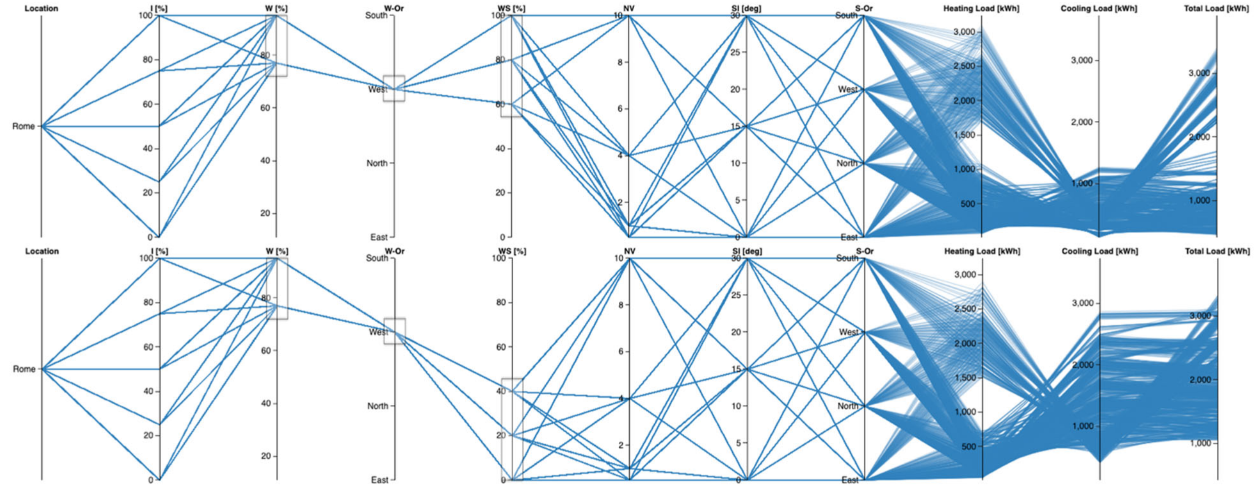


The graphs show that for high levels of insulation of the opaque envelope (top graph), the thermal energy demand for heating decreases. Vice versa (bottom graph), the cooling demand decreases. From the average situation (middle graph) it can be seen that in this climate band (Rome) there is a prevalence of cooling needs. In general, the cooling demand is often higher than the heating demand due to the radiative influence of the sun, which improves the winter thermal performance and worsens the summer one, and to the internal loads, which, remaining constant, increase the cooling energy demand.

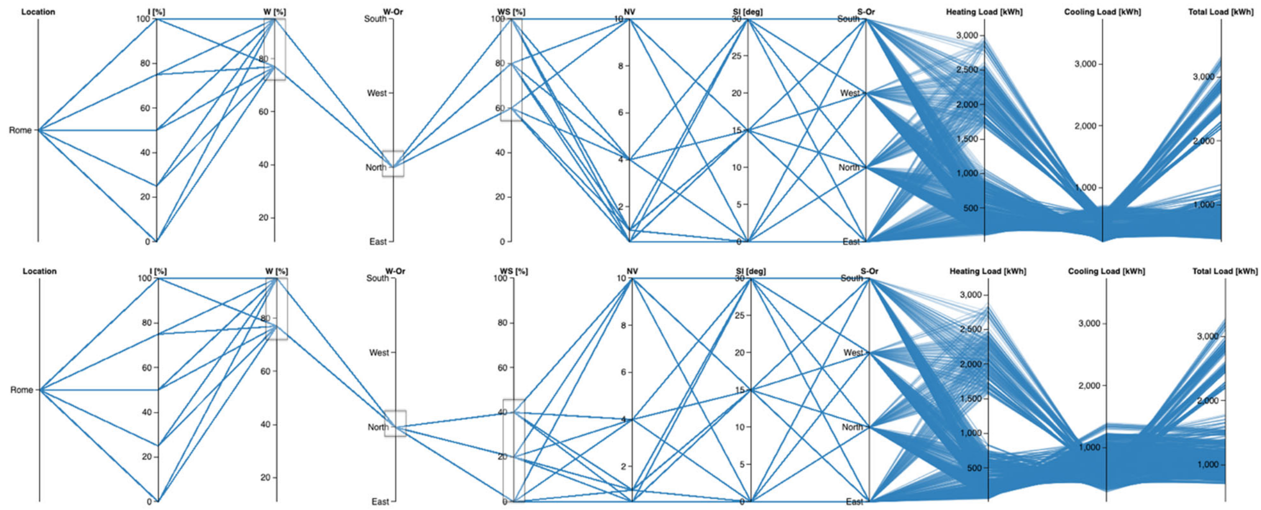
2. **Window and Shading**:
   a. High level of window percentage (77% and 99%):
      I. South



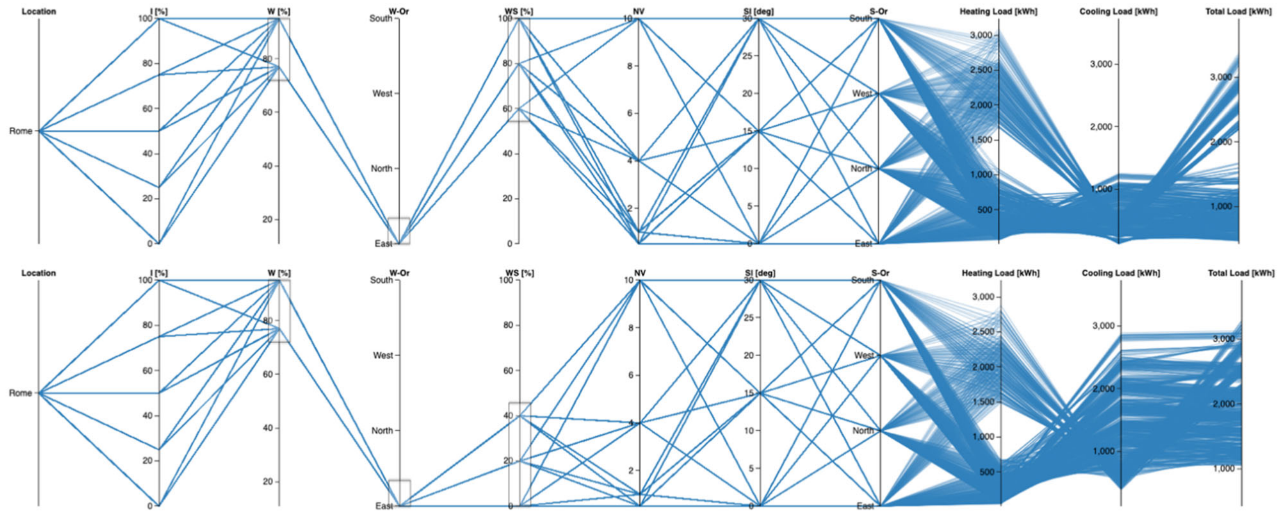
II. West



III. North

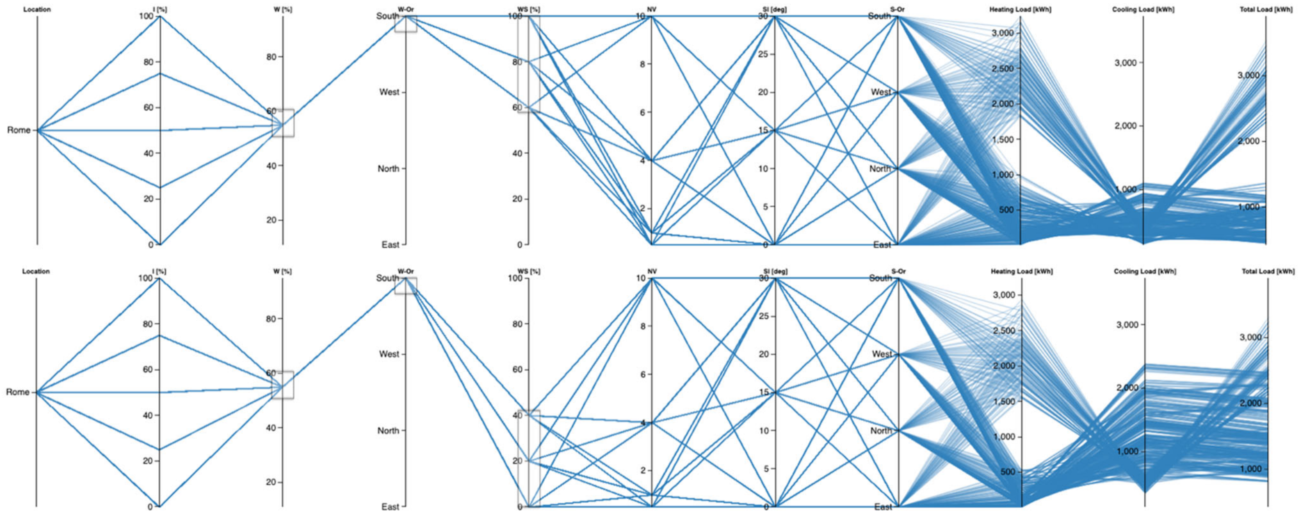


IV. East

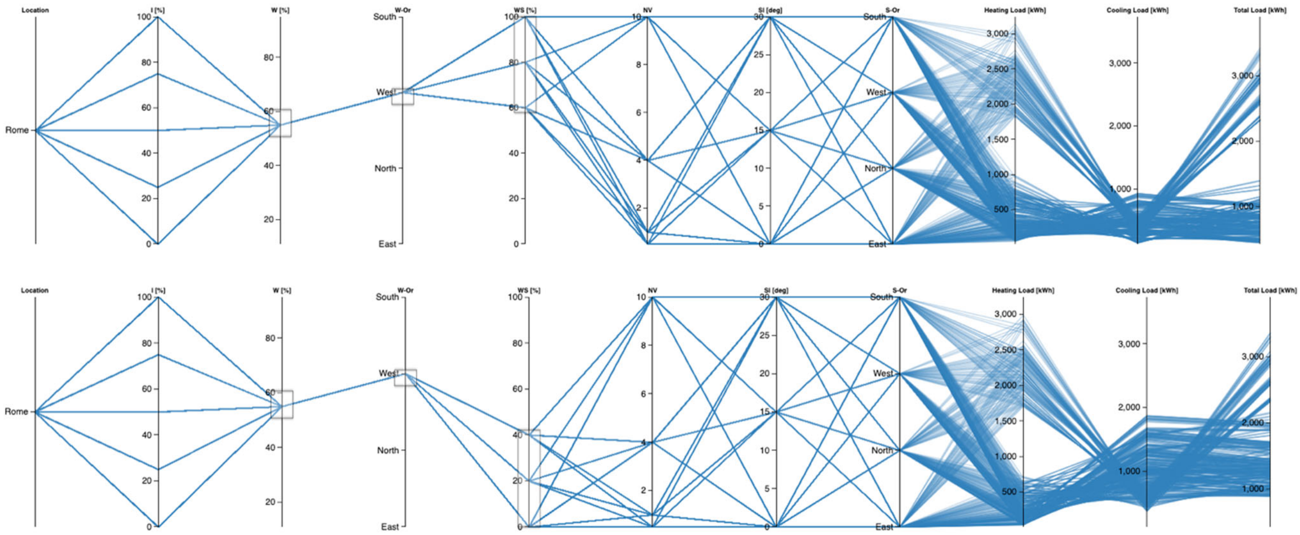


b. Medium level of window percentage (55%):

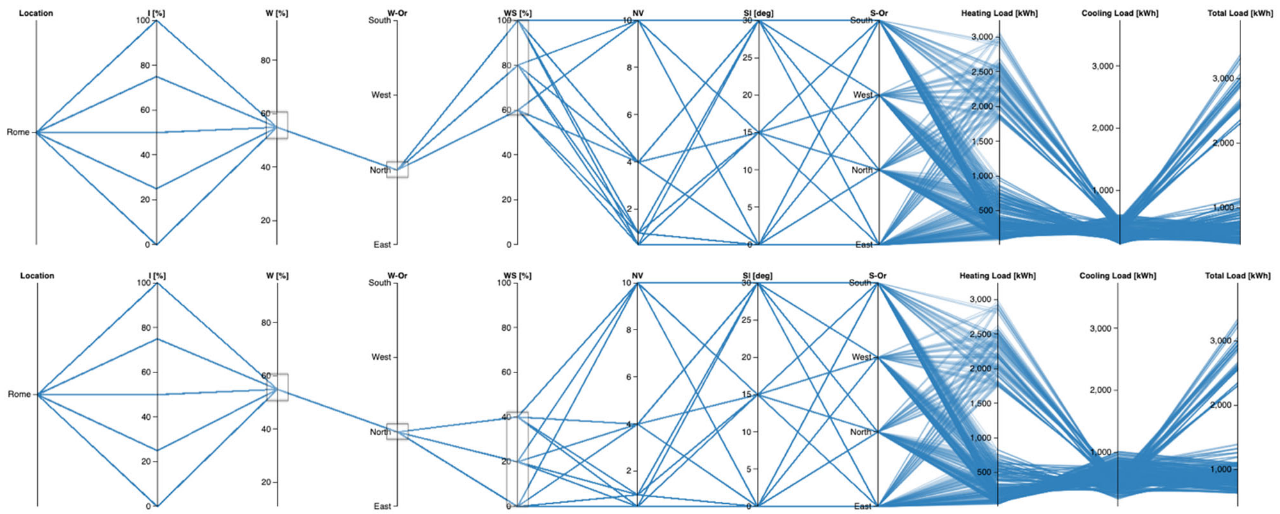
I. South



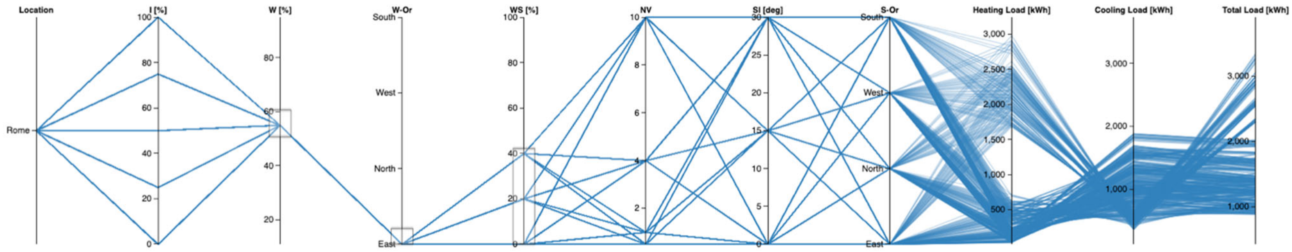
II. West

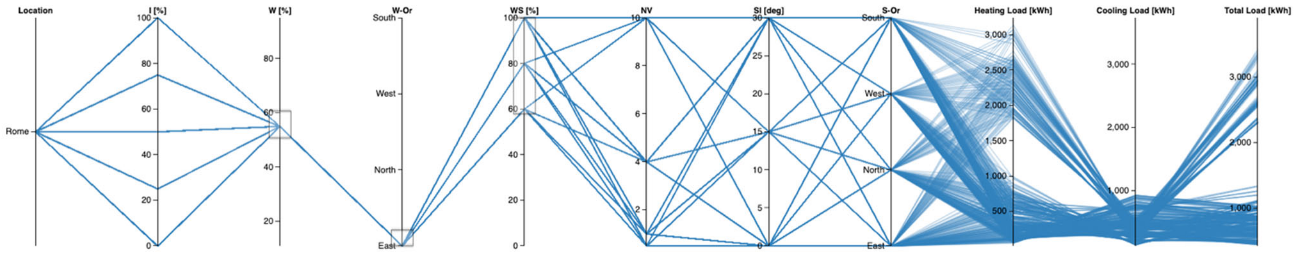


III. North



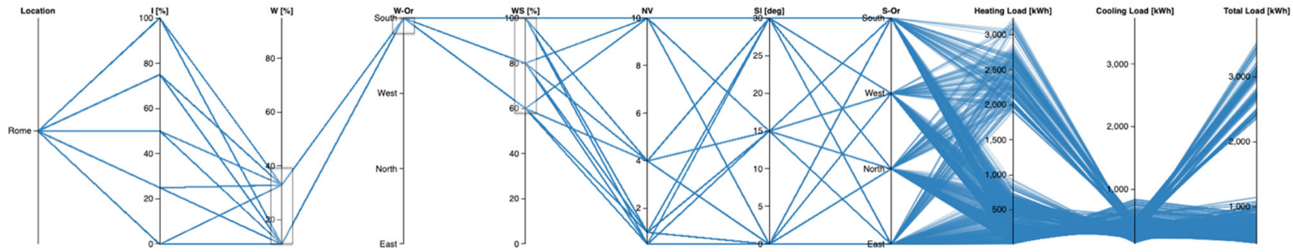
IV. East

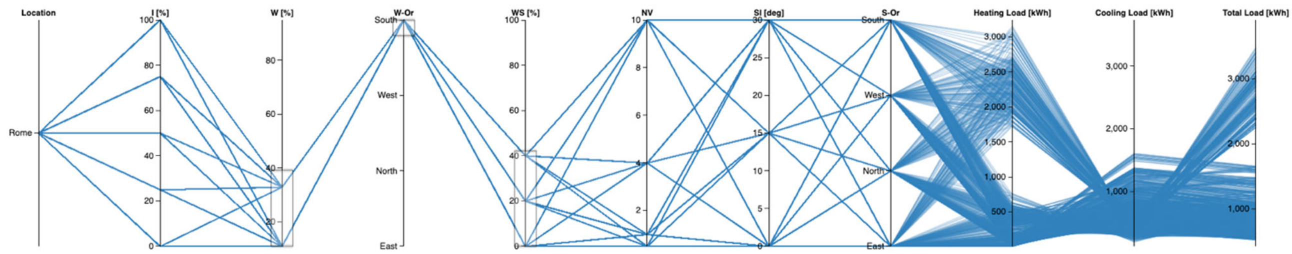




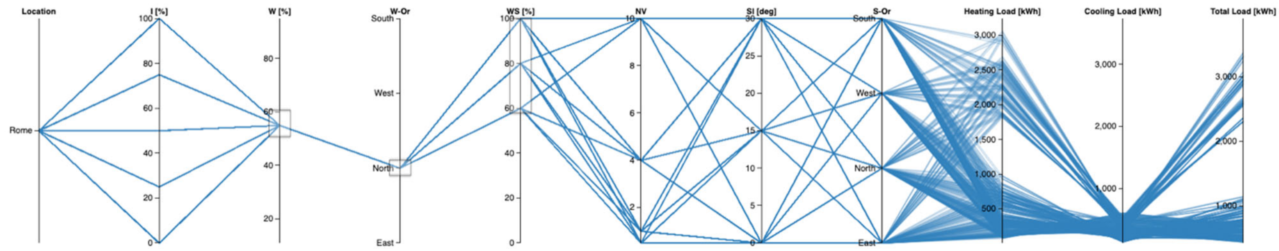
c. Low level of window percentage (11% and 33%):

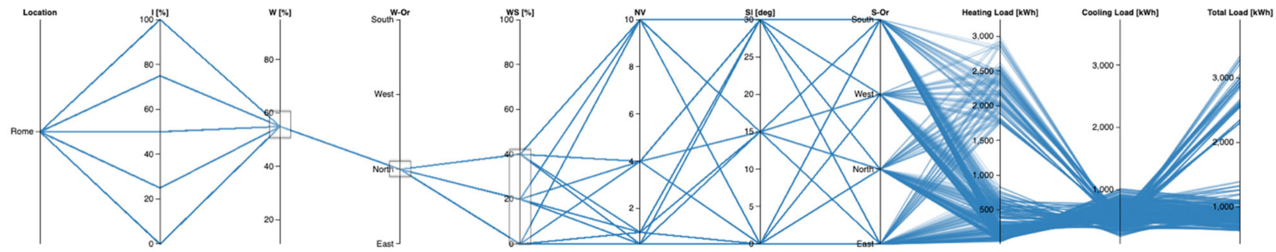
I. South



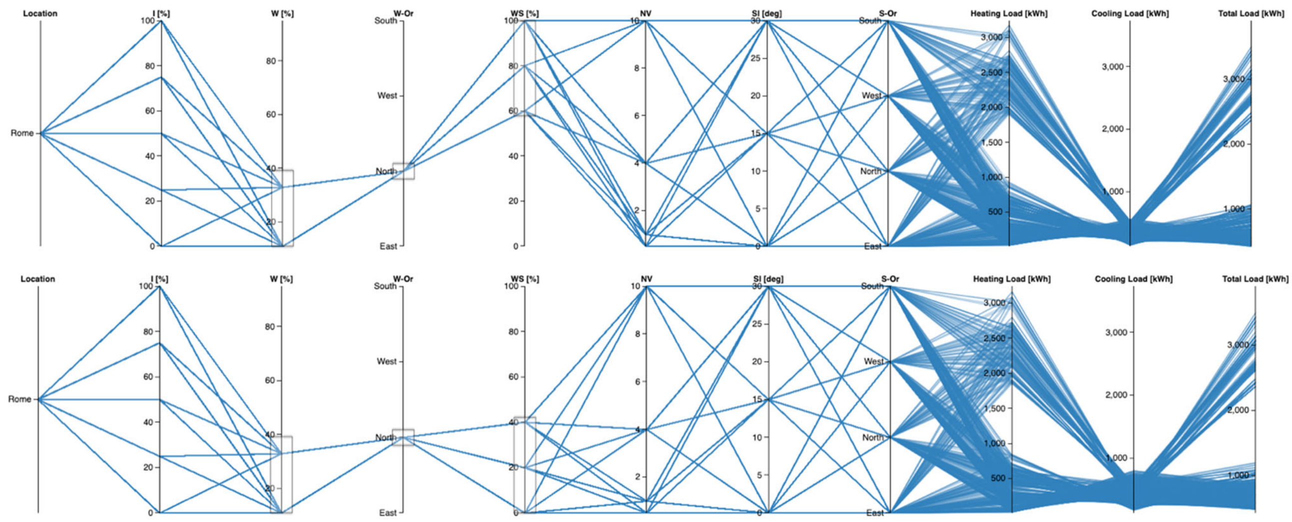


II. West

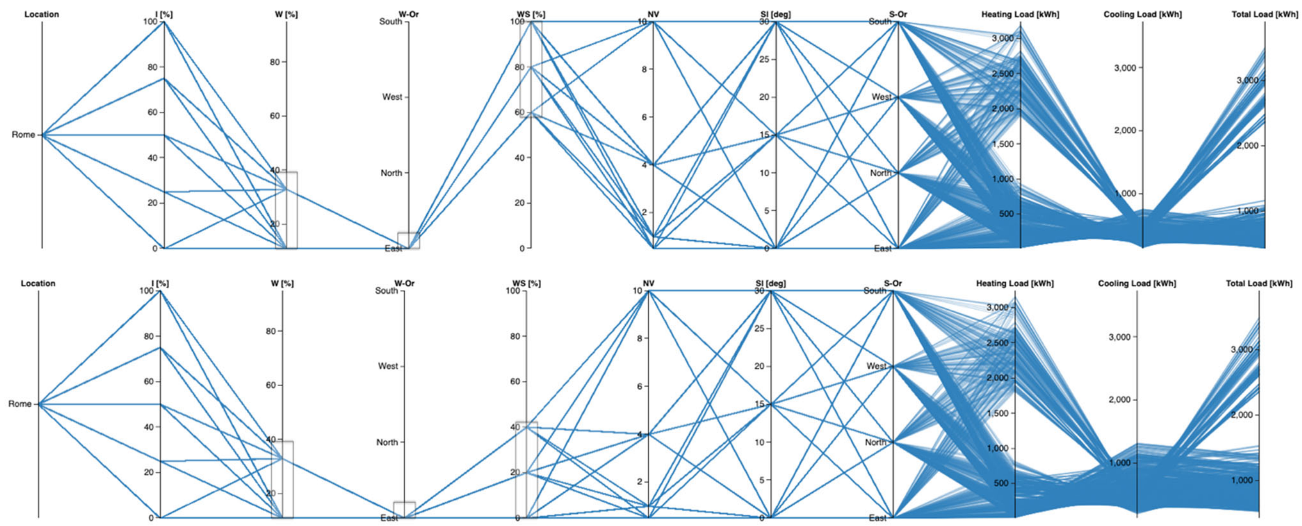




III. North

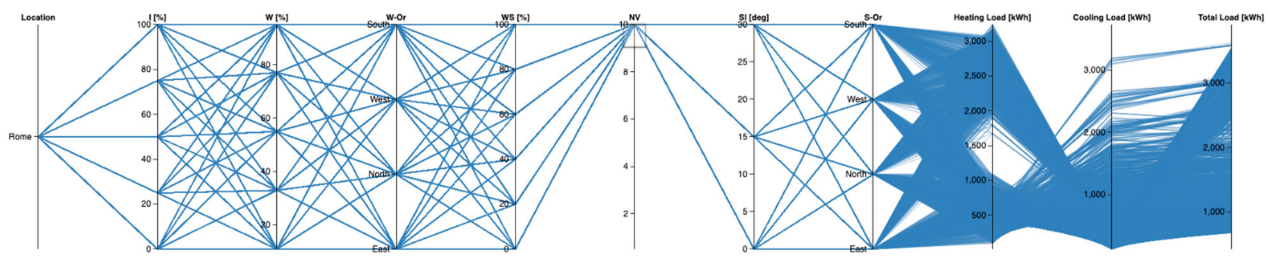


IV. East

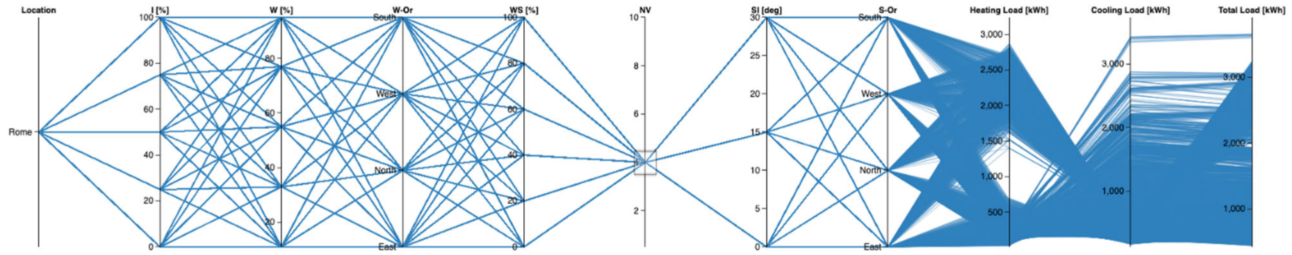


In this case, a clear influence of glazing and shading on the cooling demand is evident, especially with regard to the shading parameter. Contrary to what could be expected, analysing these data, a contribution to the heating demand is not particularly relevant. The size of the window shows a rather linear trend: the larger it is, the more the cooling demand increases and consequently the influence of the shading becomes stronger.
Generally, windows to the north decrease the thermal energy demand for cooling and, of course, the shading of the blind has almost no influence on the thermal behaviour.

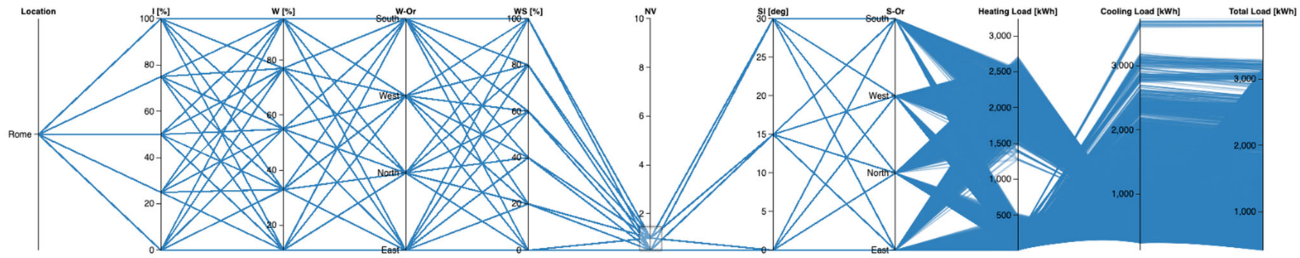
3. **Natural Ventilation**:
   a. High level of natural ventilation (10,0 vol/h):



b. Medium level of natural ventilation (4,0 vol/h):



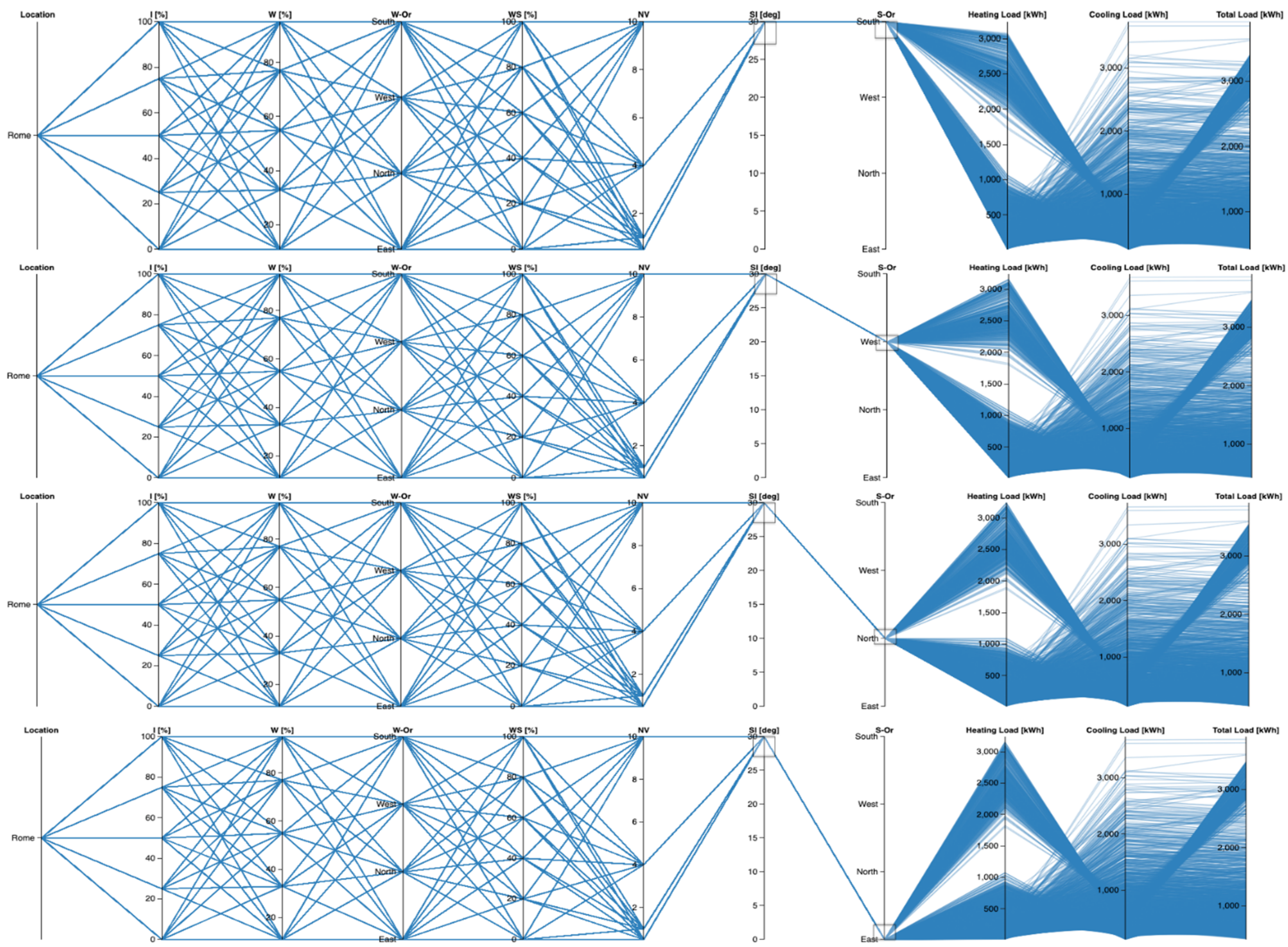
c. Low level of natural ventilation (0,5 e 1,0 vol/h):



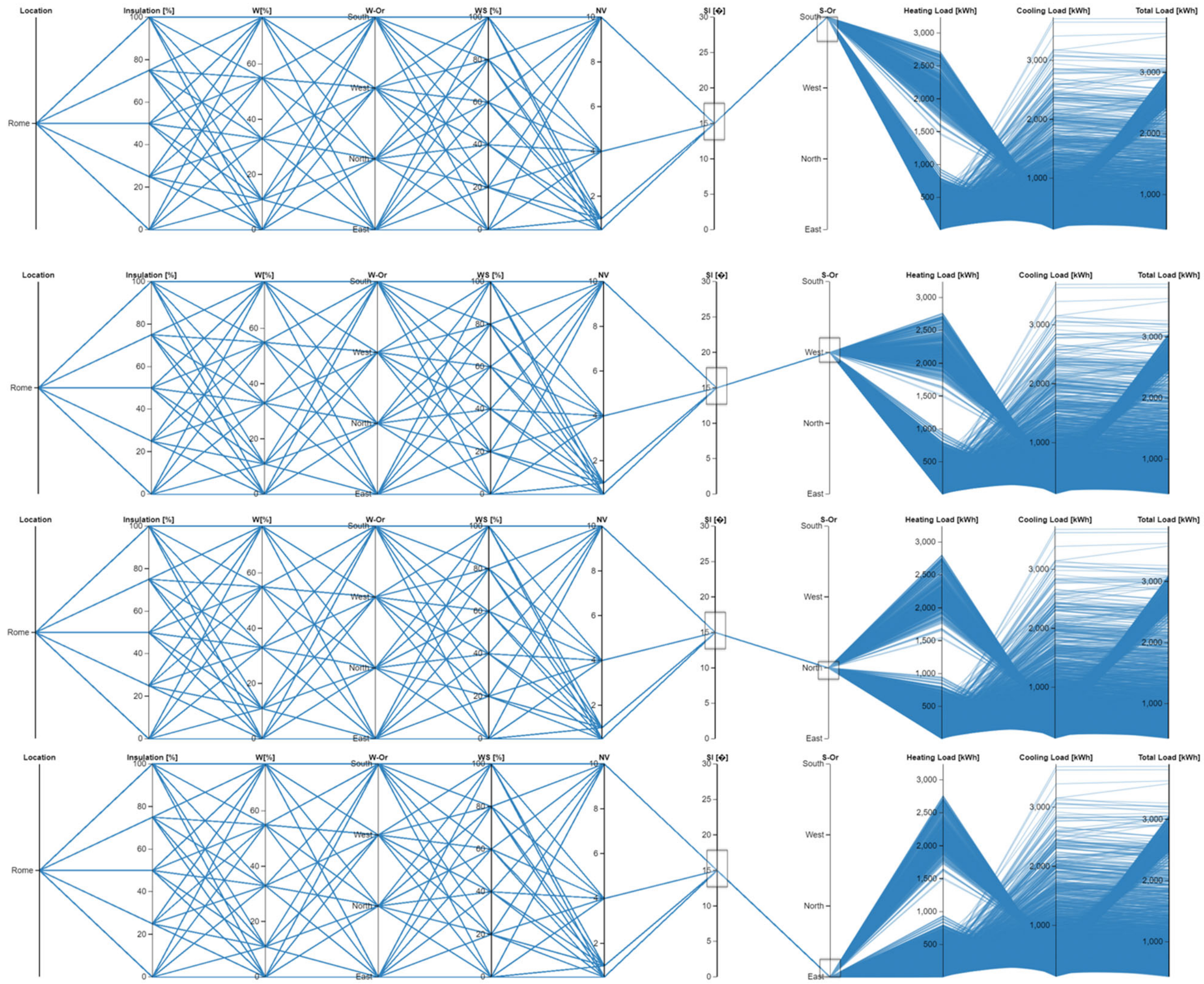
The graphs do not show a particular and evident influence of natural ventilation. There is a certain prevalence of cooling and total demand values for high and medium ventilation (graphs a. and b.). Regarding the heating, on the other hand, the situation is better with low natural ventilation (graph c.).

1. **Slope Inclination**:

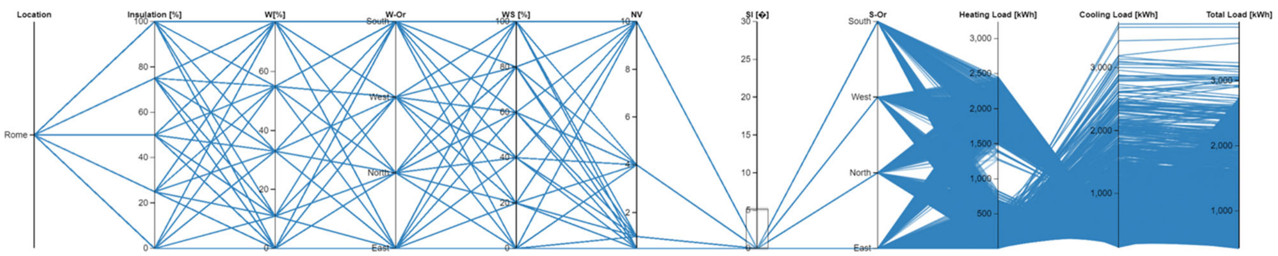
   a. High level of slope inclination (30°):



b. Low level of slope inclination (15°):



Flat slope (0°):



The slope inclination has no evident impact on requirements.

WEEKLY VALUE

For an even more detailed analysis, weekly simulations were carried out.

For such data set, the use of Design Explorer as a visualisation tool would have been cumbersome: as many as 52 charts (one for each week) would have had to be displayed. Consequently, it was decided to represent the numerical values of each week's best combination in a single table. Then, each *Parameter* was ordered by frequency, i.e., the number of times the single *parameter* appears in the best combination of each week was extrapolated, thus allowing the best value of each *Parameter* to be selected during the year: it leads to choose the most efficient module composition for that climate band.

The columns show the *Parameters,* and the rows show the weeks.

Week	Insulation %	Window %	Window Orientation	Window shading	Natural ventilation	Slope inclination	Slope orientation
1	75%	33%	South	0%	1,0	0°	//
2	50%	94%	South	40%	0,5	0°	//
3	50%	77%	South	0%	0,5	15°	West
4	50%	55%	South	0%	0,5	30°	East
5	50%	55%	South	20%	1,0	0°	//
6	50%	94%	South	40%	1,0	30°	East
7	50%	77%	West	0%	0,5	0°	//
8	50%	77%	West	0%	0,5	0°	//
9	50%	77%	West	0%	0,5	0°	//
10	50%	77%	West	0%	0,5	0°	//
11	25%	94%	South	40%	0,5	0°	//
12	75%	94%	East	40%	0,5	30°	North
13	75%	77%	West	60%	1,0	30°	West
14	75%	94%	East	40%	0,5	30°	North
15	75%	77%	West	60%	1,0	30°	West
16	75%	77%	West	60%	1,0	30°	West
17	25%	33%	South	40%	1,0	30°	West
18	25%	33%	South	40%	1,0	30°	West
19	50%	33%	South	80%	1,0	15°	East
20	50%	33%	South	80%	1,0	15°	East
21	50%	33%	South	80%	1,0	15°	East
22	50%	33%	South	80%	1,0	15°	East
23	25%	11%	East	100%	1,0	15°	West
24	50%	11%	South	80%	4,0	15°	West
25	50%	11%	South	80%	4,0	15°	West
26	50%	11%	North	0%	4,0	15°	East
27	25%	94%	East	100%	4,0	30°	West
28	50%	11%	North	100%	10,0	30°	West
29	75%	33%	North	100%	10,0	30°	West
30	75%	11%	North	100%	10,0	30°	West
31	75%	11%	North	100%	10,0	30°	West
32	75%	11%	North	100%	10,0	30°	West
33	75%	11%	North	100%	10,0	30°	West
34	75%	11%	North	100%	10,0	30°	West
35	50%	11%	East	100%	10,0	30°	West
36	75%	33%	North	100%	10,0	30°	West
37	25%	33%	East	100%	10,0	30°	West
38	0%	33%	East	80%	1,0	15°	South
39	0%	33%	South	100%	10,0	15°	West
40	0%	33%	South	100%	10,0	15°	West
41	0%	33%	South	100%	10,0	15°	West
42	25%	77%	West	80%	1,0	30°	North
43	50%	33%	South	80%	1,0	15°	East
44	50%	33%	South	80%	1,0	15°	East
45	75%	11%	South	40%	0,5	0°	//
46	50%	77%	West	0%	0,5	0°	//
47	50%	77%	West	0%	0,5	0°	//
48	50%	77%	West	0%	0,5	0°	//
49	75%	55%	South	20%	0,5	15°	West
50	25%	94%	South	40%	0,5	0°	//
51	25%	94%	South	40%	0,5	0°	//
52	75%	55%	South	20%	0,5	15°	West

Table 4 - The value of the Parameters of the configurations of the weekly best cases

Table 5 - The frequency of every Parameters is in the combination of weekly best cases

Insulation %	
0%	4
25%	9
50%	23
75%	16
100%	0

Window %	
11%	12
33%	16
55%	4
77%	12
99%	8

Window Orientation	
South	25
West	11
North	9
East	7

Natural ventilation	
0,5	18
1,0	17
4,0	4
10,0	13

Slope inclination	
0°	14
15°	17
30°	21

Slope orientation	
South	1
West	25
North	3
East	9

W-South	
11%	3
33%	12
55%	4
77%	1
99%	5

Sl-30	
South	0
West	16
North	3
East	2

From these values it is possible to identify the weekly trends of the individual parameters: that is, the specific configuration of the 5 parameters examined which gives the least amount of heat demand. Table 4 shows the numerical values of these configurations. Table 5 shows the number of times the single value of each parameter appears in one of the 52 optimal combinations. This value is important because it helps to understand which choices are the most favourable throughout the year: the more a certain value appears, the more valid it is compared to the others.

The counting of weekly values shows:

1. **Insulation**: clear predominance of 50% composition. Followed by 75% insulation. Being a rather mild climate, the behavior of the ideal envelope is balanced between Insulation and Thermal Mass.
2. **Window %**: the most advantageous exposure is considerably the South. In this exposure the amount of vertical transparent surface is 33%. This value testifies a rather high sun path in the summer months and a low one in the winter months, which generates an optimal radiation value.
3. **Window Shading %**: the results suggest 100% as the best. However, as this is an easily changeable parameter, it is more useful to follow and adjust to the weekly value rather than the annual one.
4. **Natural Ventilation**: 0,5 vol/h is the best value. In this case there is no clear distinction between 0,5 vol/h, 1,0 vol/h and 10,0 vol/h. The worst is definitely 4,0 vol/h. Looking at the frequency of cases in which the optimal air changes are lower (values 0,5 and 1,0), it is evident that they prevail in the winter period. Indeed, in cold periods the optimal ventilation is lower, while in summer the ventilation is higher. This parameter is not fixed but can also vary on a daily basis (opening and closing a window can for example make this value vary), so it can also be kept mobile. However, it gives an indication of the ideal building type to be designed. In this case it shows a balance with a slight preference for not particularly ventilated buildings.
5. **Slope Inclination**: the best roof exposure is west with a slope of 30°. This value appears in both winter and summer, with a prevalence in summer. The interesting fact is that in winter the 0° slope inclination is preferred. This is probably due more to the radiative component of the sun (i.e., the angle of incidence between the sun's rays and the roof surface) than to the increase in the volume heated. In fact, as the inclination of the roof changes, the internal volume increases. Consequently, in winter there is a greater volume to be heated (and therefore a greater demand), while in summer the heat can be concentrated at the top in the area of the vertex between the wall and the roof.

The counting of weekly values shows:

Best annual Heating:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75%	11%	South	0%	0,5 Vol/h	0°	//

Best annual Cooling:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50%	95%	East	100%	10,0 Vol/h	30°	West

Best annual Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75%	33%	North	100%	1,0 Vol/h	0°	//

Best weekly Total:

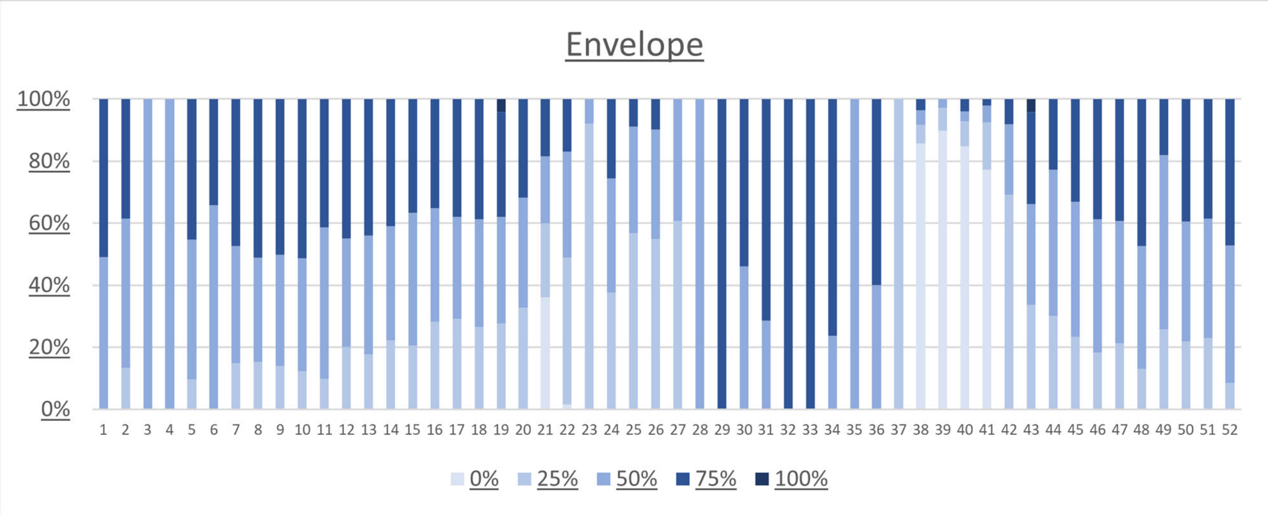
Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50%	33%	South	100%	1,0 Vol/h	30°	West

The above-mentioned values give substantial indications of the best case from the point of view of thermal energy requirements. However, as these values are the result of the collection of the best value only, they do not fully clarify the trend and risk to evaluate as "inefficient" even combinations that deviate slightly from the absolute best value. For these reasons, it was decided to also analyse and summarise the results of combinations that deviate by no more than 15% from the best value.

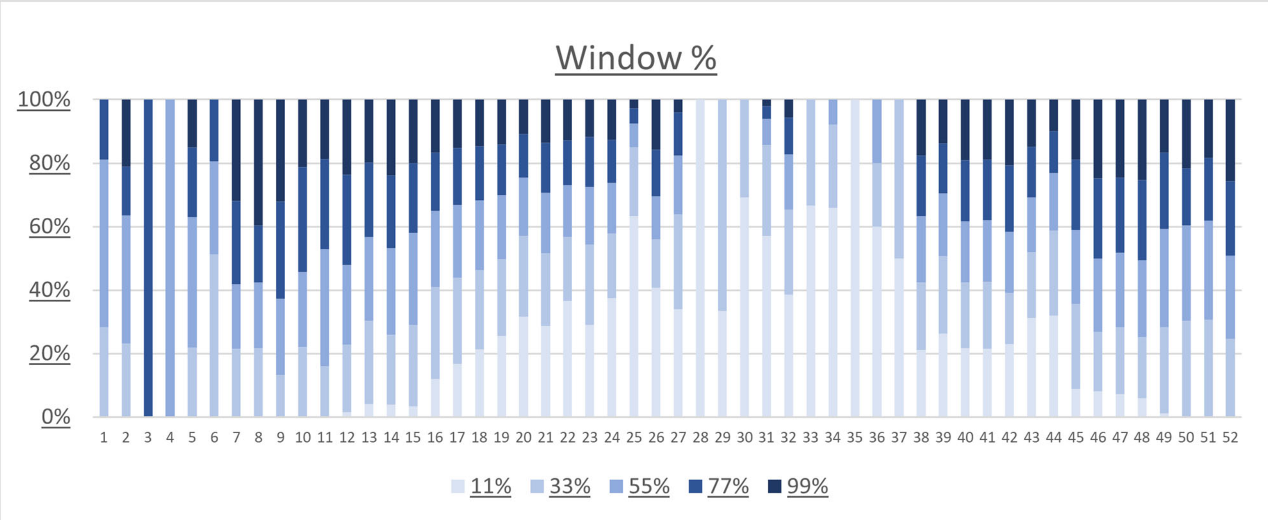
WEEKLY VALUE 15% TOLLERATION

The results of the weekly data for the best combinations and all those with values within a 15% tolerance range are shown below. This data is important to understand the "weight" in terms of requirements that each parameter realistically has on the module. The higher the percentage of times a particular parameter configuration appears, the better its contribution to demand.

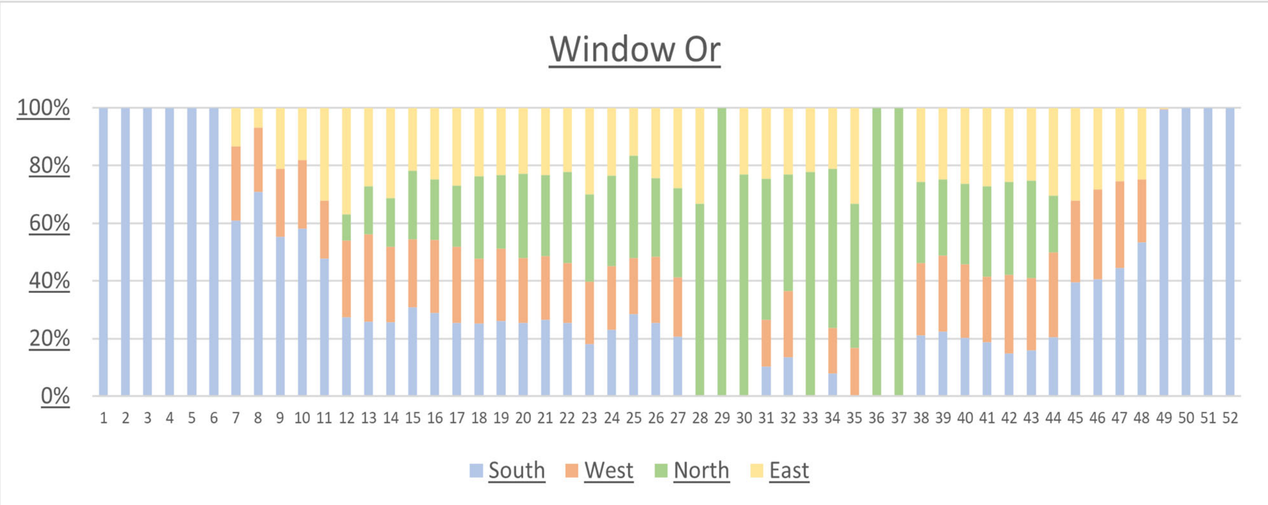
Value of percentage of insulation vs thermal mass: best case for every week in one year.



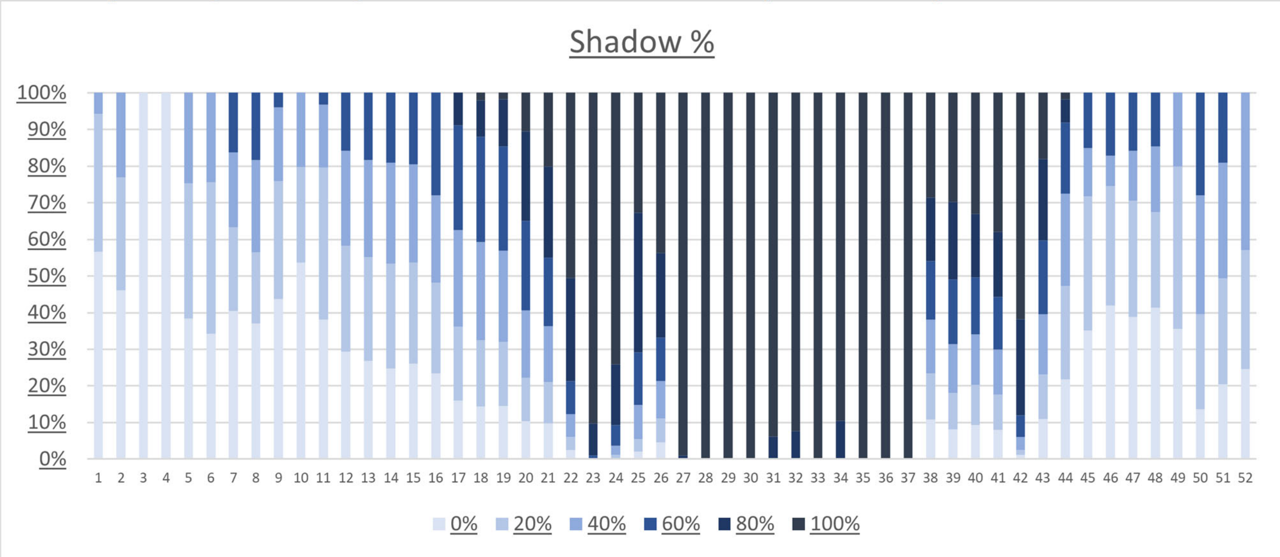
Value of percentage of the dimension of the window of the facade: best case for every week in one year.



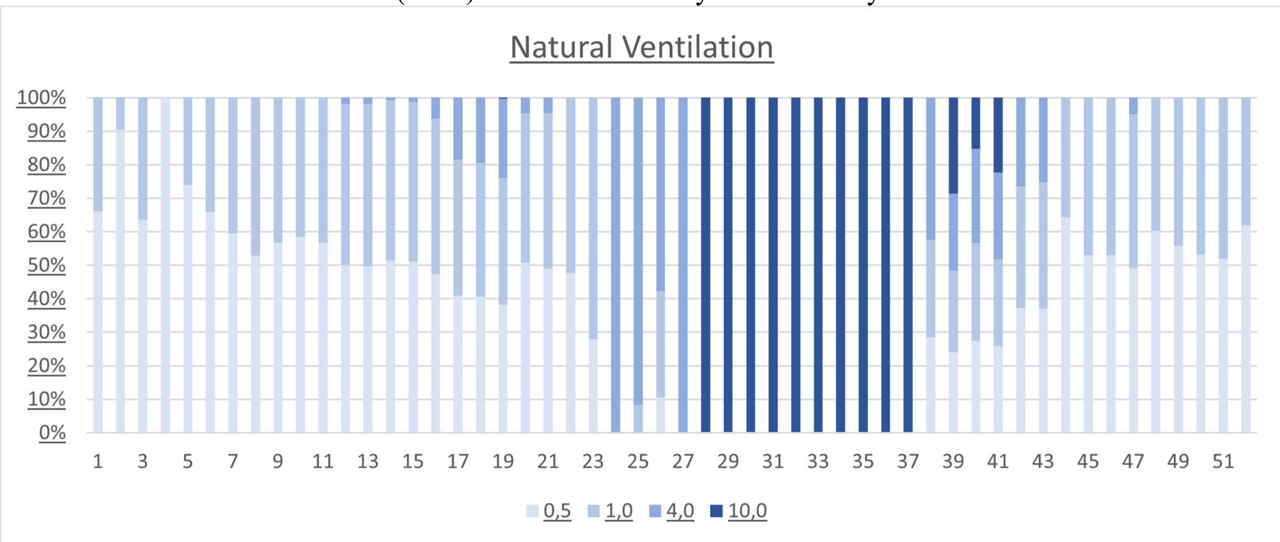
Orientation of the window: best case for every week in one year.



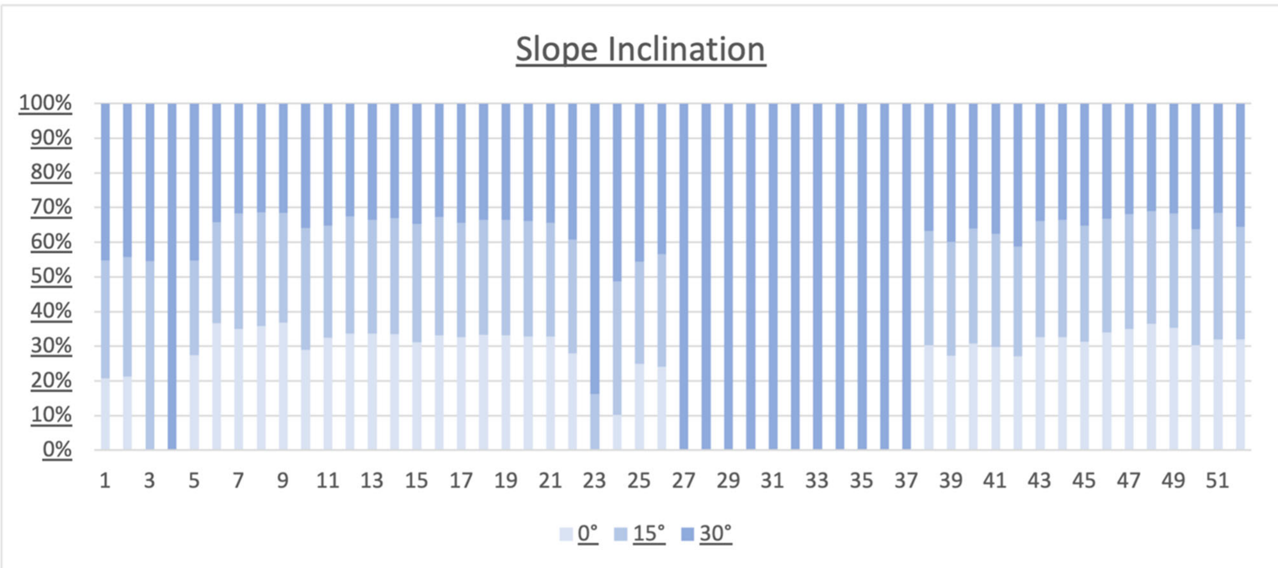
Value of percentage of shading of the window: best case for every week in one year.



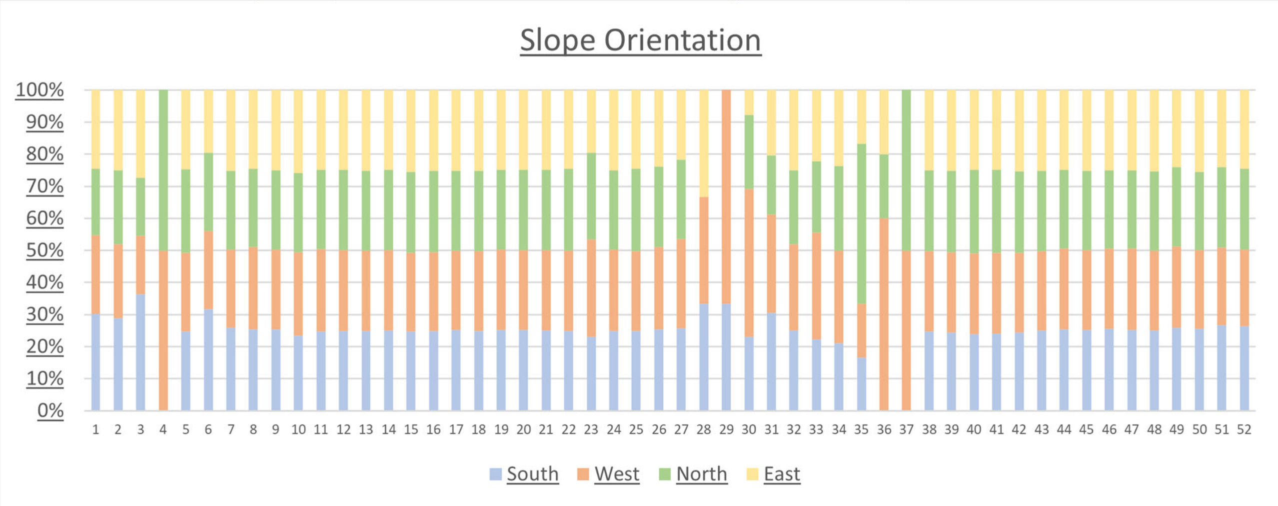
Value of natural ventilation level (vol/h): best case for every week in one year.



Value of slope inclination: best case for every week in one year.



Orientation of the slope (only the case ≠ 0°): best case for every week in one year.



Envelope		Wind. %		Wind. Or.		Sahdow %		Nat. Vent.		Sl. Incl.		Sl. Or.	
0%	19804	11%	18164	South	21084	0%	11854	0,5 Vol/h	32145	0°	25206	South	20065
25%	19911	33%	18388	West	19608	20%	12749	1,0 Vol/h	30416	15°	26630	West	20196
50%	21369	55%	16481	North	19882	40%	14250	4,0 Vol/h	14480	30°	28842	North	20311
75%	19004	77%	14435	East	20104	60%	15175	10,0 Vol/h	3637			East	20106
100%	590	99%	13210			80%	12102						
						100%	14548						

The results of the simulations/analysis show:

- **Insulation**: the results indicate that the best choice is 50% Insulation and 50% Thermal Mass. In general, there is a certain "parity" between the insulation percentage values 0%, 25%, 50% and 75%. The only value that is obviously not indicated is 100%. The latter indicates a rather balanced climate between hot and cold periods, with a slight prevalence of hot.
- **Window %**: the analyses carried out indicate a preference for the smaller sizes (11%/33%). In general, there is a tendency to increase the glazed area in colder periods (first cases of 11% start around week 11 to 49). The most preferred exposure is South. Generally, South exposure prevails during the winter period (due to a greater need to capture the radiative thermal energy of the sun) and North exposure during the summer period (for the same reason but in reverse).
- **Window shading**: as can be expected, in mild and warm periods there is a tendency towards shading. Conversely, in winter the tendency is towards openness. With a mobile system it is possible to meet the requirements for different weeks.
- **Natural Ventilation**: as expected, the results confirm the need for more ventilation during hot weeks and less during cold weeks. However, a minimal presence is also necessary and useful during the winter period.
- **Slope inclination**: 30° is the prevailing measure; the orientation is fairly constant between all exposures. South is the worst. In general, this value does not seem to be particularly decisive on the overall result.

Best configuration (range 15%) for Rome, most frequency cases weekly value:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
50%	33%	South	60%	0,5 Vol/h	30°	North

Acceptable range of value, weekly value:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
0% - 75%	11% - 55%	South- East	40%-60% and 100%	0,5 Vol/h – 1,0 Vol/h	0°-30°	All

Best annual Heating:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75%	11%	South	0%	0,5 Vol/h	0°	//

Best annual Cooling:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50%	95%	East	100%	10,0 Vol/h	30°	West

Best annual Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75%	33%	North	100%	1,0 Vol/h	0°	//

Best weekly Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50%	33%	South	100%	1,0 Vol/h	30°	West

Conclusion:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50% - 75%	33%-44%	South	60%-100%	0,5 Vol/h - 1,0 Vol/h	0° and 30°	West

3.3.2.**Minsk – Cold**

Only the final values of the other climate zones are shown. To consult the detailed data and graphs for the relevant locations, please refer to the tables at the end of the thesis (Chapter 7).

Best configuration (range 15%) for Minsk, most frequency cases weekly value:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
50%	11%	North	60%	0,5 Vol/h	0°	//

Acceptable range of value, weekly value:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
25% - 75%	11%	All	40%-80%	0,5 Vol/h – 1,0 Vol/h	0°-30°	All

Best annual Heating:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	South	0%	0,5 Vol/h	0°	//

Best annual Cooling:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
0%	99%	South	100%	10,0 Vol/h	30°	North

Best annual Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

Best weekly Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75%	99%	South	0%	0,5 Vol/h	0°	//

Conclusion:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50% - 75%	11%-44%	South	0% and 100%	0,5 Vol/h - 1,0 Vol/h	0°	//

3.3.3.**Riyadh – Hot Arid**

Best configuration (range 15%) for Riyadh, most frequency cases weekly value:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
25%	11%	North	100%	0,5 Vol/h	0°	//

Acceptable range of value, weekly value:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
25% - 75%	11%	North	60%-100%	0,5 Vol/h – 1,0 Vol/h	0°-30°	All

Best annual Heating:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75%	11%	South	40%	0,5 Vol/h	0°	//

Best annual Cooling:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

Best annual Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

Best weekly Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

Conclusion:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75% - 100%	11%	North	100%	0,5 Vol/h	0°	//

3.3.4.**Bangkok – Hot Humid**

Best configuration (range 15%) for Bangkok, most frequency cases weekly value:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
100%	11%	North	100%	0,5 Vol/h	0°	//

Acceptable range of value, weekly value:

Insulation	Window	W-Or	Shading	Nat. Vent.	Slope	S-Or
75% - 100%	11% - 33%	West, North, East	100%	0,5 Vol/h – 1,0 Vol/h	0°-15°	All

Best annual Heating:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75%	33%	South	0%	0,5 Vol/h	0°	//

Best annual Cooling:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

Best annual Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

Best weekly Total:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

Conclusion:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

3.3.5.**Comparison**

Rome good range:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50% - 75%	33%-44%	South	60%-100%	0,5 Vol/h - 1,0 Vol/h	0° and 30°	West

Minsk good range:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50% - 75%	11%-44%	South	0% and 100%	0,5 Vol/h - 1,0 Vol/h	0°	//

Riyadh good range:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
75% - 100%	11%	North	100%	0,5 Vol/h	0°	//

Bangkok good range:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

4. REAL MODEL

The *Theoretical Model* provided the necessary design basis for the real *Module*: basic squares of dimensions 3,00 m x 3,00 m each that are repeated on a grid, separated by 0,30 m thick empty intervals (structural mesh), both in plan and in elevation. In turn, the *module* is divided into 9 equal squares, the *sub-module* measuring 1,00 m x 1,00 m. Each *sub-module* can be opaque or transparent, fixed or mobile. Two overlapping mobile *sub-modules* in the elevation module generate a door; one transparent mobile *sub-module* generates a window, two transparent mobile *sub-modules* a French window.

4.1. MODULE

Modular architecture has existed since ancient times. The need and practicality of finding a measurement "module" that can be standardized, and therefore repeatable, has always characterized the history of architecture. This approach has been seen at all scales: from the architectural scale through, for example, the *pedales* and thus the brick, to the urban scale through the street grid, the *cardo* and *decumanus* [98] [117].
Due to the advent of industry and the gradual abandonment of craftsmanship, most products underwent a process of standardization. This is valid also for architecture, which from the 18th century started to be realized and conceived also in a serial-industrial key. The real boom in the industrialization of the building industry undoubtedly took place after World War II: as matter of fact, modern technologies together with the huge need for reconstruction, especially in the residential sector, triggered an unprecedented expansion of this construction technique, and consequently of the related way of designing, also with innovative matrixes.
Conventionally, [118] two types of approach to the industrialization of construction are identified: closed-cycle and open-cycle.

- **Closed cycle**: it consists in the prefabrication of a complete and consequently "closed" object. It means that the produced objects (of varying sizes), when assembled (on site or in the factory), constitute a specific building.
- **Open cycle**: it consists of multi-purpose building components: it means objects that can be assembled for different buildings and different functions.

The present research uses the open cycle because of its greater adaptability and flexibility. This, on the other hand, imposes a greater design effort as it is necessary to foresee all the variables, since, unlike the closed cycle, objects are not designed and manufactured for a specific use and place.
Modular dimensional co-ordination is a very important element and many studies have been carried out in this regard, especially following the post-war building boom. It was in the 1950s that the *international basic module* (1M = 10 cm) was established at European level. The *module* **M** thus became the yardstick and every object designed and manufactured using such yardstick could communicate with each other and create a system. To this extend, however, it is necessary to establish a system in which these objects must act: a sort of grid or a pre-established and standard environment in which each element can be inserted. When the reference system is conceived in theoretical terms *a priori*, it is called *module-measure*; instead, when it is three-dimensional and the system is a direct consequence of the objects that it composes, it is called *module-object.*

- **Module-measure**: it represents a theoretical approach based on the identification of a basic module that is repeated in sequence n times. A sort of design grid that regulates the project at all scales.
- **Module-object:** it is an approach based on a three-dimensional entity, an object, which determines and guides the whole system: that is, an object is created and given its morphological characteristics, it represents the module that repeatedly regulates the configuration and conformation of the building organism.

4.1.1. Base-module

As mentioned, the basic module **M is 10 cm**. This measure determines the smallest element that the system can support. The measure of 10 cm has been chosen precisely because it allows to include all the components that make up a building and to have a whole measure. For example, the thickness of the partitions, which are the smallest building element, is 10 cm. In other words, the basic module is the correlation between real needs (e.g., the need for a room, natural light, a roof, etc.) and industrial needs (i.e., the building components that make up the building system). In the case of the closed cycle, these correlations are direct as the modular element is known and fixed and therefore has a pre-established correlation with the other elements; on the other hand, they are indirect for the open cycle, as one wants to produce building components whose direct application is not known, but whose *n* correlations need to be assumed.

Consequently, in the case of the open cycle, it is necessary to provide for all fields of application and applicability of the individual component to correctly size and type it, or at least to identify the field of action in which this component is still valid and usable. To determine it, it is therefore necessary to identify a certain seriality or repetition, i.e., groupings of the basic module which serve to identify “zones” which have common and repeatable characteristics.
In the case the repetition of M is one-way, the basic modular reference line will be used:

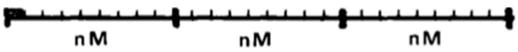


Figure 30 – Reference Line – [118] [118]

If, on the other hand, the field of action is two-dimensional, there will be a *basic modular reference plane grid*; in the case of three dimensions, a *basic modular reference spatial grid*:

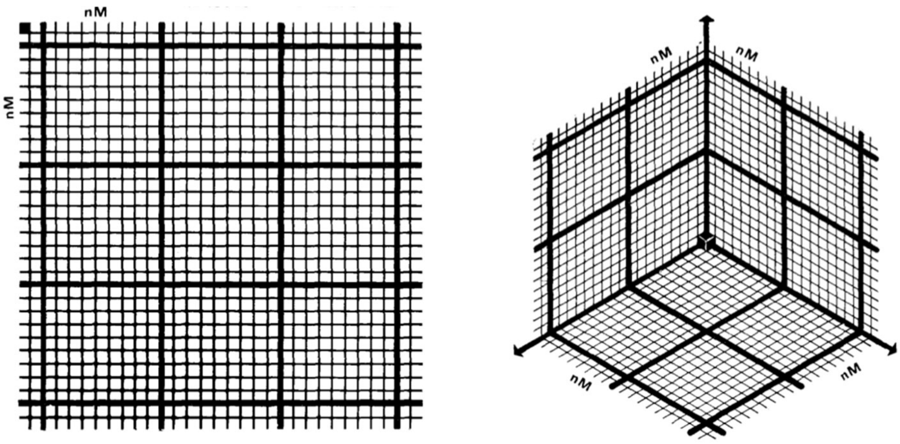


Figure 31 – Planal and Spatial modular grid - [118] [118]

Grouping on a unit basis is often insufficient to meet the complexity of the building system. Therefore, a preferred parameter multiple of the basic module M can be adopted. Also, in this case (called *Scottish net*) three cases are determined: *linear*, *plane* and *spatial multimodular*:
Furthermore, *multimodular* grouping can be *simple* or *compound*. *Simple* means that it is formed by a single combination (a single *multi-module* for linear and a single lattice or *fixed lattice* for spatial solutions); *compound* means that it is formed by several combinations of *multi-modules* (Tartan).
The use of several *multimodules* can result in other *fixed lattices*. Aiming to know the maximum number of possible combinations of *multimodules* in a pair, the *number system formula* is used:
(a - 1) x (b - 1) = Nc
Where a and b are the values of the pair and Nc is the *critical value* of possible combinations, with a and b increasing by 1M.

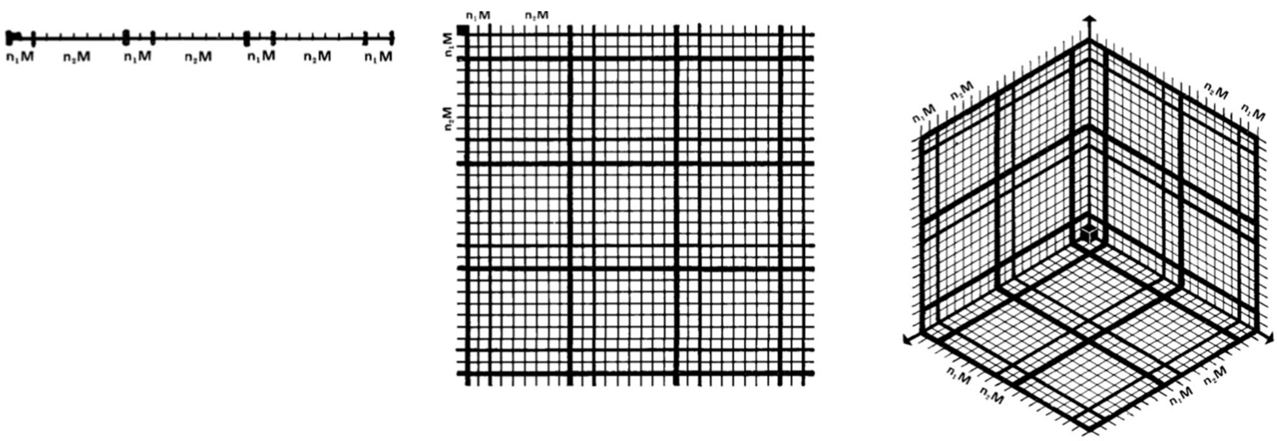


Figure 32 – Linear multi-module, Plane and Spatial multi-module grid (Scottish net) - [118] [118]

4.1.1.1. Module-measure in the building project

Generally, in the case of the open cycle, we tend to differentiate between what happens in the elevation and in the plan.
In the case of the elevation, we will therefore have a linear reference system since the heights of the elements will be the unique reading parameter of the system in analysis, and they are usually composed of a single module. Indeed, building heights are prescribed by building regulations, which require measurements corresponding to two module classes: 3M and 5M. From these two modules the heights can be obtained: 24M, 27M, 30M, 33M and 36M (respectively: from 240 cm to 360 cm with a 30 cm pitch) and 25M, 30M, 35M and 40M (respectively: from 250 cm to 400 cm with a 50 cm pitch).
For the plan, however, the situation is more complex, and therefore a multi-module composition is almost always used, which in turn can be composed in other simple (*Tartan* or *Scotch*) or variable meshes. In general, square-based meshes with a single simple multi-module (e.g., 3M x 3M; 11M x 11M etc.) or variable (based on the number pair) or combination of meshes (*Tartan* or *Scotch*) are used for the plant. However, it is also possible to use grids with a rectangular base whose sides are sized according to prime numbers: e.g., 3M x 5M; 5M x 7M etc.:

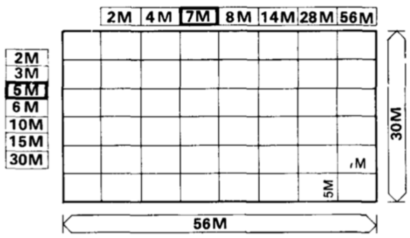


Figure 33 – Rectangular grid based on the method of the "prime numbers" - [118] [118]

Statistically, it has been seen that the preferred fixed lattices are:
2M x 2M, 3M x 3M, 5M x 5M, 7M x 7M and 11M x 11M, with the resultant lattices from these (e.g. 6Mx 6M is a resultant of both 2M and 3M).
The 3M module is particularly suitable because it can both give shape to many other grids (6M, 9M, 12M etc.) and because it can "accommodate" the dimensions of infills and structures (generally 30 cm). It is no coincidence that many of the dimensions that make up buildings are derived from the 30 cm value.
The structural mesh is important in the definition of the grid in the plan, as it is necessary to foresee the encumbrance of the vertical components that affect the plan. In this regard, 4 solutions can be adopted for the interaction between the plan mesh and the vertical components of the structure:

a) Place the centre line of the components of the structure coincident with a grid line.
b) Place components tangential to the grid line.
c) Place components tangent to the grid line but peripheral to it.
d) Placing components outside the grid

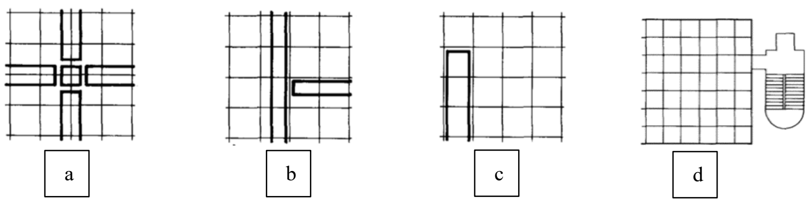


Figure 34 – Possible place of the components on the grid - [118] [118]

In conclusion, the *Scottish* grid (i.e., *tartan* combination of several plan grids) is particularly suitable for placing both in-plant and fixed elevation components that have important consequences in the plan (e.g. structure).

The following is an example of modular design using a *Scottish* grid, divided by phase and type of component to be located:

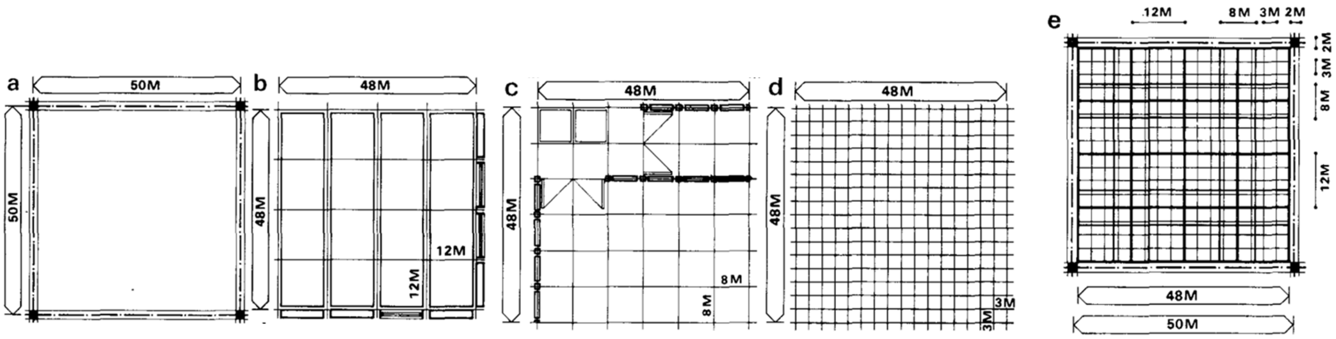


Figure 35 – a) Frame; b) Envelope grid and floor frame; c) Internal partitions grid and false ceiling; d) Floor grid; e) Complete "Tartan" [118]

For each component, in plan and elevation, to be able to dialogue with all the others, the entire system must be designed to accommodate all the components and therefore the grid must be based on the right module. The following modulation principles are generally adopted to identify the correct module:

- *Multimodular:*
    - **Simple linear multimodules:** a single simple multimodule repeated *n* times is chosen.

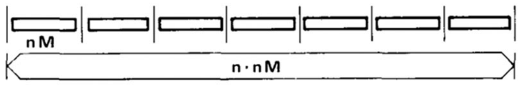


Figure 36 – Simple linear multimodules - [118] [118]

    - **Multimodular linear composites**: in this way it will be possible to accommodate a greater number of different components as the lattice will have variable dimensions. The increase of 1M in 1M will clearly always be possible as 1M is the unitary element. The number pair system indicates the value beyond which the increase will only be allowed through the unit component 1M. To identify it, called the critical value Nc, we use the relation (n_1 M-1)) x (n_2 M-1)) = Nc (where n_1 M and n_2 M are prime numbers). For example, the values 4M and 5M have the critical value 12M. This means that from 12M onwards you can only continue with

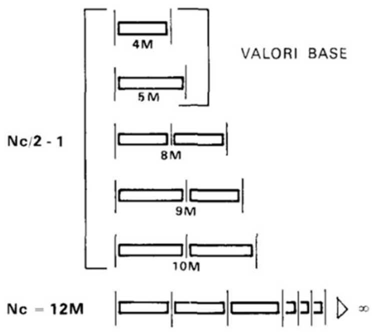


Figure 37 – Multimodular linear composition - [118] [118]

a unit increment of 1M.

    - **Simple bidirectional multimodules**: a spatial module is chosen (two dimensions) but fixed. In this case a fixed repeated mesh is formed (e.g., 3Mand x 3M).
    - **Multimodular bi-directional composite:** the same principle as linear composites applies but in two dimensions. For example, to cover a floor you could choose 2M x 2M, 3M x 3M and

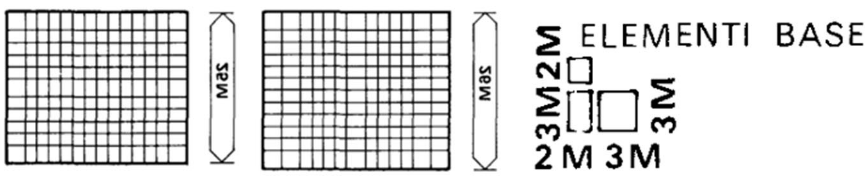


Figure 38 – Multimodular bi-directional - [118] [118]

2M x 3M tiles. In this way all dimensions can be covered in 1M increments from the critical 2M value.

- *Multimodular size classes*: modular industrialized components are produced according to recurring statistical dimensions.
- *Modular indifference conditions*: one or more component dimensions are identified that are free to assume values outside the modularity.

There are some components that are always recurring (such as doors and windows, for example) and therefore require a separate discussion to determine their size classes and how they fit into the modular discourse.

- **Vertical closures**: the facade panels have a thickness ranging from 1M (e.g., curtainwall), 2M (insulated sandwich or cavity walling) and 3M (load-bearing or external infill panels) and a width that generally follows the modules: 9M, 10M, 11M, 12M for load-bearing panels, 18M, 20M, 22M, 24M for load-bearing and load-bearing panels, 36M, 40M, 44M and 48M for load-bearing panels only. For the heights it is usual to work on the inter-floor heights, which are generally: 24M, 27M, 30M and 36M. The *n*M value of the floor thickness may be added to these.
- **Internal partitions**: the same principles as for the external partitions are used for the internal, load-bearing and load-bearing partition panels.
- **Horizontal closures**: the thickness of the floors depends on three factors: lights and loads, environmental comfort and possible integration with installations. The most commonly used modular pitches are 3M, 4M, 5M, and 6M (5M and 6M typical of floor + false ceiling).
- **Stairs**: for the width of the ramp, the size is calculated according to the number of people who have to use them: 9M for one person, 12M for two and 15M for public buildings. For the length, it depends on the height difference that the staircase has to overcome. In general, for standard intermediate floor heights (from 24M to 36M and floor thicknesses from 3M to 6M) the ideal tread size has been found to be 3M. A table for reference measurements follows:

H_l	H_i	n° A	n° P	A	P	L_M
24M	27M	9	8	15	3M	24M
	28M	9	8	15,55	3M	24M
	29M	9	8	16,11	3M	24M
	30M	9	8	16,66	3M	24M
27M	30M	10	9	15	3M	27M
	31M	10	9	15,5	3M	27M
	32M	10	9	16	3M	27M
	33M	10	9	16,5	3M	27M
30	33M	11	10	15	3M	30M
	34M	11	10	15,45	3M	30M
	35M	11	10	15,90	3M	30M
	36M	11	10	16,36	3M	30M
36	39M	13	12	15	3M	36M
	40M	13	12	15,38	3M	36M
	41M	13	12	15,76	3M	36M
	42M	13	12	16,15	3M	36M

Figure 39 – Modular stairs dimensions [118] [118]:
H_l = Net high value inter floor
H_i =Gross high value inter floor
n° A = Number of risers per ramp
n° P = Number of treads per ramp
A = Risers in cm
P = Tread in module M
L_M = modular value in plan for the length of the ramp

- **Structural mesh**: for the heights there is a tendency to determine one overall dimension for the whole building. For the floor plan, the pillars are coordinated by footprint classes, the most common of which are: 1M x 1M, 2M x 2M, 3M x 3M, 4M x 4M. For the height of the pillars, the storey height is followed.

- **Functional blocks**: for functional blocks we tend to work in 3 dimensions, considering them as objects in their own right.

4.1.1.2. Object module

In this case, the *module* is a separate three-dimensional object, which forms and regulates the grid. In essence, it is the object that is the yardstick of the system. The object module can be declined either as a *cell* or as a *spatial grid*.

- **Spatial cells**: consist in the aggregation, even on several floors, of entire elements of a dwelling or complete dwellings. Examples of this type are Habitat 67 by Moshe Safdie and Nagagin Capsule Tower by Kishō Kurokawa.

Figure 40 – From the left: construction phase of the Nagagine Capsule Tower; Nagagine Capsule Tower now; construction phase of the Habitat 67; Habitat 67 now

- **Spatial grids**: in this case the object module consists of the single structural element which, when coupled with other such objects, creates a complex surface that gives rise to forms and buildings. Examples of this typology include the Eiffel Tower and the works of R. Buckminster Füller.

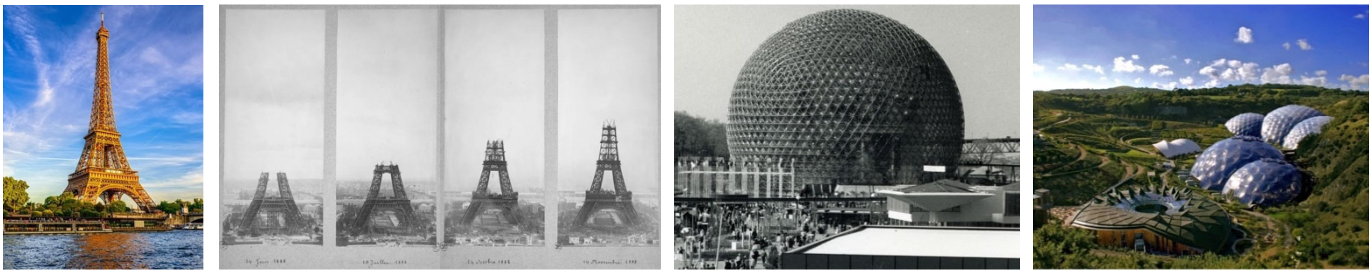


Figure 41 – From the left: Eiffel tower now and construction phases; USA pavilion, Montreal expo 1967, by R. Buckminster Füller dome; the Eden Project, UK, by Nicholas Grimshaw

As mentioned before, the industrialization of construction involves the need to standardize measurements and production methods. Contemporarily, it is necessary to find effective and practical methods of joining and connecting the various components that make up the building system. The joints between the various elements can be of various types, depending on the function they have to perform (structural, thermal, watertight, etc.) and the type of elements they have to join (load-bearing, load-bearing, load-bearing-bearing, etc.).
Joints, therefore, are defined as:

- **Strength joints**: with structural function
- **Sealing joints**: with water and/or air-tightness function
- **Point joints**: connecting linear elements
- **Linear joints**: connecting flat elements
- **Interface joints**: connecting spatial elements
- **Mixed joints**: connecting elements of various types

There are two types of joint: *embedded*, if the joint is part of the component, or *separated*, if the joint is a separate entity. In the case of a *split* joint, it can be made on site (*wet* joint) or made in the workshop (*joint* equipment, *dry* joint or *mechanical* joint).

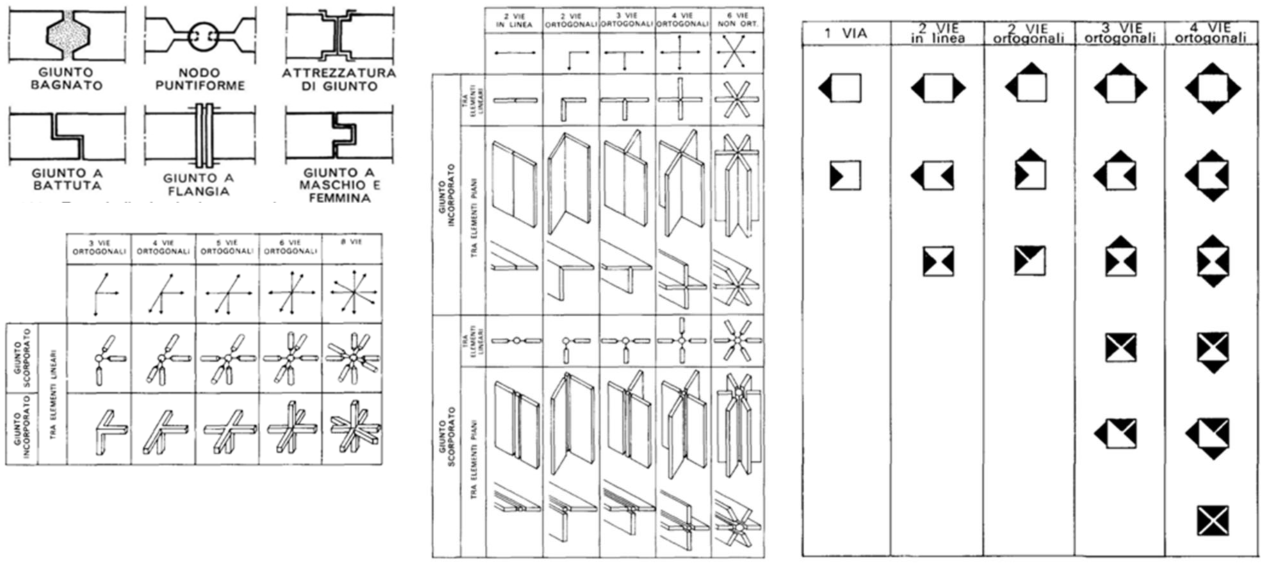


Figure 42 – Joints typology - [118] [118]

4.1.2. **Project application**

As already observed, the first step in defining a modular system is to identify the useful measurements. In this case it was decided to start with the measurements of the intermediate floor. Indeed, the storey height is one of those measures that are quite standard all over the world and therefore a good starting point for the definition of a measurement system. Conventionally, the minimum height of a residential building is 2,70 m (27M). Another requirement to which we want to respond is certainly the reduction to a minimum of the number of elements that make up the system and therefore also of the facade, both in terms of difference of "pieces" and in terms of number. For an inter-floor height of 2,70 m a full-height modular panel could be used. However, in this case, ad hoc panels would have to be made to insert windows, doors and holes, and in general a 2,70 m long panel would be impractical to handle, both in terms of transport and assembly. To isolate the door and window component from the facade panel and to ensure greater freedom of composition of the system, it was decided to divide the height of the façade into several elements. There are two dimensions to take into consideration: 27M (net inter-floor height) and 21M (net door height). The first number to guarantee both dimensions is therefore **33M**, in fact: 2 x 11M = 22M (2,10 m net door height + 0,10 m frame) + 11M (height above the door and space to accommodate any false ceiling/plant).
Consequently, in terms of height, it was decided to use 3 elements of 11M.
To this measure must be added the footprint of the structure, which was generally set at 3M (0,30 m). This measure is the result of a simplification due to the reduced spans (within 4,00 m) and limited loads and number of floors (residential of maximum 5 floors). Adding up, therefore, the structure both above and below gives 3M + 33M + 3M = 39M (36M as inter-floor height). The result is a tartan of 36M gross and 33M net.
Continuing the attempt to minimize the number of different elements to be made for the system, we tried to apply the system to the floor plan as well. Therefore, a minimum room is 9 m^2. Always using 3 panels of 11M would give a net size of 10,89 m^2. Therefore, it was decided to use this module also for the floor plan with the same footprint also for the vertical structure.
In conclusion, a modular system was adopted which is composed on a Scottish spatial grid of **36M** net and 39M structural span.

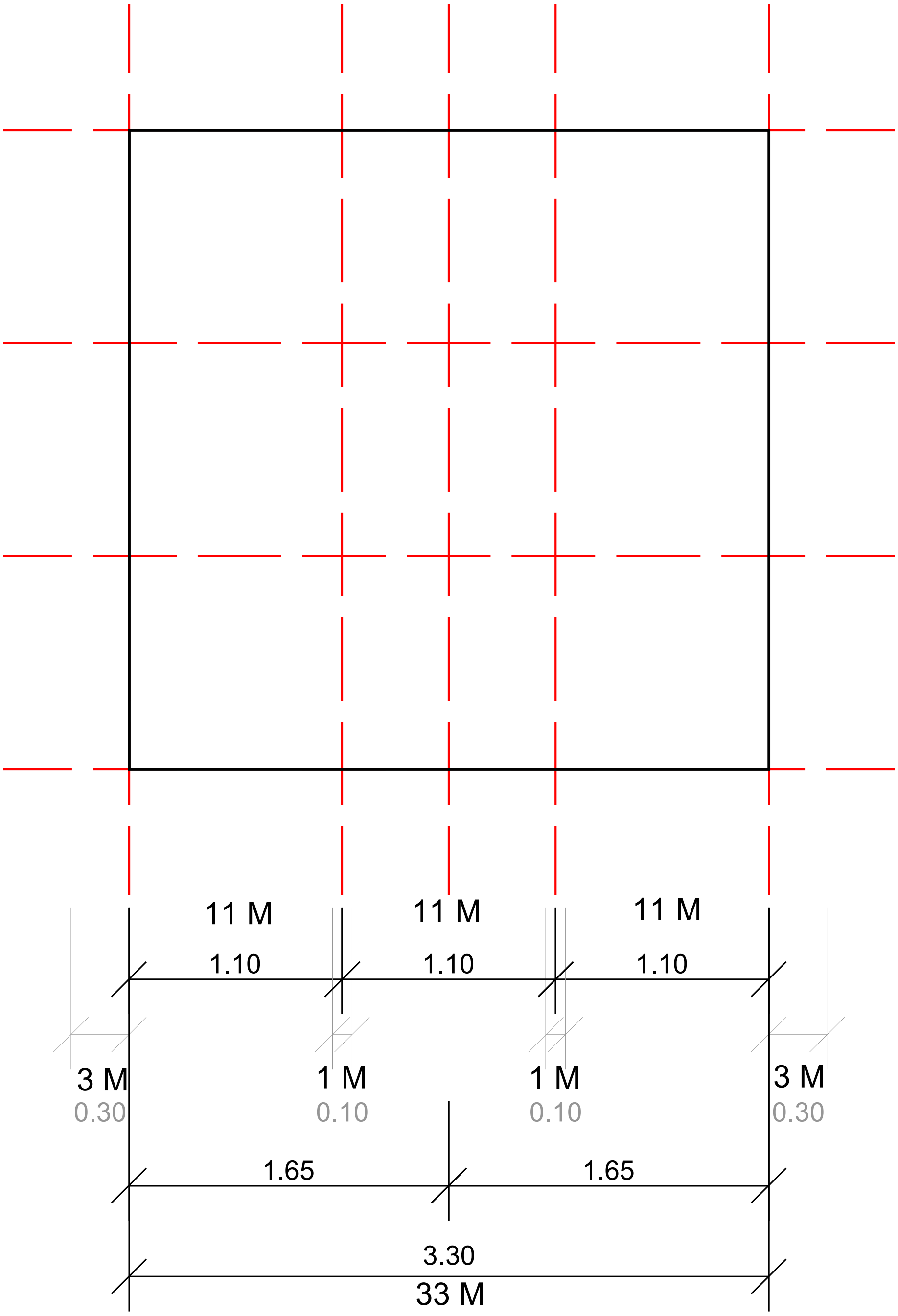


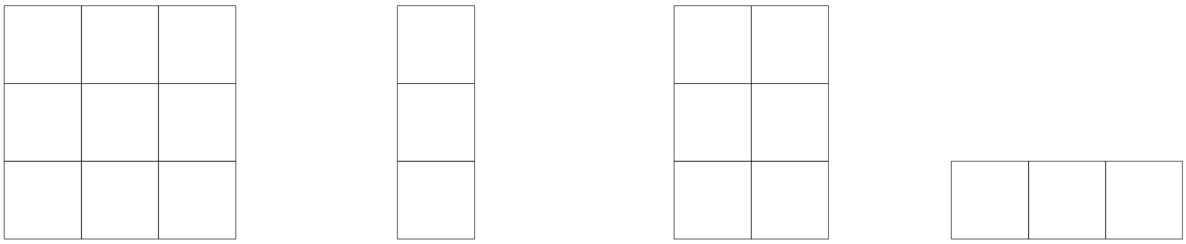
Figure 43 – The Module in cm and module M dimensions

4.1.3.**Façade**

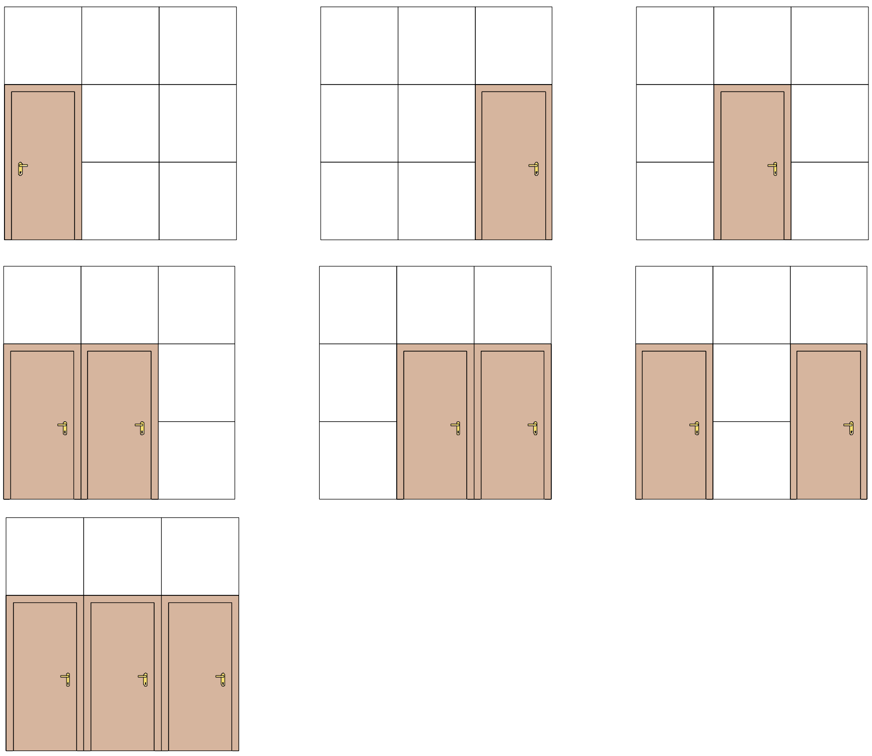
4.1.3.1. Wall

Theoretically, each *sub-module* can be set up as desired; however, obviously, the number of combinations is reduced when such a system is dropped into the real requirements (for example: it becomes not so useful and it is very infrequent to have a window on the top row of the module at a height of 2.20 m).
Therefore, only the combinations considered useful for each façade are given below.

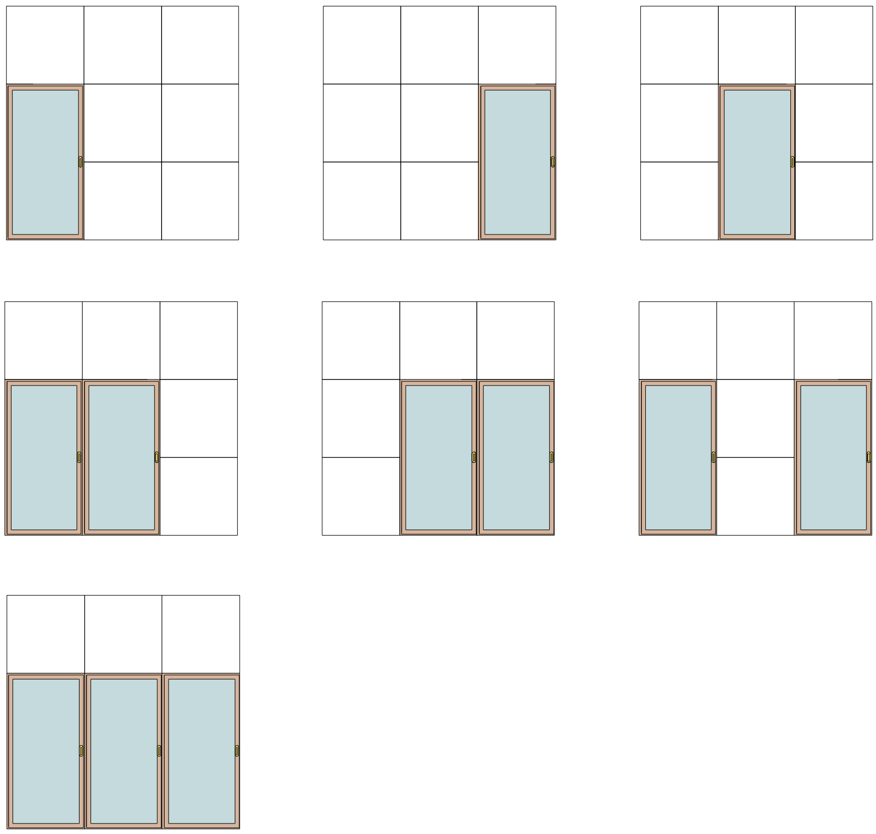
Basic elements:



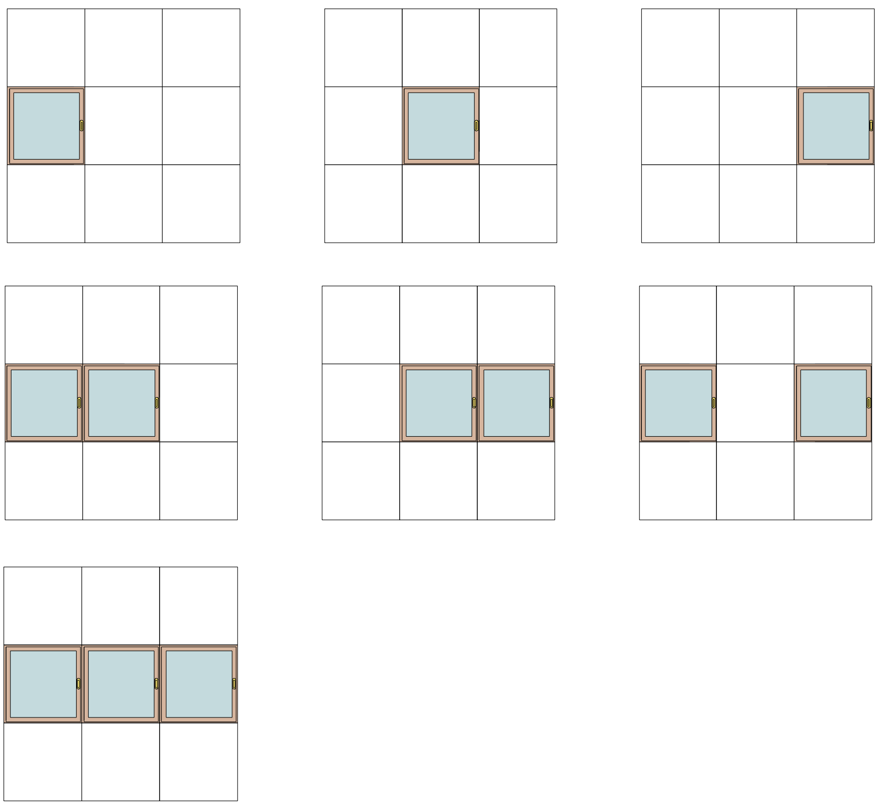
Door combinations:



French window combinations:

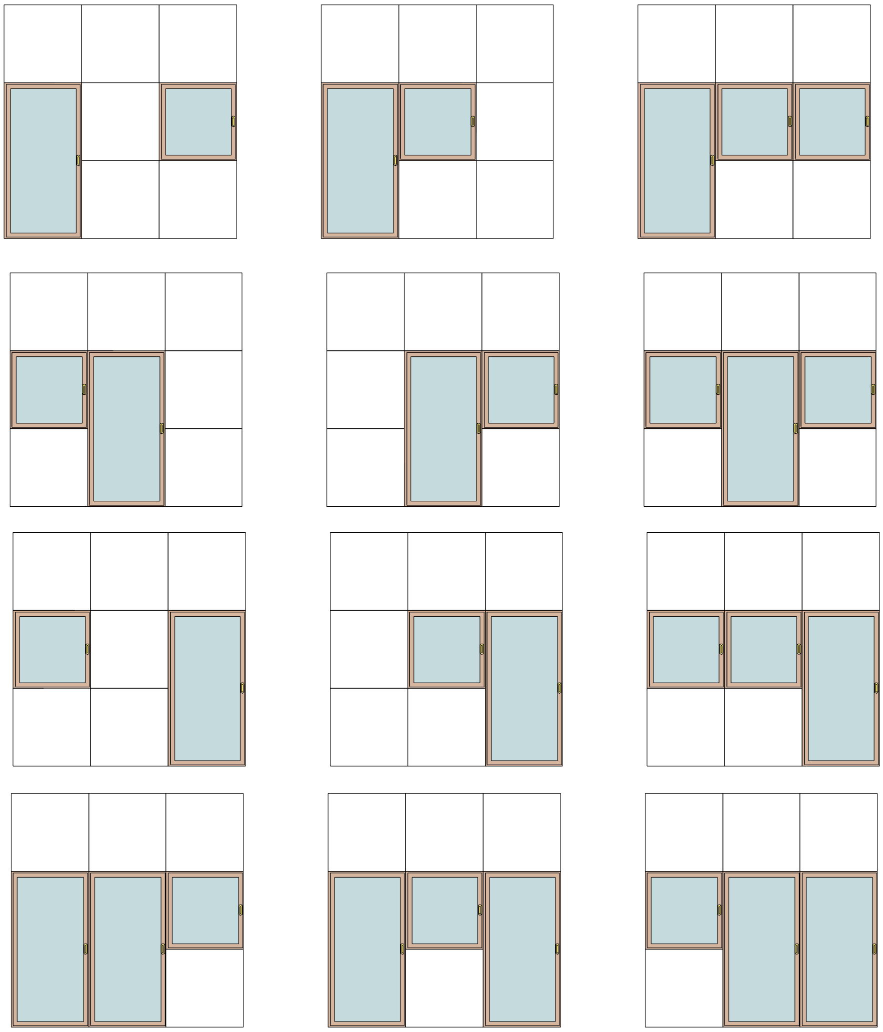


Window combinations:



Window and door combinations:

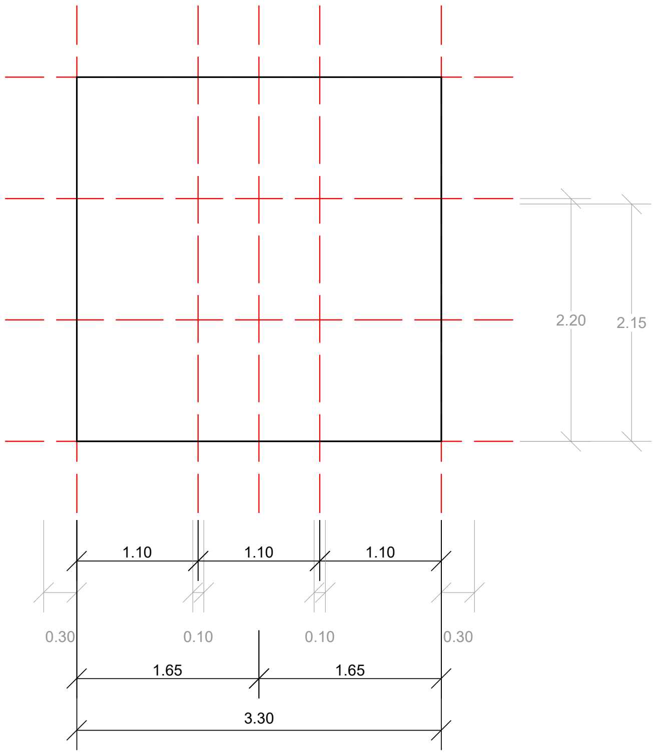
French window and window combinations:



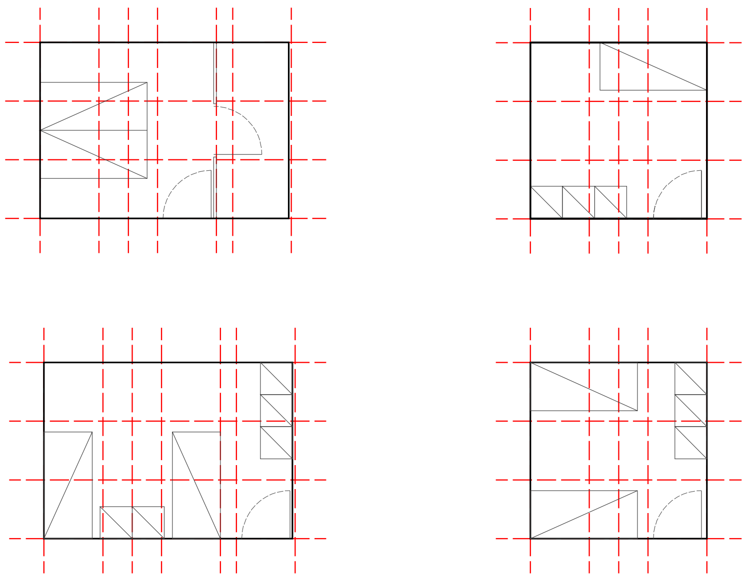
4.1.4. **Plant**

4.1.4.1. Room

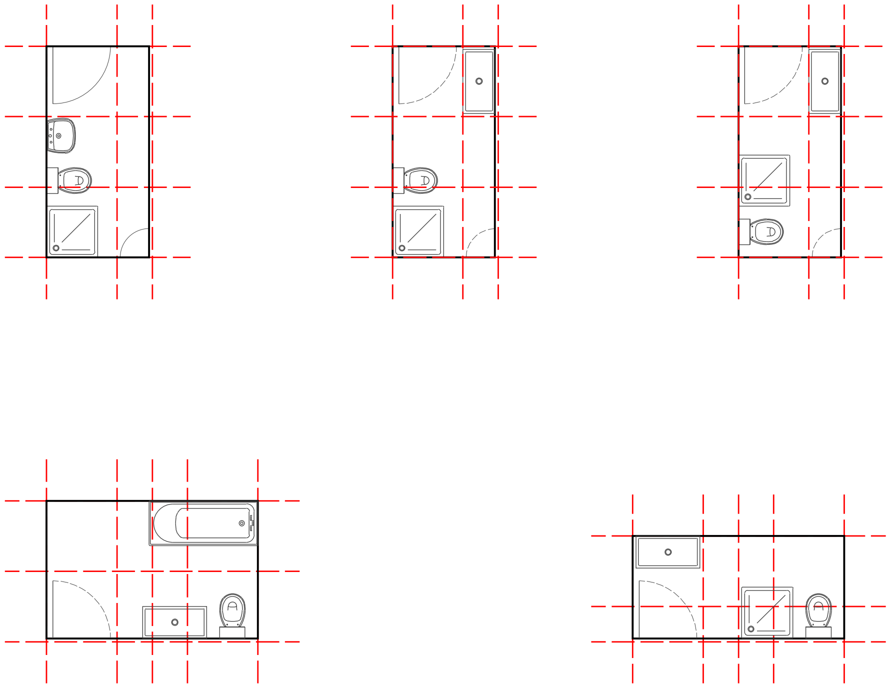
The same design procedure was applied to the floor plan: a modular "x" system of 3.30 m x 3.30 m, with sub-modules of "*x/2*" of 1,65 m and "*x/3"* of 1.10 m. In a modular logic, for the rooms it is more important to achieve mobility in the positioning of the walls: this allows the spaces to be adapted to the individual functions and needs of the rooms, as illustrated in these examples of combinations.



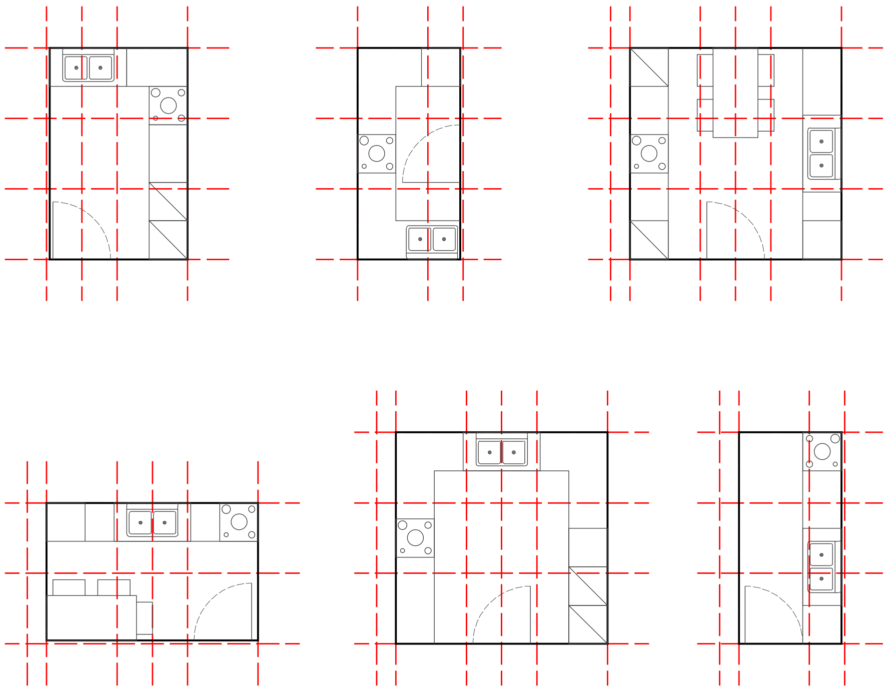
Bedroom



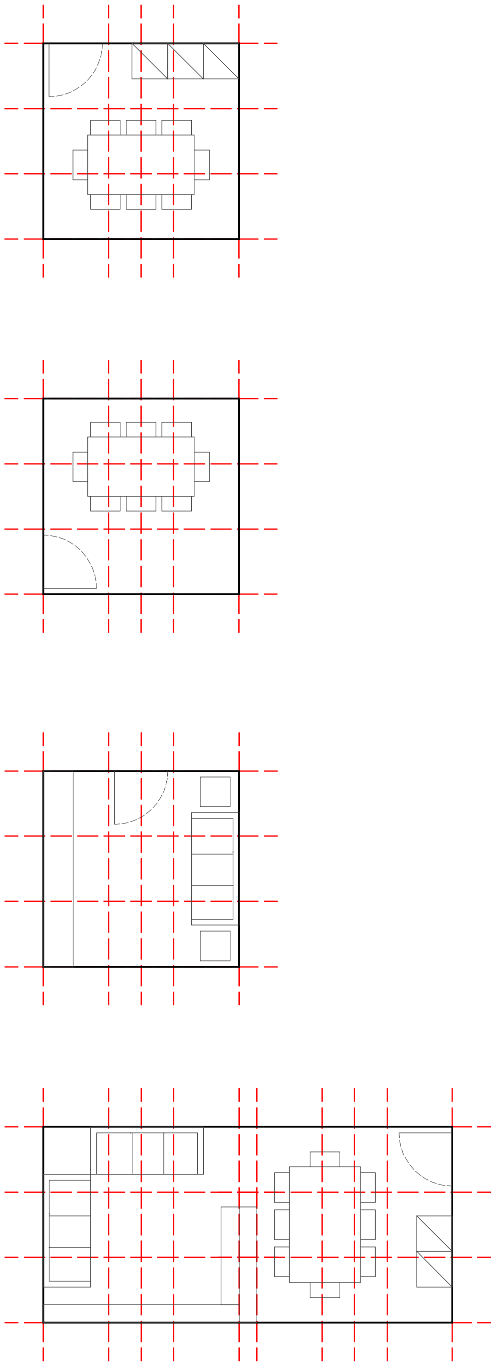
Bathroom

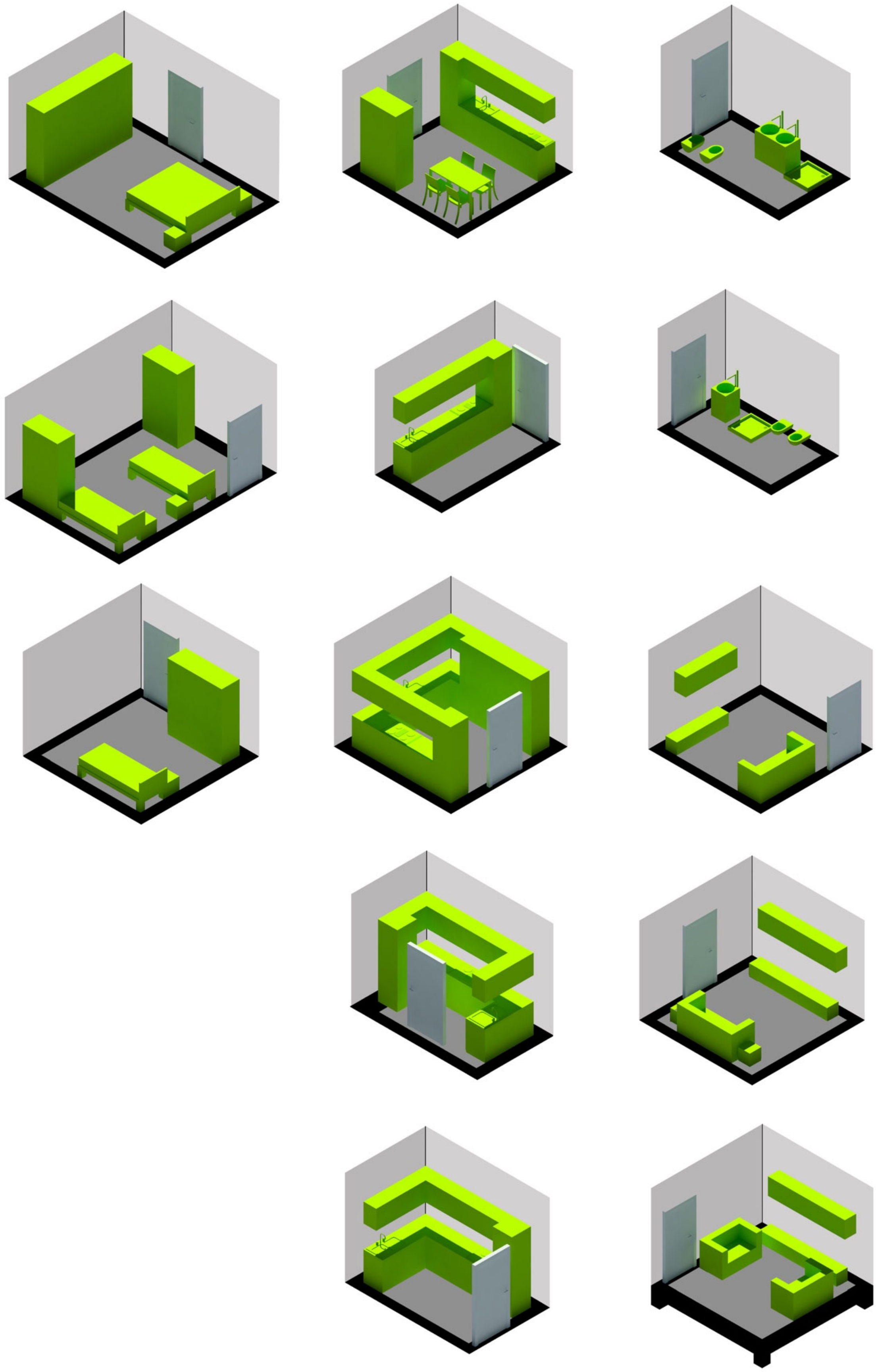


Kitchen



Living



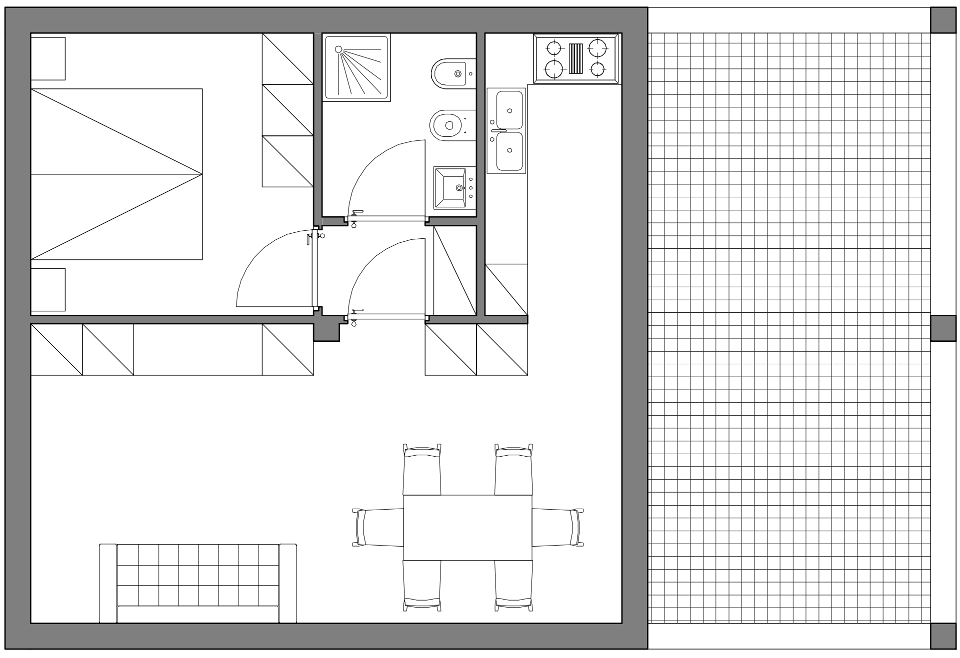


4.1.4.2. House

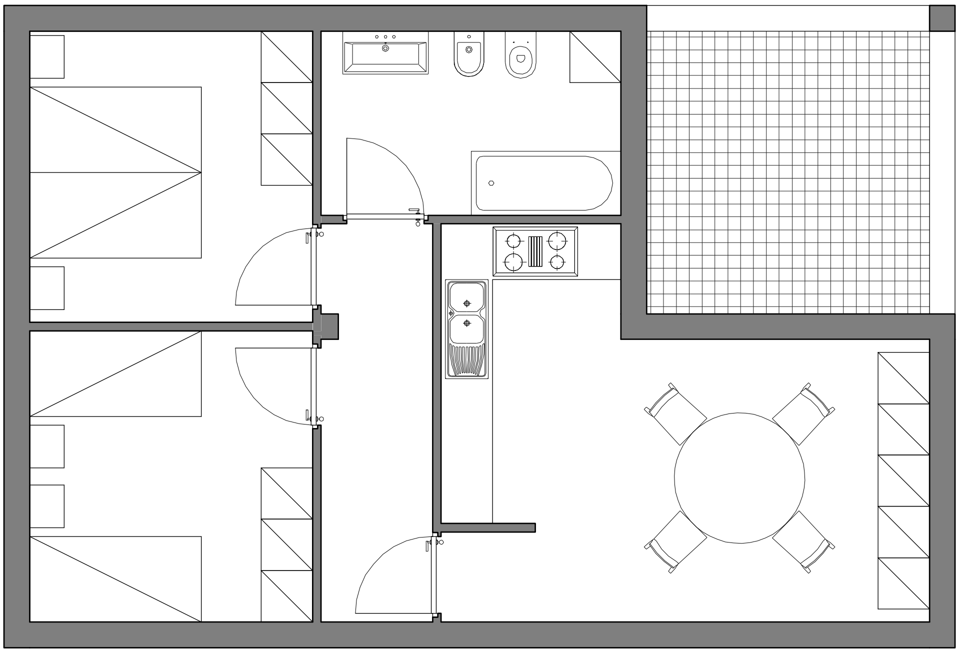
Each housing project starts with the definition of a modular grid made up of standard *modules* 3.30 m x 3.30 m within which the necessary rooms and services will be inserted. To this extend, flats, blocks, etc. are created both in plan and in elevation.

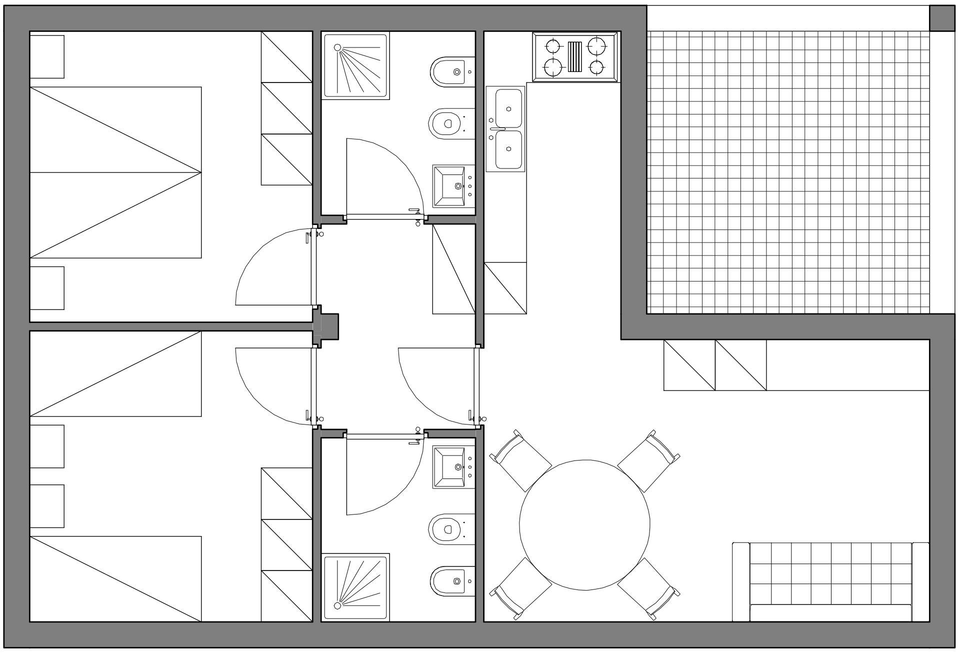
Figure 44 – Examples of composition of the houses in the grid

House (45 m^2) for 1-2 people: 4 interior modules (house) + 2 exterior modules (veranda)

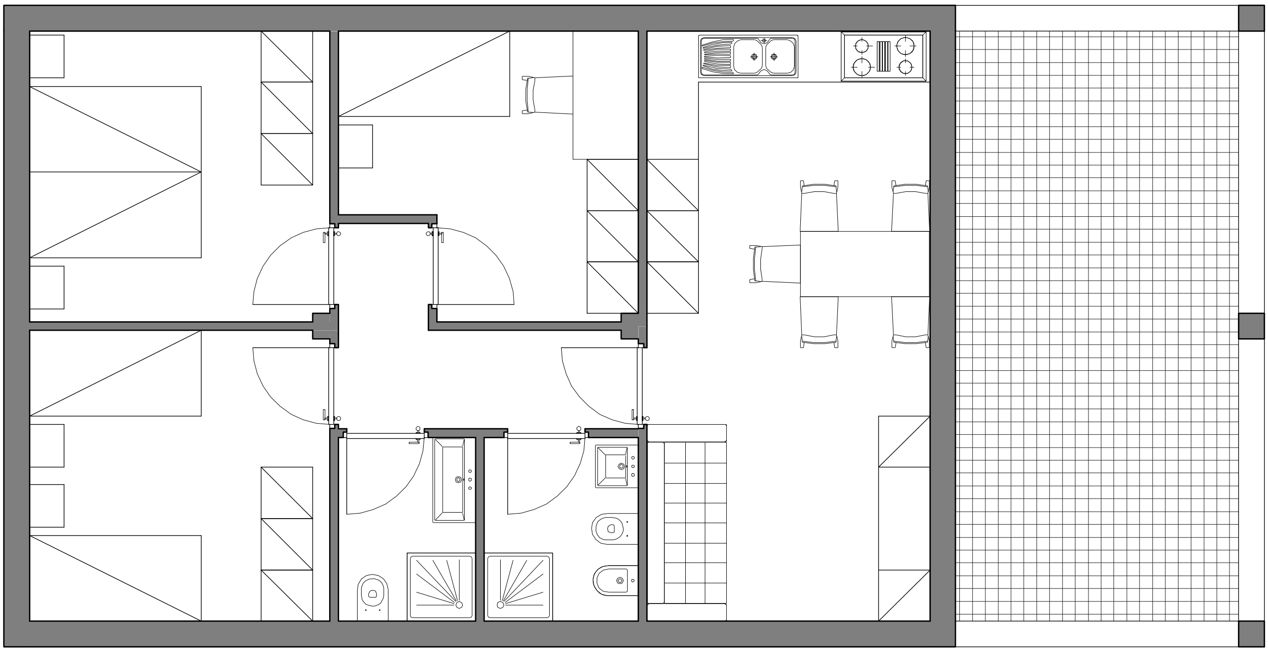


House (55 m^2) for 3-4 people: 5 interior modules (house) + 1 exterior module (veranda)





House (65 m^2) for 5 people: 6 interior modules (house) + 2 exterior modules (veranda)



4.2. System

The proposed system must guarantee all the compositional and technical possibilities examined and highlighted up to now. From the construction and production point of view, it has been decided to use, as mentioned, the opportunities offered by prefabrication and therefore industrial mass production. This means that the elements that make up the system, or pieces, must be designed so that they can be easily produced and assembled according to this logic. Consequently, it is important to minimize the quantity and variety of parts that make up the system, as each part has its own production cycle and therefore the greater the number of different parts, the lower the yield.
There are various examples in the market of companies and manufacturers of prefabricated modular buildings. Below are two examples that are considered to be valid:

4.2.1. **Eco-Space**

Eco-Space is a British company specialising in timber frame construction. The concept behind the company's work is one of sustainability and modularity. Currently the offer includes both residential and office and school buildings. The modular residential system includes both standard and customised cuts. The standard sizes range from less than 10 m^2 to approximately 110 m^2, all with a net internal height of 2,70 m. It is possible to

Figure 45 – Eco-Space modular construction possibility – source: ecospaceitalia.com

The offer proposed by the company is very valid, however, it clearly classifies itself towards a rather defined target: the finishes and the type of construction require a fairly high level of equipment, labour, etc. Therefore, they are feasible in a rather high economic and social context, which is not always easy to find in emergency situations.

4.2.2. **U-Build**

U-Build is a project created by Studio Bark. The system consists of small, assembled panels. Each panel forms a sort of "box" or container that holds the insulation. In this way the panel is both finish and structure. With the proposed system it is possible to build from Tiny Houses to real houses.

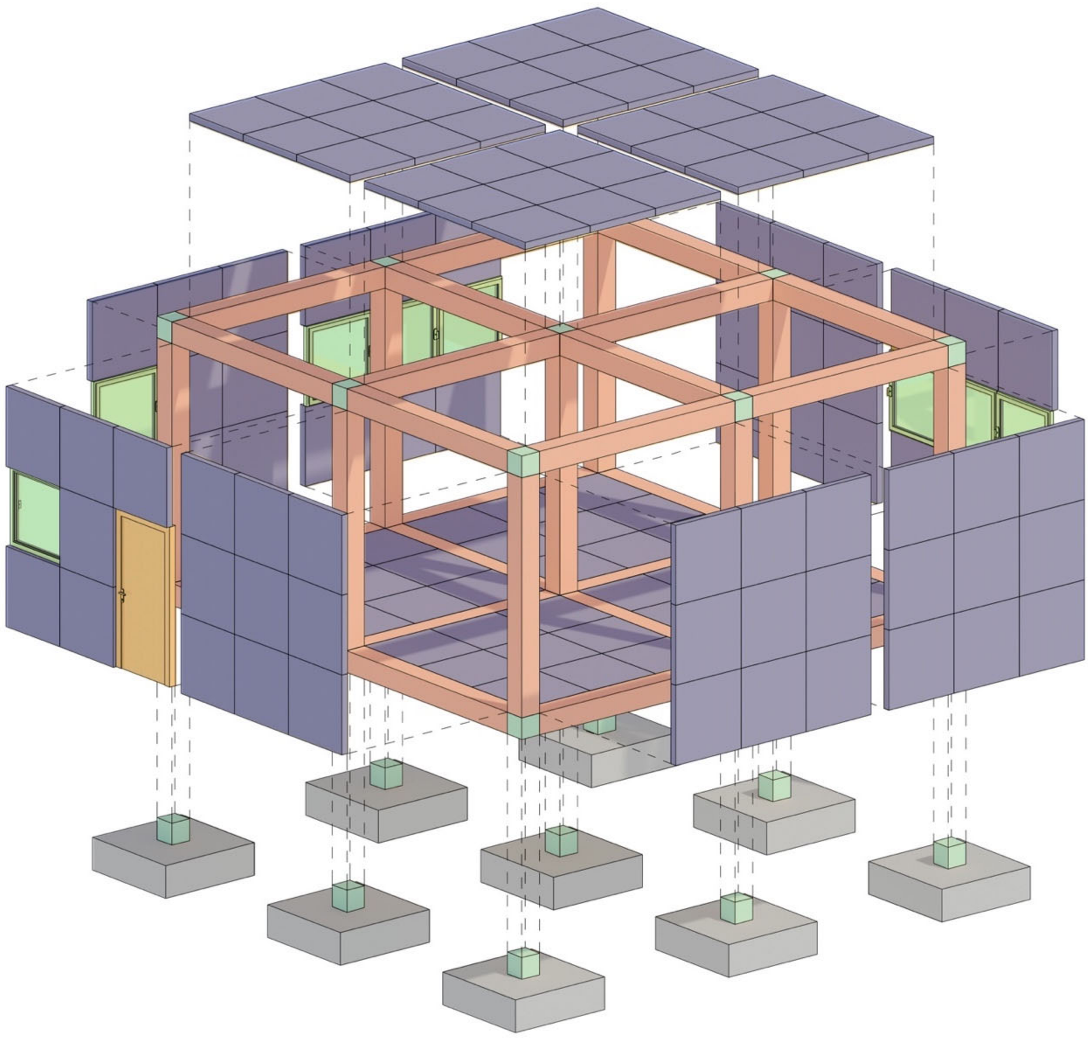
Figure 46 – U-Build residential example – source: u-build.org

In this case the system is practical and economical (about £1,000.00 per m^2). The critical points are represented by the little possibility of customizing the stratigraphy of the wall and by a maximum height of elevation that seems to be at most two storeys.

4.2.3.**Suggested system**

The suggested system must therefore satisfy both the technical requirements to reach at most of the Off-Site modular mass production system and allow for easy assembly and customization. Therefore, a modular system is proposed which foresees the use of both a load-bearing frame structure (to guarantee a certain structural and anti-seismic solidity) and a panel curtain walling system (to be able to customise the composition of the envelope and the design of the facade).
The overall design system is therefore composed of a number of predefined pieces that are repeated. The compositional elements of this system are shown below. The proposed elements are intended as schematic and functional, and thereby do not identify a material or an interlocking system. The dimensions of the sections of each element are also to be understood as identifying and general, to be verified and correctly dimensioned when the system is translated into a precise and definitive material and joint system. Indeed, at this stage, we want to identify the system from a theoretical point of view so that it can then be declined according to the specific needs of each situation. This is designed to allow the greatest possible flexibility.
The parts that compose the system are shown below:

a) **Frame**: structural element, beam or column, 3.30 m long and 0.30 x 0.30 m section
b) **Joint**: structural connection element, consisting of a cube of side 0.30 m
c) **Panel**: the sub-module, which consists of a 1.10 m x 1.10 m panel and a thickness of 0.10 m. The panel can be used for both the elevation (wall) and the plan (floor and roof).
d) **Window**: an opening window 1.10 m x 1.10 m and 0.10 m thick
e) **Door**: a door consisting of two overlapping 1.10 m x 2.20 m panels. It can be opaque or transparent (French doors)
f) **Foundation**: “structural 'feet' consisting of height-adjustable elements



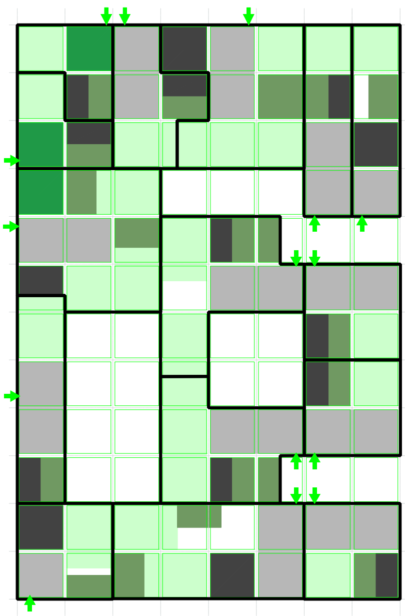
4.3. Building

According to the same logic of modular design, by aggregating several dwellings, buildings can be composed (even the stairwell is conceived in a modular way).

Figure 47 – Aggregation example

4.4. Cluster

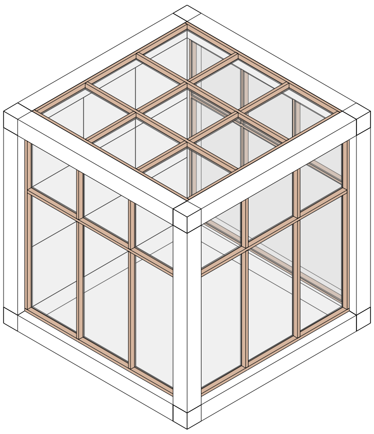
By aggregating several dwellings and several buildings, both in plan and in elevation, a "cluster" is generated.

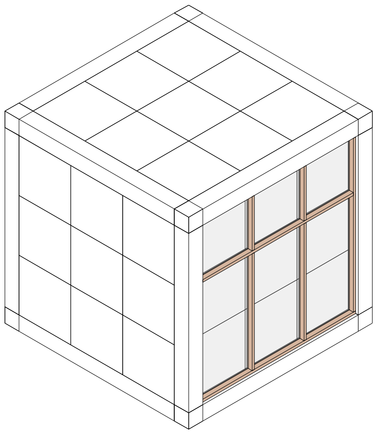


4.5. BIOCLIMATIC MODULES

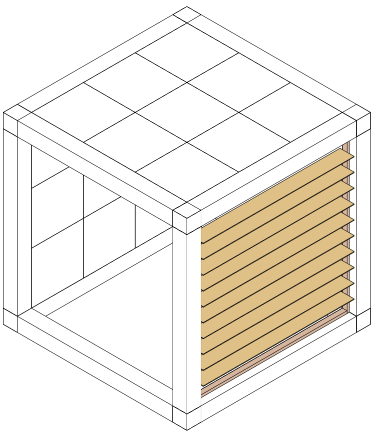
Through the theoretical model, it has been evident how the *module*'s compositional choices have a significant influence on energy requirements and internal comfort. From the numerous simulations carried out, it can be observed that through the correct choice of combinations, it is possible for the *module* to achieve zero requirements. However, there are cases in which this result, despite the efforts to optimize the *module*, is not achievable (e.g., in some weeks of the year in the cold climate, as in our example of Minsk, despite the optimal configuration a certain heating demand is necessary to reach the comfort zone).
For these cases, accessory *modules* are proposed which, in addition to the standard *modules*, increase one or other of their bioclimatic characteristics:

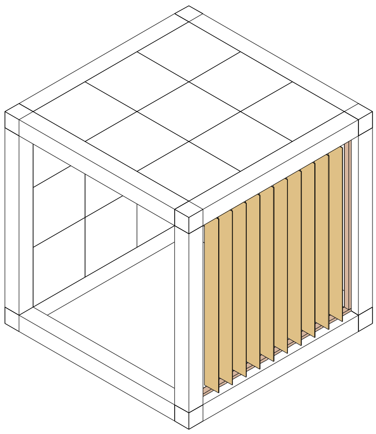
- **Heating requirements**: greenhouse module and Trombe wall module



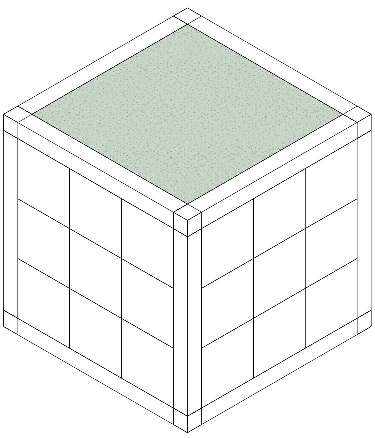


- **Cooling requirements**: horizontal and vertical brise soleil module





- **Envelope requirement**: garden roof module; it is both useful for thermal insulation and thermal mass.



4.6. BUILDING IN THE 4 CLIMATIC ZONES

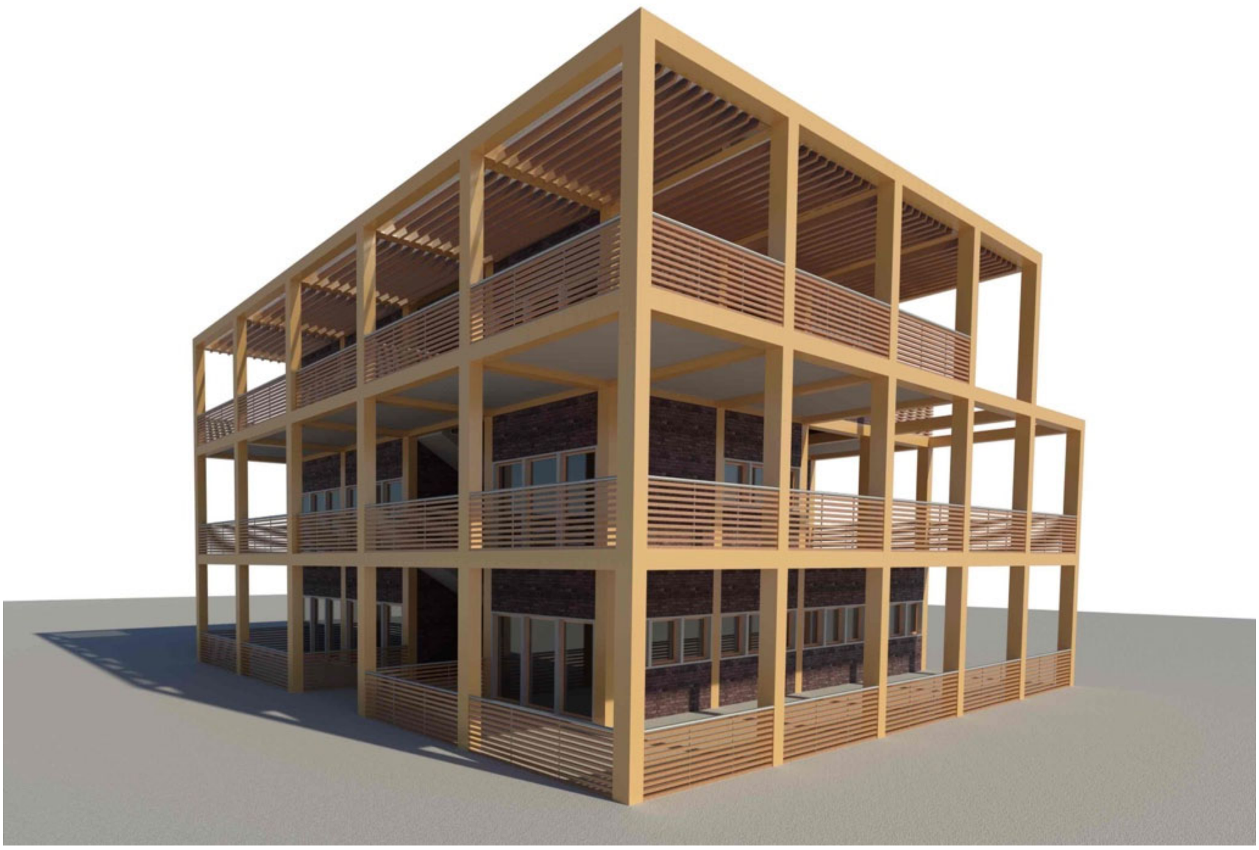
Following the indications of the theoretical models, 4 examples of architectural projects were realised, depending on the climate band elaborated:

4.6.1. **Rome**

Reference value:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50% - 75%	33%-44%	South	60%-100%	0,5 Vol/h - 1,0 Vol/h	0° and 30°	West

1. **Envelope**: 50% Insulation, 50% Thermal mass – Fixed thickness 40 cm → 20 cm Insulation + 20 cm Thermal Mass
2. **Window %**: 33%-44% South – 9 *sub-modules* for each façade → 3-4 transparent module for each façade (1 French door + 2 windows; 3 windows; 2 French windows etc.)
3. **Shading %**: 60%-100% - mobile shadow or horizontal brise module (or overhang)
4. **Natural Ventilation**: 0,5 vol/h – 1,0 Vol/h – mobile opening of the windows: lower in winter period (0,5) and upper in summer period (1,0).
5. **Slope inclination**: both 0° and 30° West.



4.6.2. **Bangkok**

Reference value:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

1. **Envelope**: 100% Insulation – Fixed thickness 40 cm → 40 cm Insulation
2. **Window %**: 11% North – 9 *sub-modules* for each façade → 1 transparent module for each façade
3. **Shading %**: 100% - horizontal and vertical brise module (or overhang)
4. **Natural Ventilation**: 0,5 vol/h – mobile opening of the windows: constant throughout the year (0,5) during mid-season there is a small period of more ventilation requirement (1,0).
5. **Slope inclination**: 0° is the best case.

4.6.3.**Riyadh**

Reference value:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
100%	11%	North	100%	0,5 Vol/h	0°	//

1. **Envelope**: 100% Insulation – Fixed thickness 40 cm → 40 cm Insulation
2. **Window %**: 11% North – 9 *sub-modules* for each façade → 1 transparent module for each façade
3. **Shading %**: 100% - horizontal and vertical brise module (or overhang)
4. **Natural Ventilation**: 0,5 vol/h – mobile opening of the windows: constant throughout the year (0,5) during mid-season there is a small period of more ventilation requirement (1,0).
5. **Slope inclination**: 0° is the best case.

4.6.4.**Minsk**

Reference value:

Insulation	Window	W-Exp	Shading	Nat. Vent.	Slope	S-Exp
50% - 75%	11%-44%	South	0% and 100%	0,5 Vol/h - 1,0 Vol/h	0°	//

1. **Envelope**: 50%-75% Insulation, 50%-25% Thermal mass – Fixed thickness 40 cm → 20/30 cm Insulation + 20/10 cm Thermal Mass
2. **Window %**: 11%-44% South – 9 *sub-modules* for each façade → 1-4 transparent module for each façade (1/2/3 Windows; 1 French door; 1 French door + 2 windows; 2 French windows etc.)
3. **Shading %**: 0% and 100% - mobile shadow or horizontal brise module (or overhang). In winter period 0% in summer 100%.
4. **Natural Ventilation**: 0,5 vol/h – 1,0 Vol/h – mobile opening of the windows: lower in winter period (0,5) and upper in summer period (1,0).
5. **Slope inclination**: 0°.

In winter there are weeks when, due to low outside temperatures, a significant amount of thermal energy is required (even in the best cases). *Greenhouse modules* can be used to intervene during these periods.

4.7. CONCLUSIONS

From the values analysed on the 4 climate zones it emerges that:

- **Envelope**: overall, it is evident that the best envelope composition is represented by a balanced mix between Insulation Level and Thermal Mass, with a slightly higher percentage of Insulation. What deserves attention are the cases of high temperatures: contrary to what one would normally think, the best envelope composition in hot climates prevails towards the absence of Thermal Mass. This is due to the fact that the *Thermal Mass* is a favourable element in cases where there is a balance between day and night: that is, in cases where over 24 hours there are temperatures within the comfort zone or in any case sufficiently low to provide a "reservoir" to draw on during the hot hours. In fact, the *Thermal Mass* dampens and displaces the thermal wave, and therefore does nothing but "delay" (as well as reduce) the effects of a given external thermal situation towards the inside. Therefore, for situations in which the external temperatures are far from the comfort zone and that over a 24-hour period (or in any case within the period of thermal lag of the wall in question) never reach temperatures below 26° C, the best situation is that of strongly insulated walls. However, all this is to be understood in air-conditioned situations such as the one being analysed. In fact, in cases where there is no air-conditioning, this does not apply, as the temperature at night is lower than during the day and therefore it would be advantageous to be able to use it.
- **Window %**: the analyses show a widespread prevalence of small, glazed surfaces (11% is a fairly recurring value and almost never over 44%). In line with expectations, there is a tendency to have larger windows in contexts where a greater solar contribution is needed (e.g., winter Minsk). It should be considered that for the case under analysis the solar contribution is not particularly desirable since the volume to be heated is not large (27 m^3) and the internal loads play a rather important function, given the size of the *module*. Therefore, in this condition, it is very often more convenient to increase the opaque envelope (with higher performance) as much as possible at the expense of the window size and the consequent solar heat contribution.
  - **Window Orientation**: for the orientation of the windowed facade, the same applies as for the glazing percentage: in climates where a certain amount of solar heat input is required (Rome and Minsk), a southern exposure is preferred. As matter of fact, in these cases the South is particularly suitable both because of a greater radiative contribution in winter and because in summer it is easier to screen it (for example with overhangs or horizontal brise-soleil). In contrast, in hot climates, the preferred exposure is North, as solar radiation is minimal.
- **Shadow %**: this parameter is one of the two furniture. Therefore, it is not very useful to identify only one configuration. It is useful to see how this value changes according to the periods of the year. In line with expectations in warm periods the tendency is towards shading, and in cold periods towards openness.
- **Natural Ventilation**: the widespread tendency is to have low natural ventilation values. This is due to the fact that the system under analysis is artificially air-conditioned. Therefore, the introduction of air at external temperature is a disadvantageous element, especially for more extreme climatic situations.
- **Slope Inclination**: the analyses suggest that this value has little influence. It should be considered that the analyses were carried out considering an increase in internal volume in cases of roof inclination ≠ 0°, which influences the final results of this parameter.
  - **Slope Orientation**: the same applies, of course, to the orientation, which does not vary much.

5. DESIGN APPLICATION

Through the *practical model*, a series of ideal targets (*theoretical model*) were translated into elements (*modules*) with a defined *form*. This chapter deals with assigning the material to these forms, defining the technical details (construction materials: wood, metal...) and designing details (joints, panels, structure...). As soon as the *material* is combined with the *form*, the theoretical objects become real and concrete, and it is as consequence necessary to define technical details to understand how the *material* can give substance to the *form*. The project is precisely the definition of the details that make the *practical model* a feasible element.
Of the construction methods currently available, it was decided to limit the study of the design system of modules to two: wooden and metallic.
By wood we mean the whole world of construction systems of organic origin (bamboo, solid wood, processed wood, etc.).
Metallic, on the other hand, means the entire world of metals (steel, aluminium, alloys in general, etc.).
The “metallic system” is valid for both steel and aluminium, just as the “wood system” is valid for both solid pine and laminated bamboo, etc. This clarification is necessary to reiterate the concept of constant adaptability with which the system was designed and built. As matter of fact, certain materials are present and can only be processed in specific parts of the world. Fixing the system to specific materials means limiting its applicability to predetermined contexts, places and resources.
Other materials and building types, although widely used in modern construction, have been excluded, such as, for example, concrete because of its heaviness, which would reduce its mobility and adaptability. Brick was also excluded due to its “constructive rigidity” which limits both its pre-fabrication and modifiability.

Moving from the *Theoretical Model* to the *Practical Model* and following the comparison with the requirements of industrial production, it was decided, during the course of the work, to modify the dimensions of the *sub-module*. Indeed, during this phase of practical elaboration it emerged that the *sub-module* size of 1,20 m is the most congenial to industrial production requirements: in fact, cladding panels, plasterboard, sheet metal, etc. very often follow the multiple of 0,60 m and therefore 1,20 m is the first useful size to combine 0,60 m with the minimum size of 1,10 m (minimum length identified up to the practical model). Consequently, in the design application worked out with the company, the module has a net internal length (without structural mesh) of 3,60 m and a gross length (including structural mesh) of 4,20 m.

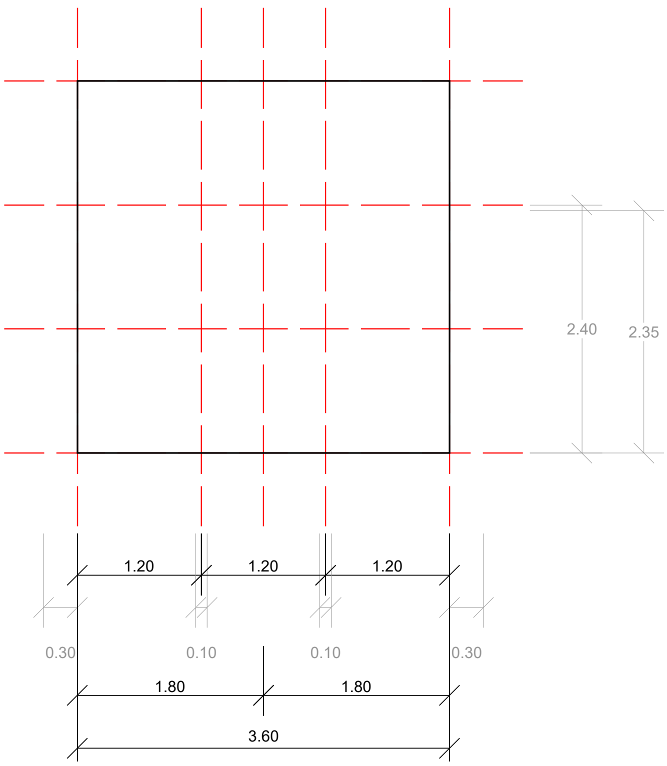


Figure 48 – The Module adapted to the sub-module dimensions of 1,20 m (12M)

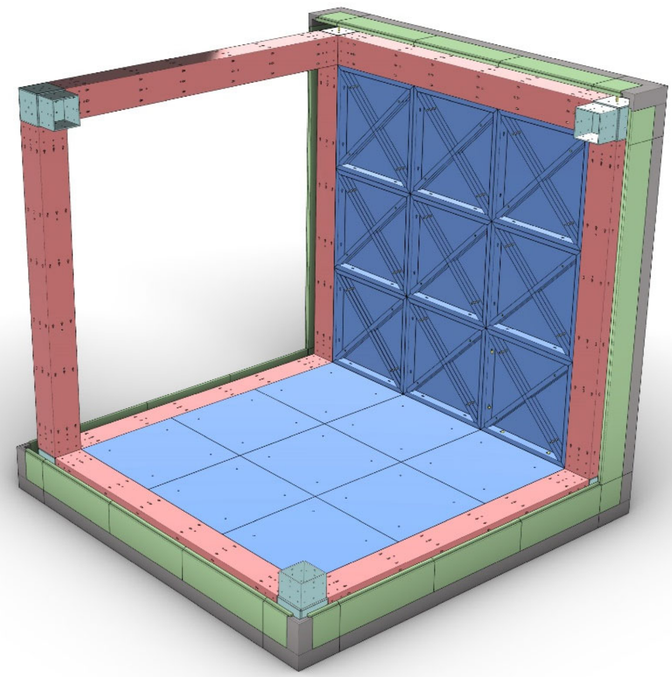
In the research, however, we will proceed with the dimension of 1,20 m as the *module* has been designed as a theoretical system that can be adapted to the requirements from time to time.

5.1. METAL

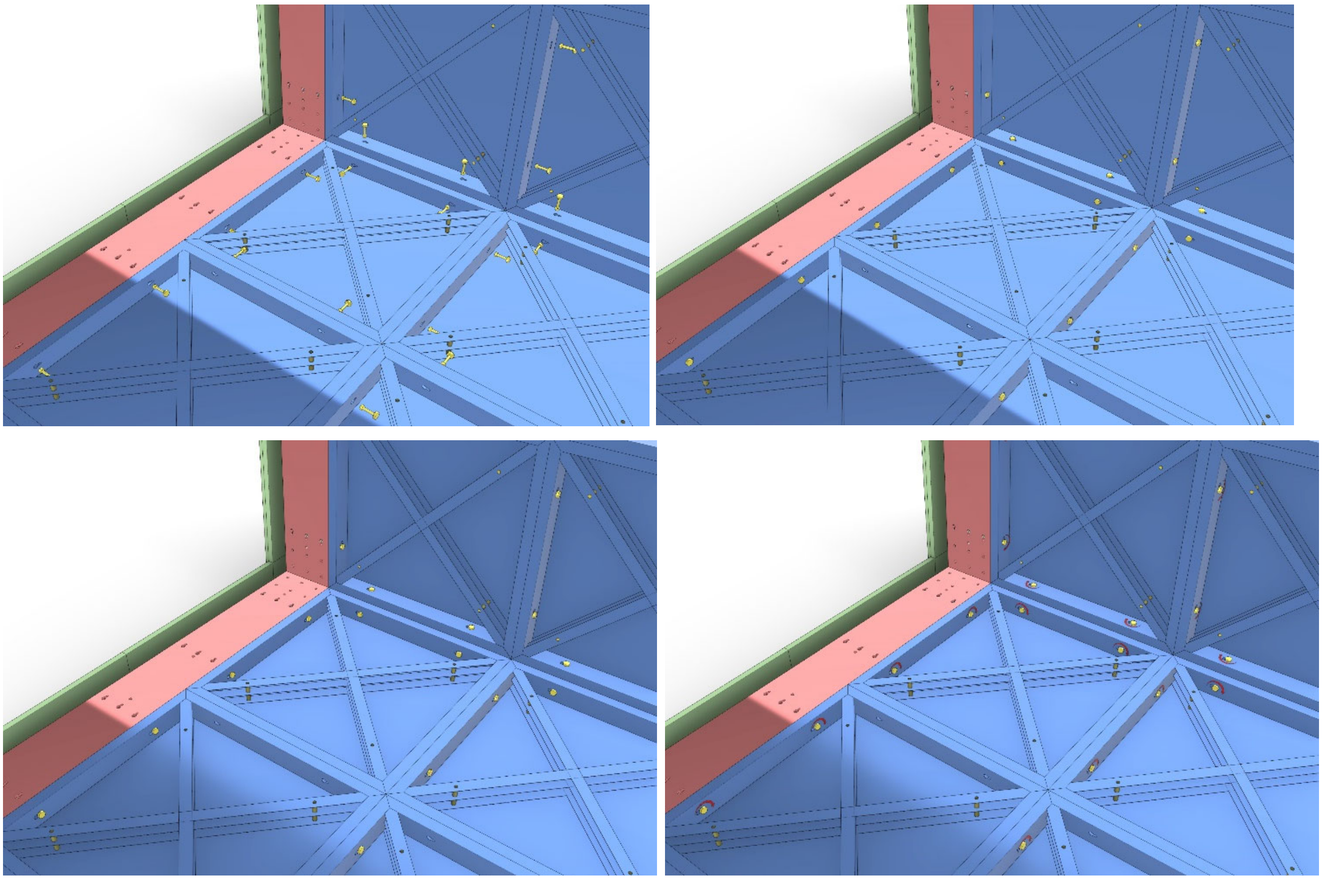
The most widely used metal in building construction is undoubtedly steel [119] However, in the last decades, aluminium is also becoming more and more popular, due to its lightness and reusability.
In overall, any metal is rather expensive economically and energetically, at all stages of its life: from production to transport, disposal, etc. At the same time, however, it has an advantage in terms of energy efficiency and it has an excellent strength-to-weight ratio and is easily shaped. Moreover, it has a potentially infinite life cycle as it can be reused many times (Steel Recycling Institute reports that steel is recycled more than paper, plastic, glass, copper, lead and aluminium combined). [120]
The resistance of metallic materials is to be understood both in static terms and also in terms of durability. From a thermal point of view, on the contrary, it has poor characteristics due to its high thermal transmissibility and is often the cause of thermal bridges.
All metals are isotope materials, which have the same tensile and compressive functioning, therefore, they are very well adapted to the use required in the structural elements of the *module*: in particular, in the beam and the column, which are composed of the same piece.
Having said this, we propose the development of the parts identified in Chapter 4 (paragraph 4.3 page 65) adapted to a construction system based on the material "metal".
The parts which make up the system are proposed below. The fastening system between the various elements is designed to be of the screw and bolt type so that it can be assembled and disassembled (each detailed element is exposed in Chapter 7):

- g) **Frame**: structural element, beam or column, consisting of a metal square section 3,30 m long, 0,30 x 0,30 m section and 0,01 m thickness → **Fr_1_1**
- a) **Joint**: structural connection: a "cave box" with a side of 0.30 m and the setup for "host" the beam and column. Can be 3 to 6 ways → **Jn_1_1**
- b) **Panel**: the sub-module, which consists of a 1,10 m x 1,10 m panel and a thickness of 0,10 m. The panel can be used for both the elevation (wall) and the plan (floor and roof). → **Pa_1_1**
- c) **Secondary joint**: metal screws joining panel-panel and panel-beam

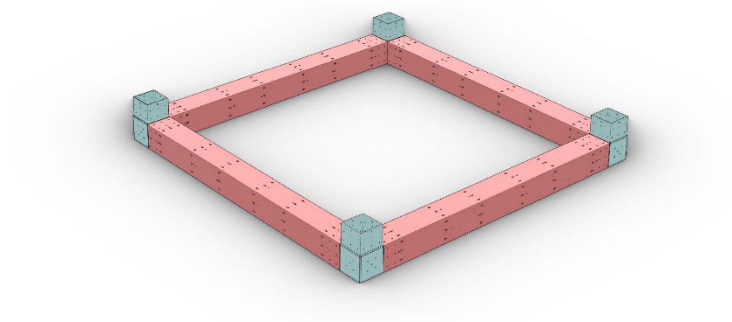
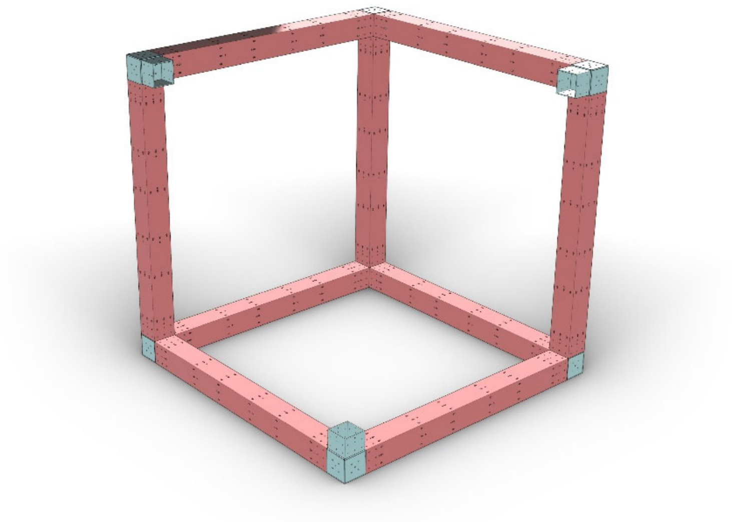
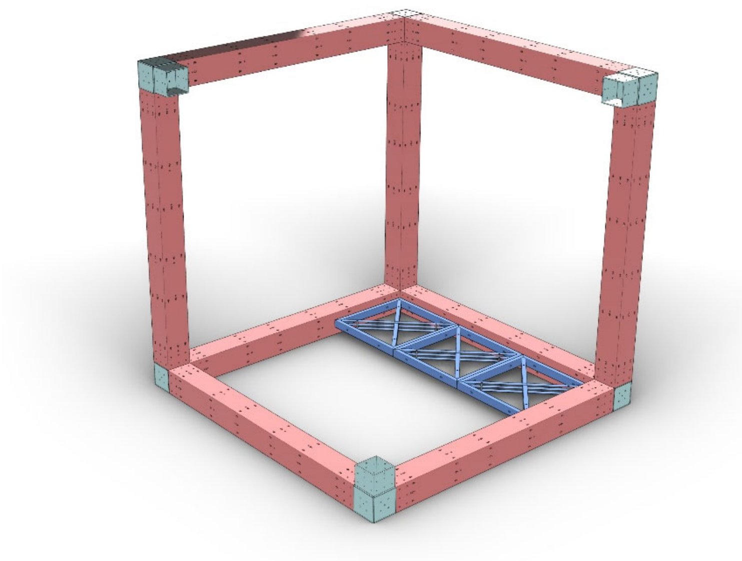
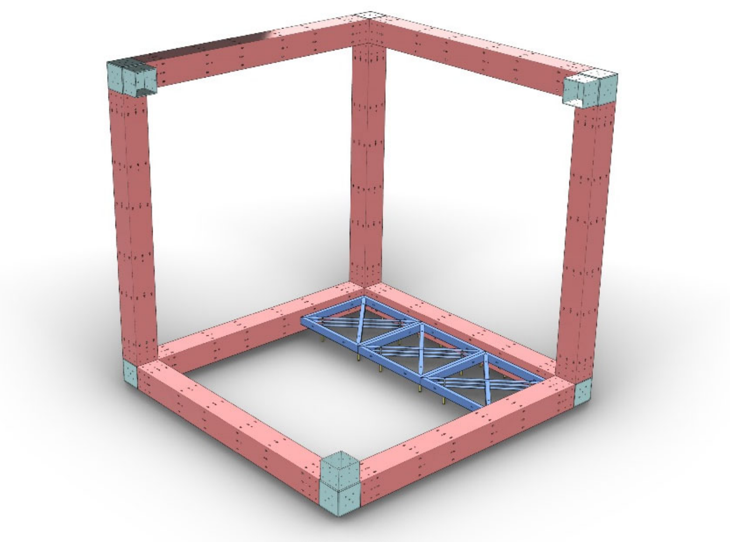
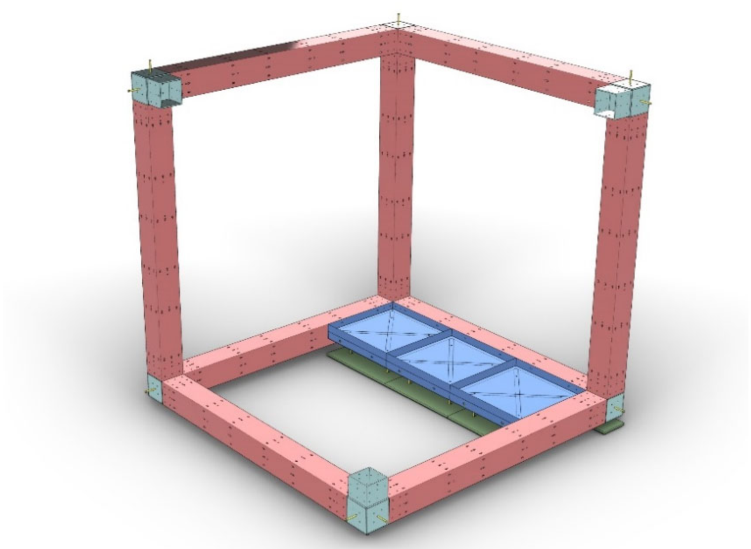
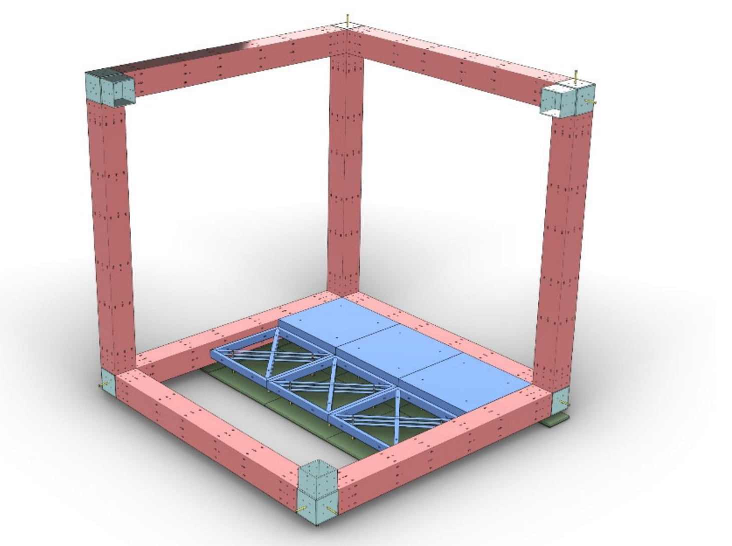
All the elements together form a *module*:

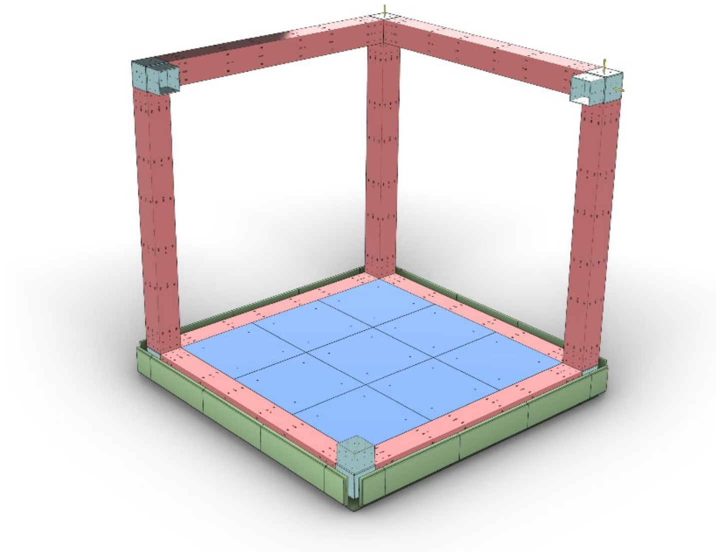


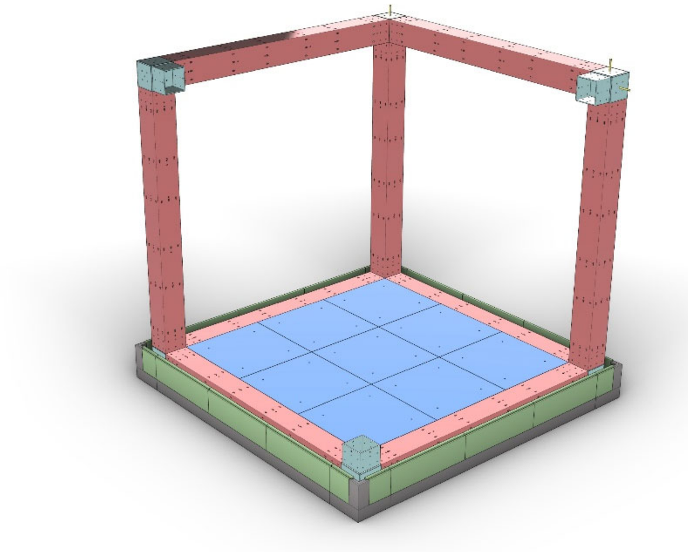
Detail of panel assembly and interlocking:

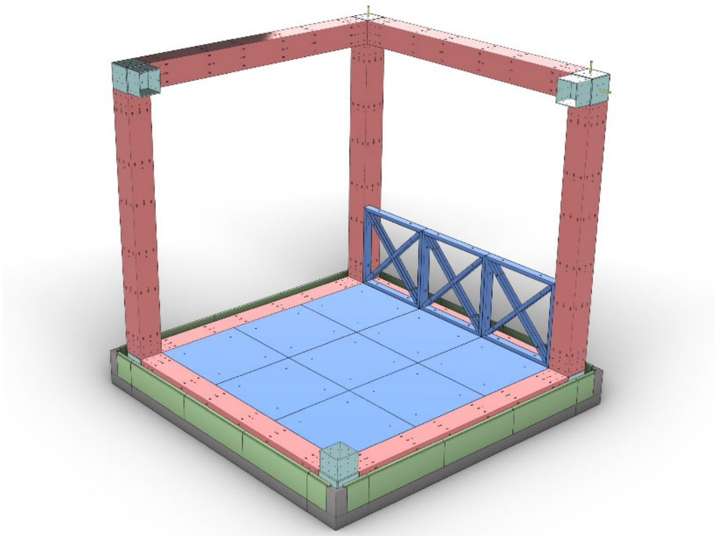


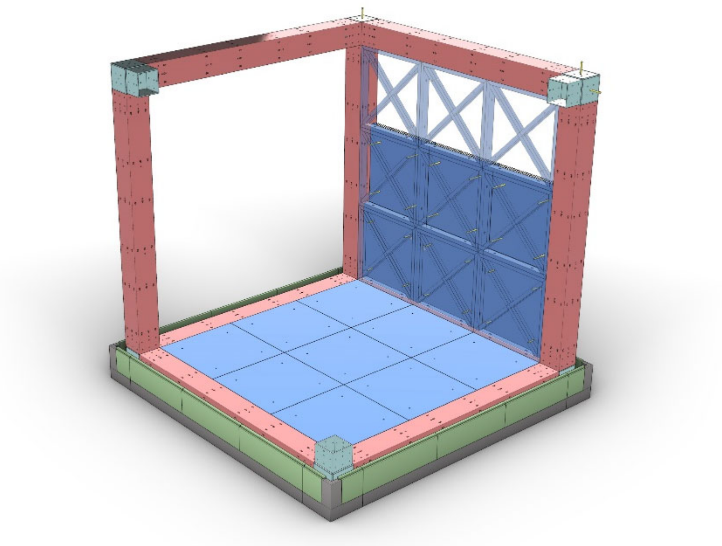
More detailed assembly technical sheets are presented on the Chapter 7.

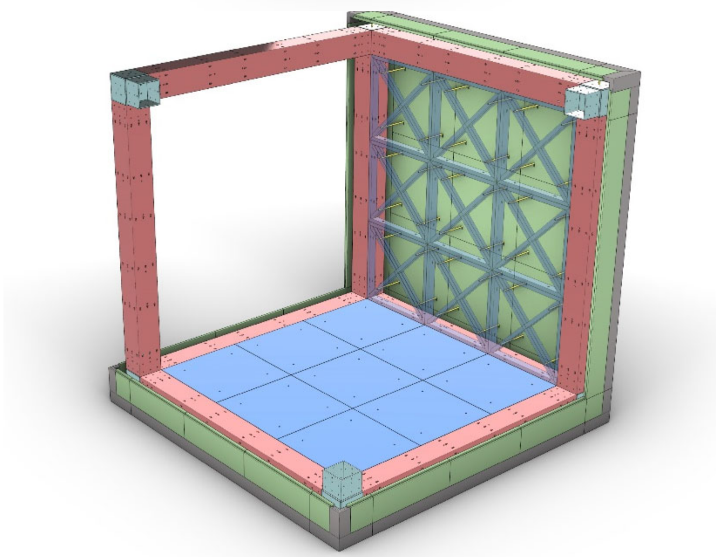







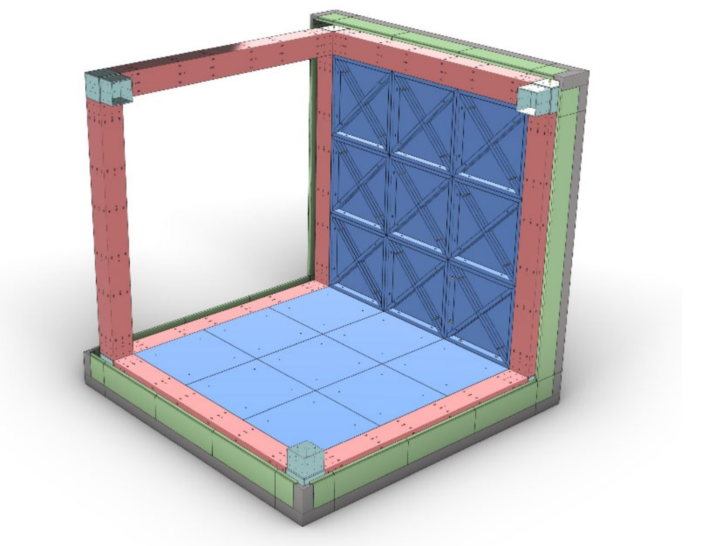










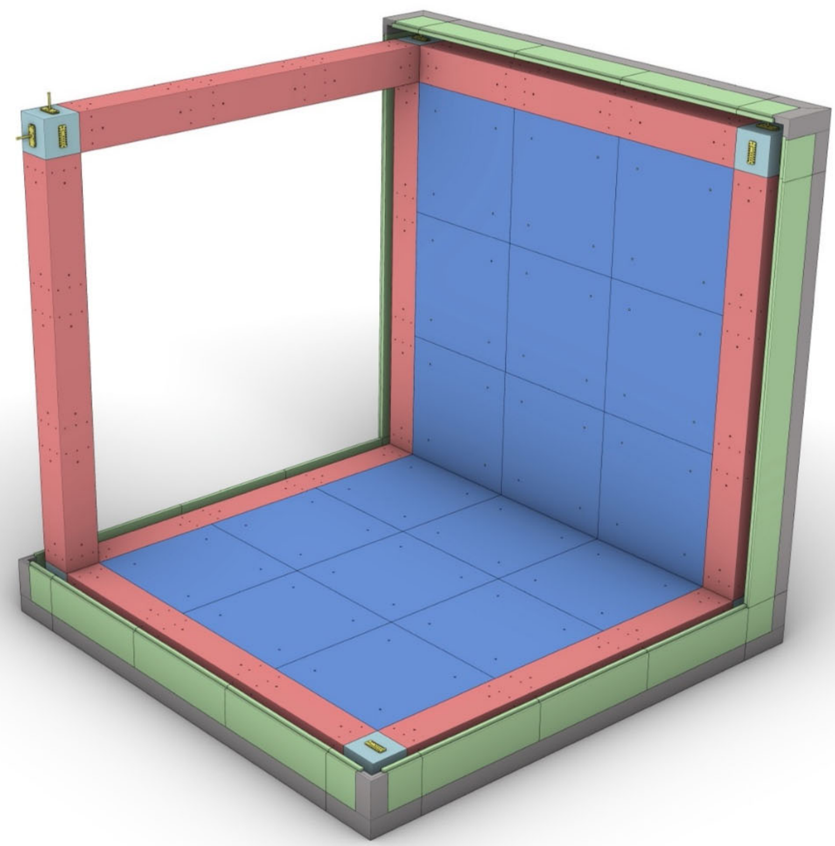


5.2. Wood

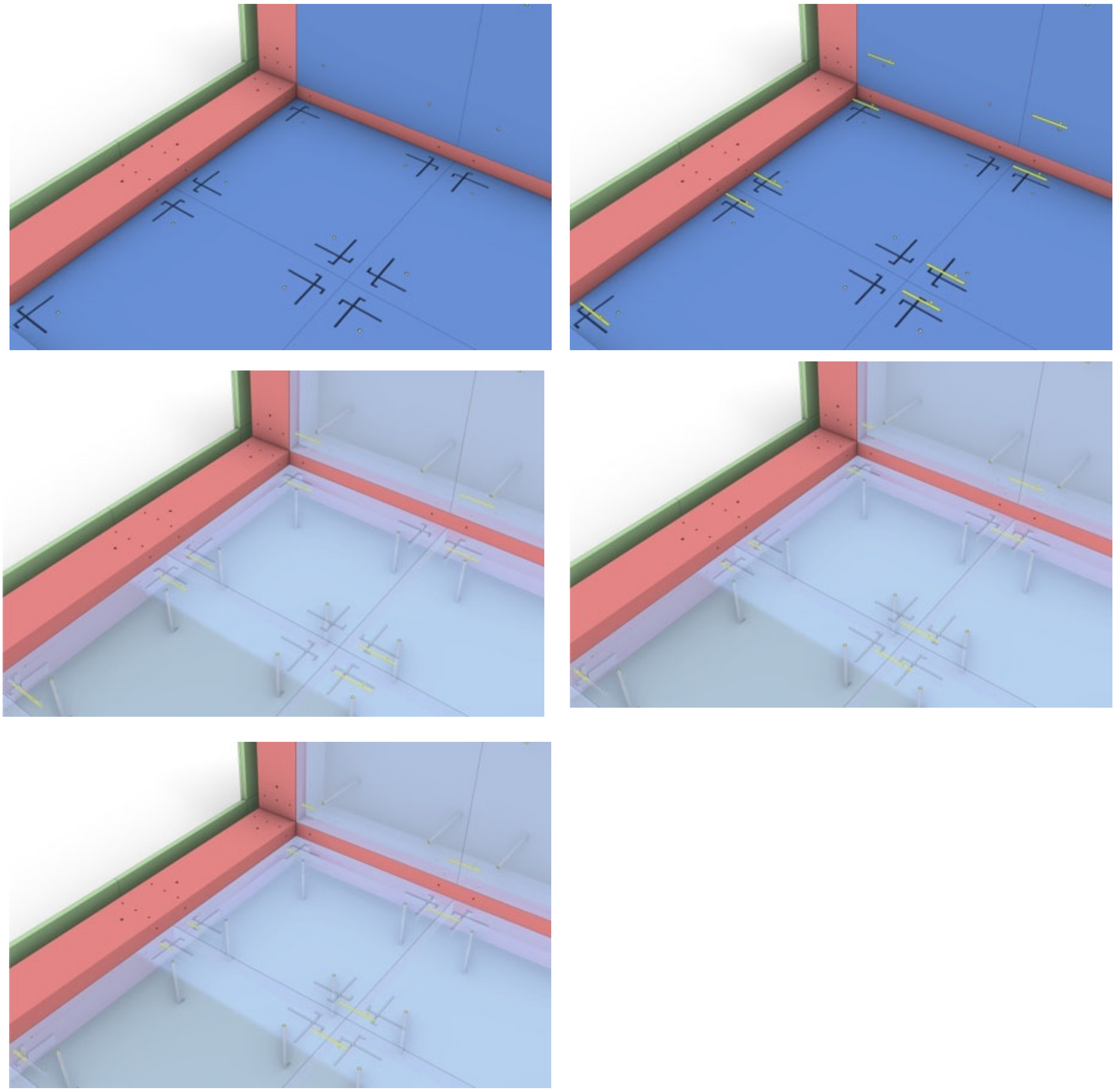
From a static point of view, the functioning of wood can be compared to the steel. On the contrary, from the thermal point of view, wood has a more advantageous behaviour due to its good thermal resistance capacity (about 20 times higher than that of metal).
The interlocking systems between the elements and the fastening systems are in any case made of metal: for the structural joints a mobile interlocking system such as Rothoblaas's UVT model was envisaged; for the panel joints a simple mobile interlocking system was envisaged using a metal "piston" which can be inserted and locked inside special holes in the panel and in the beam and column structure.
Each detailed element is exposed in Chapter 7:

- h) **Frame**: structural element, beam or column, consisting of a solid extruded wooden material 3,30 m long and 0,30 x 0,30 m section → **Fr_1_1**
- d) **Joint**: structural connection, consisting of a cube with a side of 0,30 m. It has the all the 6 ways setup for receive the beam → **Jn_1_1**
- e) **Panel**: solid wood panel 1.10 m x 1.10 m and 0.10 m thick → **Pa_1_1**
- f) **Secondary joint**: metal plunger for joining panel-to-panel and panel-to-beam

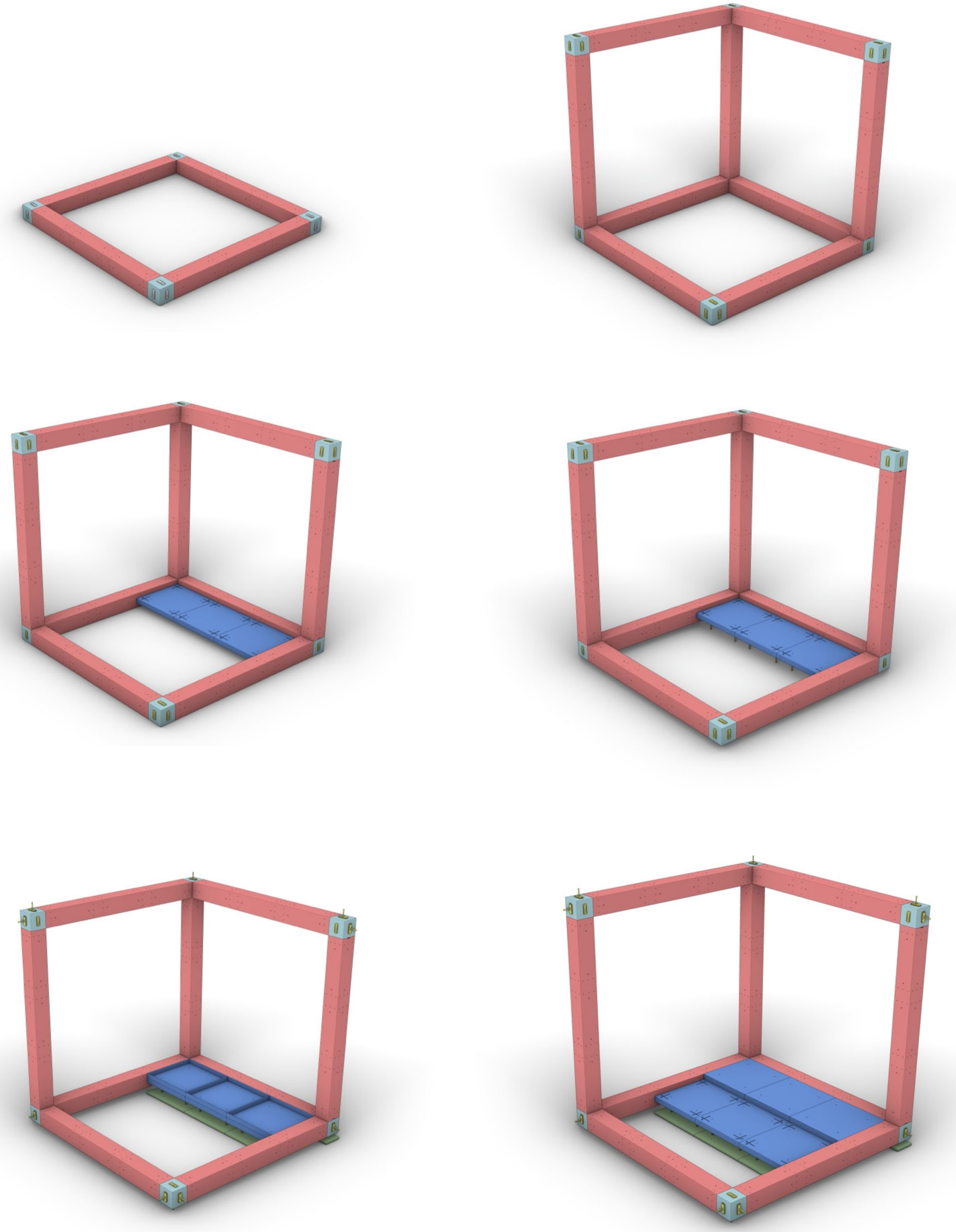
All the elements together form a *module*:

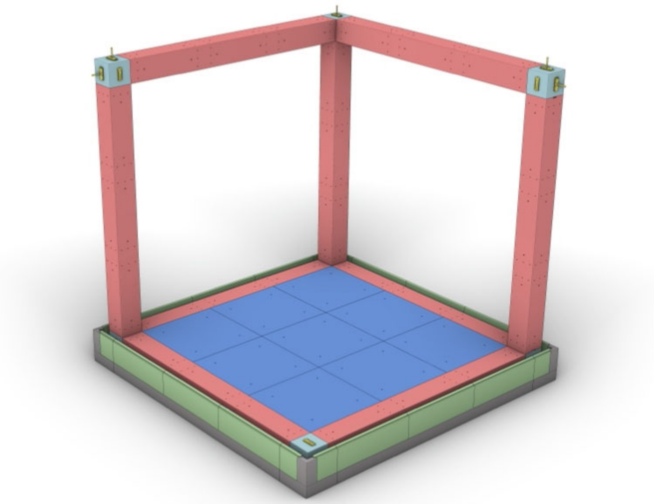


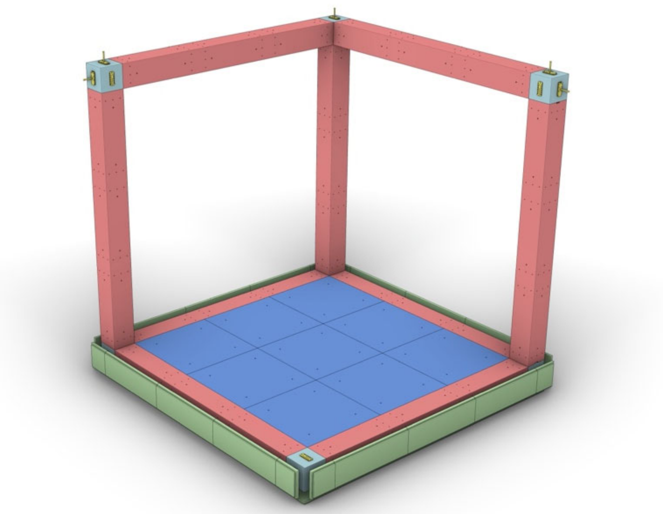
Detail of panel assembly and interlocking:

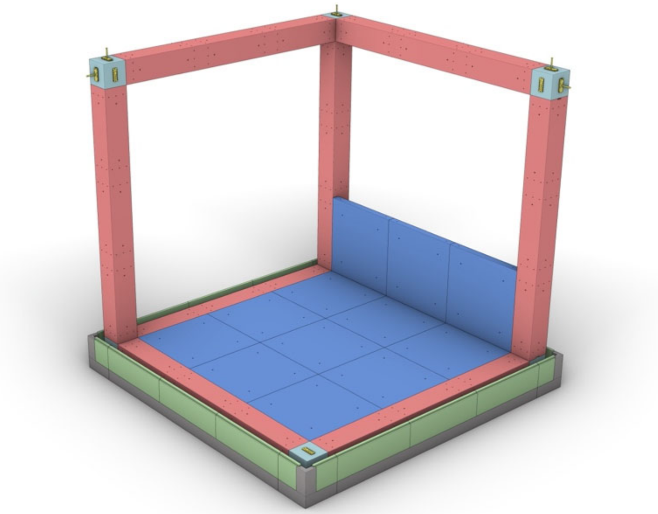


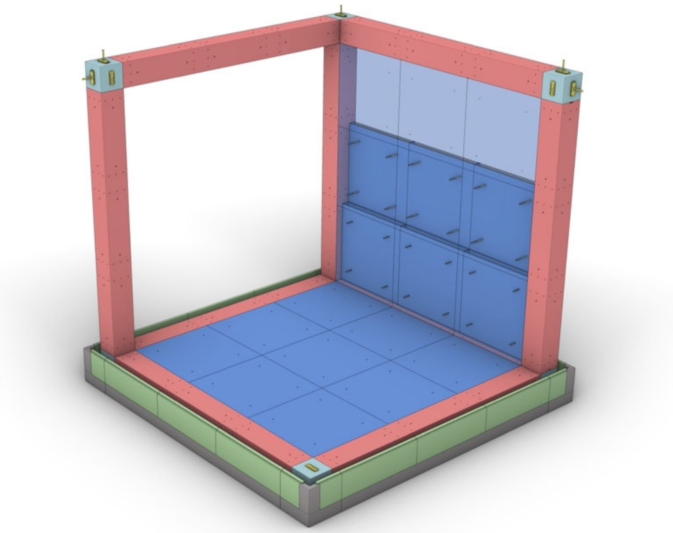
More detailed assembly technical sheets are presented on the Chapter 7.

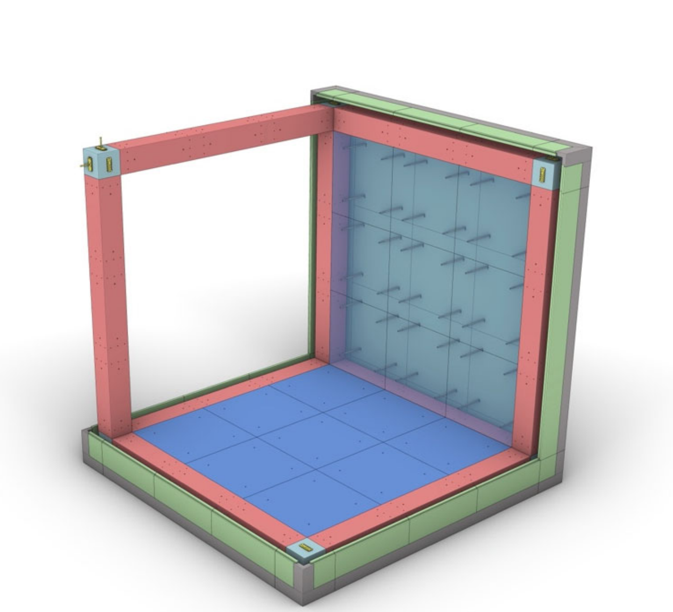


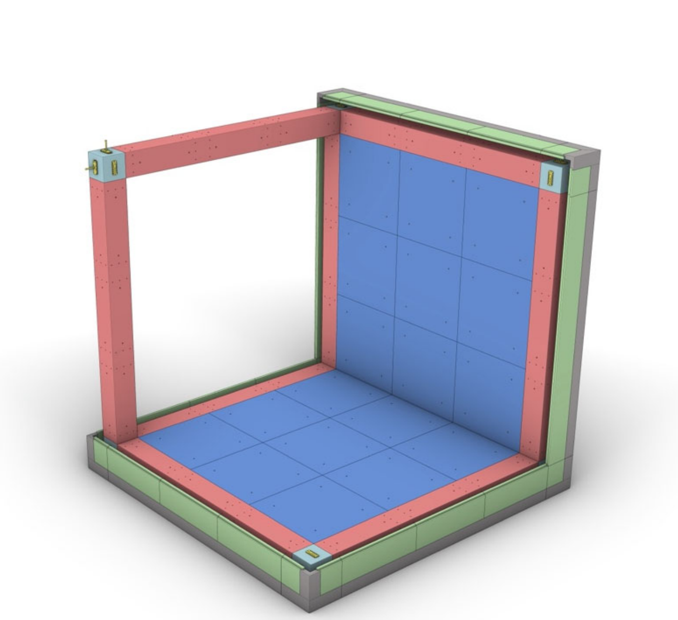












5.3. APPLICATIONS

Below the first application studies of the transformation of the practical model into an executive project and the proposals of products on the market considered particularly suitable to carry out the function required by the elements highlighted in this paragraph, both for the “metal” and “wood” systems.

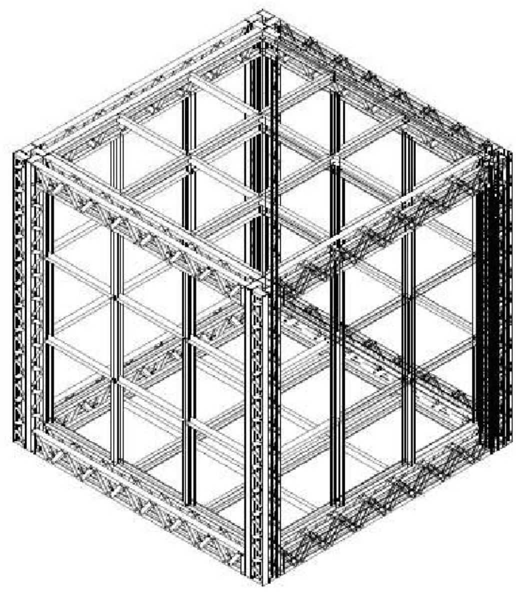
5.3.1. Metal application: Module COGI

With the company COGI srl, specialised in prefabricated steel buildings, a first attempt at a real declination of the *module* system has been launched in the Calliano (TN) plant.
The hypotheses developed, which then led to the realisation of an executive project, were 3

- Module “Type 0” - direct transposition of the *practical model* adapted to the company's current production capacities. Frame system consisting of 4 x 20 cm lattice girders joined together to form a 30 x 30 cm pillar, 4.20 m high; 2 x 30 cm high by 10 cm thick lattice girders placed 10 cm apart to form the 30 x 30 cm beam, 3.60 m long. Curtain walling system composed of panels with light metal frames made of 10 cm C-profiles. Sloping roof with trusses shaped according to 15° or 30° inclination. Maximum height of storeys allowed in seismic areas: 4 storeys. A rough economic cost has also been developed.

Module type 0

DIMENSION	EXTERNAL	INTERNAL
Length	4200 mm	3600 mm
Width	4200 mm	3600 mm
Height	4200 mm	3600 mm
Gross surface	17,56 m^2	
Net surface	13,00 m^2	
Internal volume	74,10 m^3	



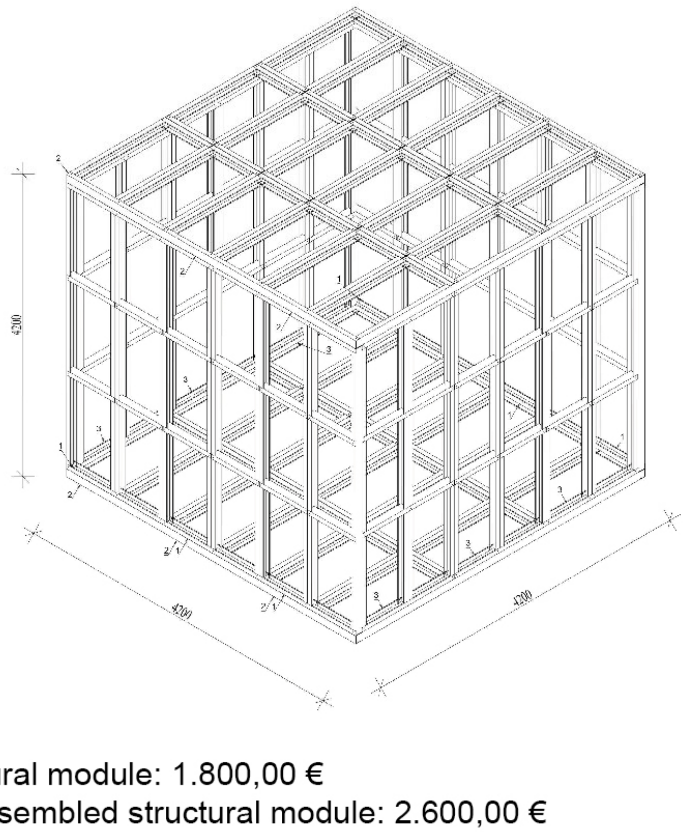
Total cost structural module: 4.000,00 €
Total cost pre-assembled structural module: 5.500,00 €

Total cost complete module with finish: 7.300,00 €

- Module “Type 1” - reworked according to the SteelMax® construction system. Frameless system made of 10 cm C-profiles with 70 cm vertical and 140 cm horizontal grid spacing. This system can also be assembled without the use of a crane. Maximum permitted storey height in seismic areas: 2 storeys.

Module type 1

DIMENSION	EXTERNAL	INTERNAL
Length	4200 mm	3600 mm
Width	4200 mm	3600 mm
Height	4200 mm	3600 mm
Gross surface	17,56 m^2	
Net surface	13,00 m^2	
Internal volume	74,10 m^3	



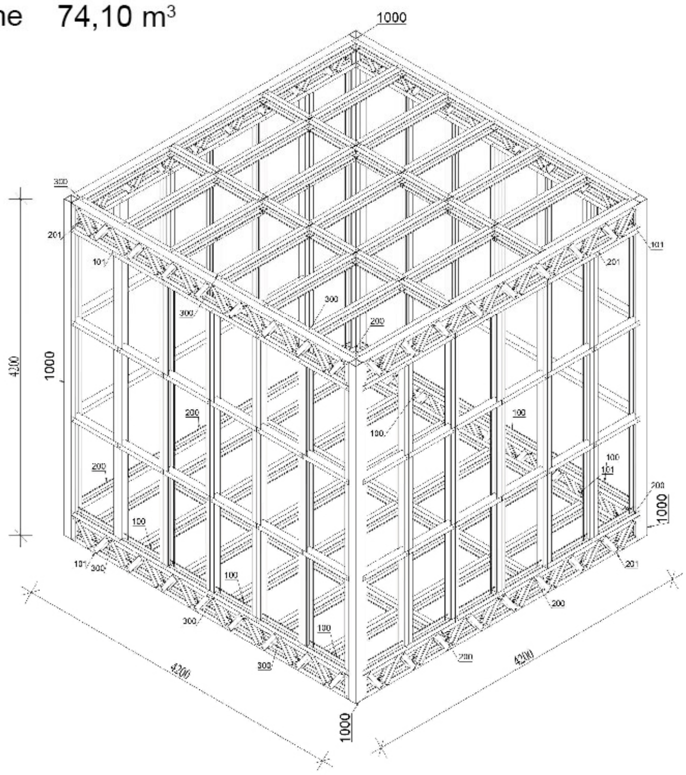
Total cost structural module: 1.800,00 €
Total cost pre-assembled structural module: 2.600,00 €

Total cost complete module with finish: 4.400,00 €

- Module “Type 2” - Same as Module “Type 1” but with structural reinforcement (lattice girder and box girder). This model is designed to be pre-assembled and placed on site by crane. Maximum height of storeys allowed in seismic zone: 2 floors.

Module type 2

DIMENSION	EXTERNAL	INTERNAL
Length	4200 mm	3600 mm
Width	4200 mm	3600 mm
Height	4200 mm	3600 mm
Gross surface	17,56 m^2	
Net surface	13,00 m^2	
Internal volume	74,10 m^3	



Total cost structural module: 3.000,00 €
Total cost pre-assembled structural module: 3.800,00 €

Total cost complete module with finish: 5.600,00 €

The company, considering the type of its building system (SteelMAX: system for “load-bearing walls” without structural frame), proposed the development of the Module “Type 1 and 2”. In particular, Type 1 is the one that is closest to the company's traditional way of constructing buildings.
Below are the construction drawings for Type 1:

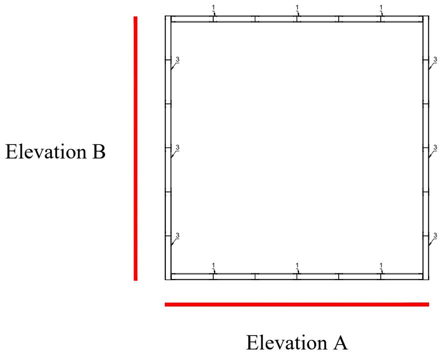


Figure 49 – Plant scheme of the Module

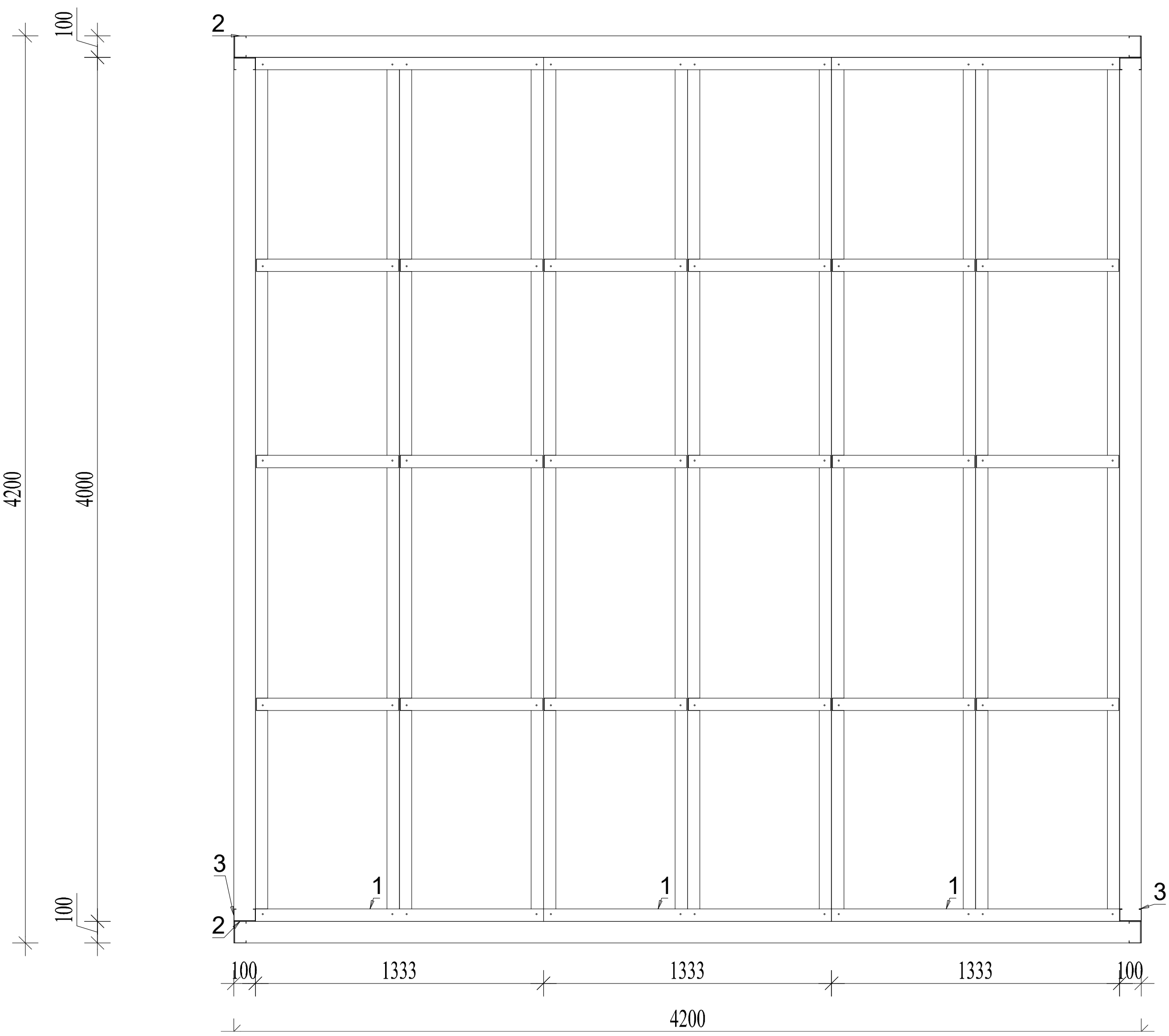


Figure 49 - Elevation A

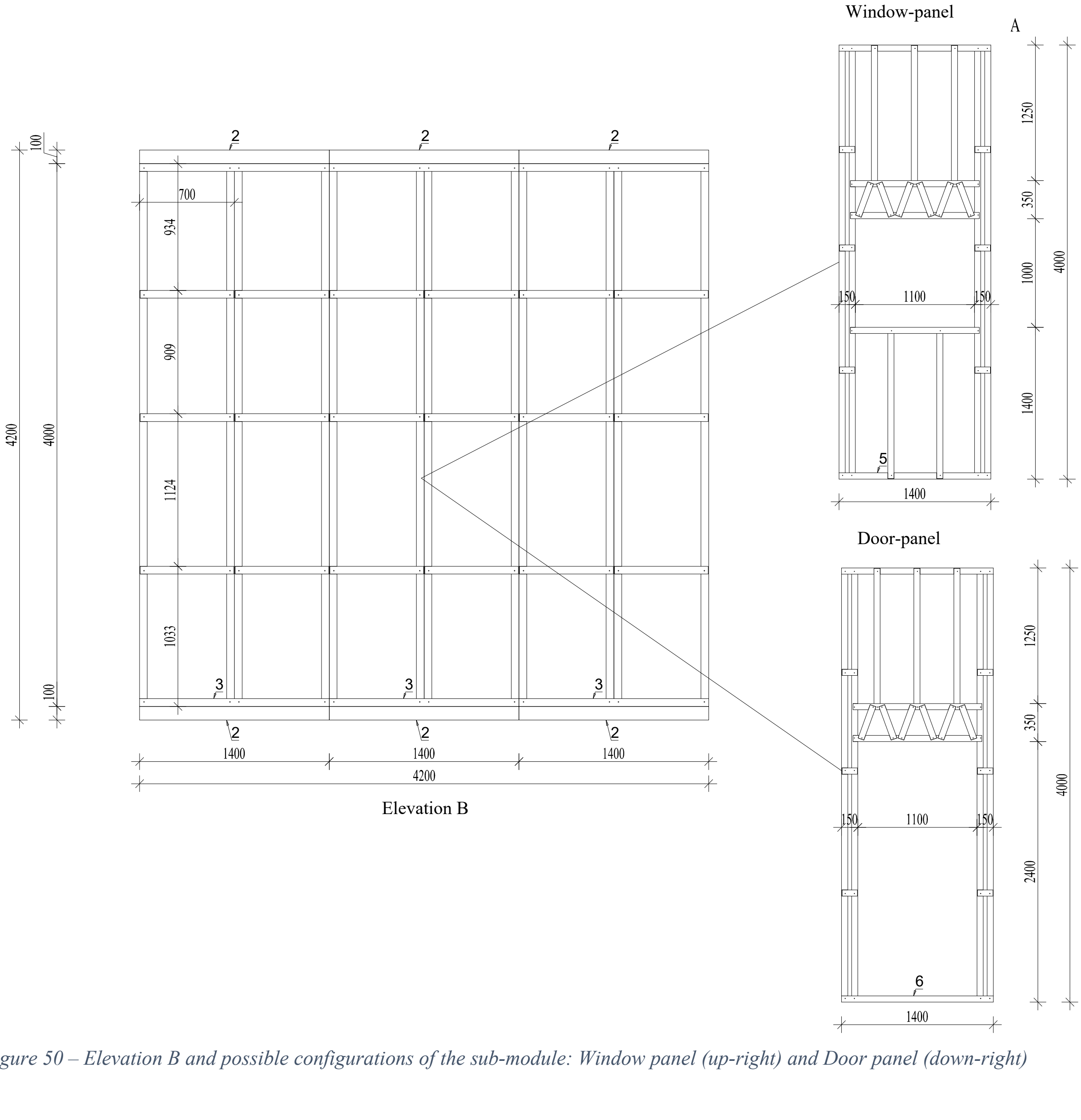
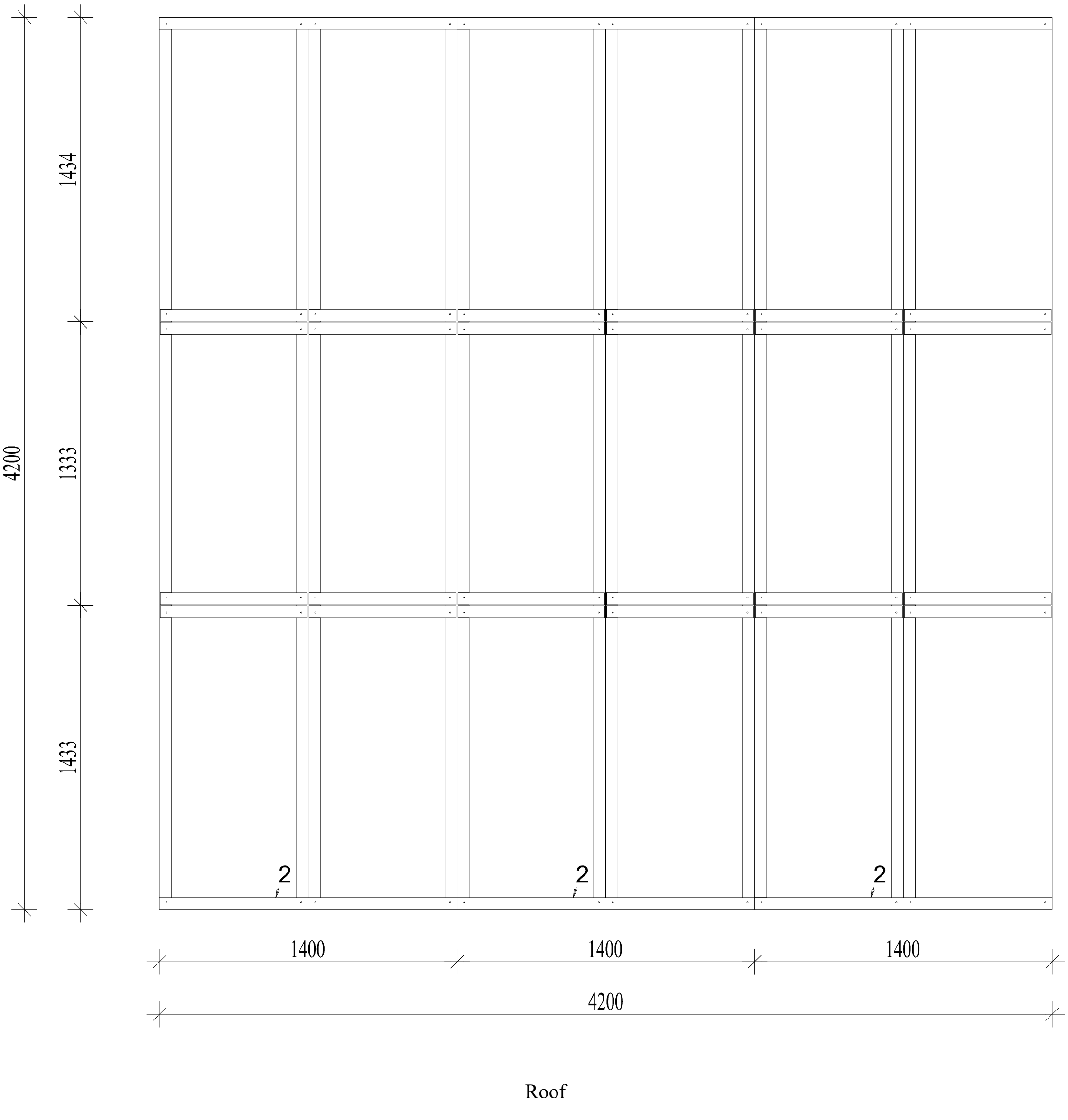


Figure 50 – Elevation B and possible configurations of the sub-module: Window panel (up-right) and Door panel (down-right)



Roof

5.3.2. **Foundations – Metal and Wood**

For the foundations, of the many solutions examined, the system of the British company Jackpad was considered the most suitable. The foundations proposed by this company can be modulated according to the load they have to support and are made of recyclable and recycled material. In addition, they can be laid on solid, freshly levelled ground (without any special levelling, as they are adjustable in height).

Furthermore, as shown in the sequence (from sn: 48 kN, 96 kN, 146 kN and 295 kN), the foundations can be calibrated according to the different working load to be supported.

5.3.3. **Thermal bridge - Metal**

Regarding the metal system there is a problem related to the heat transmission (thermal bridges). To overcome this issue, Farrat's solution was chosen. The system (inserting a plate of a special alloy, with high thermal resistance capabilities, between the two structural elements) allows structural continuity and at the same time the interruption of heat transmission.

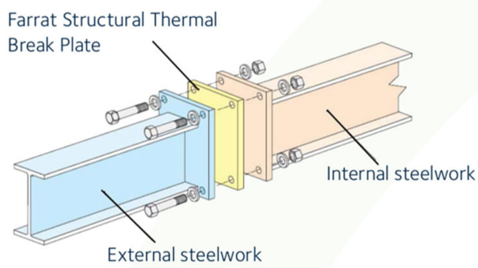


Fig 1.1 steel to steel connection

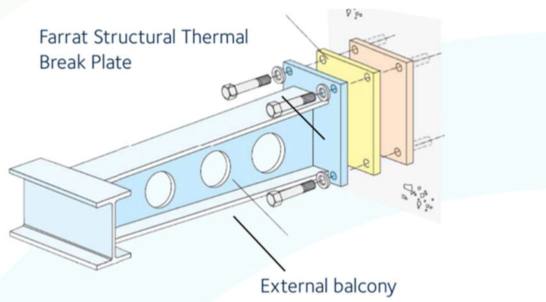


Fig 1.2 steel to concrete connection

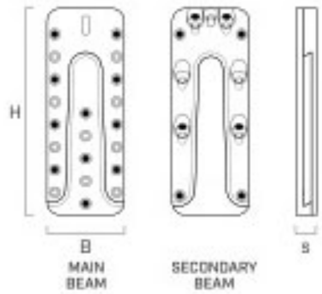
5.3.4. **Wood joint - Wood**

The company Rothoblaas was chosen for the interlocking of the wooden elements, specifically: the UV-T concealed wood-to-wood connector. This type of joint allows each element to be hooked in and removed without difficulty if necessary. There are different sizes, and the connector can have strengths of over 60 kN.

Given the standard size of the beam and the abutment (30 cm x 30 cm), UVT60160 was considered the most suitable joint to ensure the proper connection between the structural elements of the module; in fact, being 16 cm high, it fits perfectly into the 30 cm length.

UVT60160

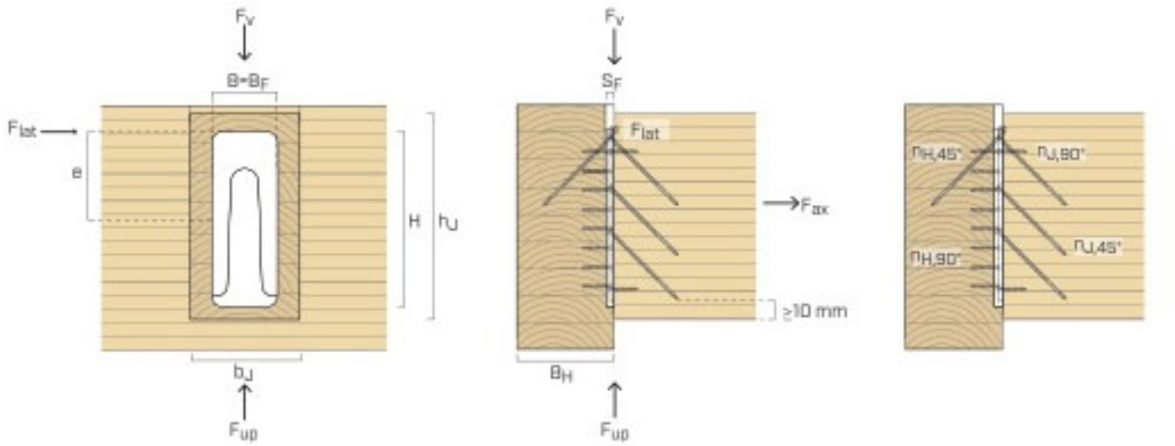
TIMBER ELEMENTS MINIMUM DIMENSIONS



UV CONNECTOR		45° SCREWS TYPE	MAIN BEAM			SECONDARY BEAM[1]	
				grooving			
type	B x H x s [mm]	Ø x L [mm]	$B_{H,min}$ [mm]	B_F [mm]	S_F [mm]	$b_{J,min}$ [mm]	$h_{J,min}$ [mm]
UVT60160	60 x 160 x 16	VGS Ø6 x 100	80	60	16	100	180
		VGS Ø6 x 160	120			100	220

FASTENERS

type	nailing		MAIN BEAM $n_{H,90°}$ [pcs - Ø]	MAIN BEAM $n_{H,45°}$[3] [pcs - Ø]	SECONDARY BEAM $n_{J,90°}$ [pcs - Ø]	SECONDARY BEAM $n_{J,45°}$ [pcs - Ø]
UVT60160	total	●+○	21 - LBS Ø5	1 - VGS Ø6	4 - LBS Ø5	6 - VGS Ø6
	partial[2]	●	11 - LBS Ø5	1 - VGS Ø6	4 - LBS Ø5	4 - VGS Ø6



STATIC CHARACTERISTIC VALUES | TIMBER-TO-TIMBER JOINT

			FULL NAILING ●+○ 45° screws type VGS Ø6 x 100 [kN]	FULL NAILING ●+○ 45° screws type VGS Ø6 x 160 [kN]	PARTIAL NAILING ● 45° screws type VGS Ø6 x 100 [kN]	PARTIAL NAILING ● 45° screws type VGS Ø6 x 160 [kN]
90° screws type	LBS Ø5 x 50	$R_{ax,k}$	**2,90**	**2,90**	2,90	2,90
		$R_{v,k}$	**28,00**	**44,85**	18,67	23,49
		$R_{up,k}$	**4,67**	**7,85**	4,67	7,85
		$R_{lat,k}$	**3,01**	**3,01**	2,71	2,71
	LBS Ø5 x 60	$R_{ax,k}$	**3,53**	**3,53**	3,53	3,53
		$R_{v,k}$	**28,00**	**47,09**	18,67	24,93
		$R_{up,k}$	**4,67**	**7,85**	4,67	7,85
		$R_{lat,k}$	**3,15**	**3,15**	2,83	2,83
	LBS Ø5 x 70	$R_{ax,k}$	**4,16**	**4,16**	4,16	4,16
		$R_{v,k}$	**28,00**	**47,09**	18,67	26,38
		$R_{up,k}$	**4,67**	**7,85**	4,67	7,85
		$R_{lat,k}$	**3,28**	**3,28**	2,95	2,95

5.4. Project

After the verification of the practical feasibility of the module, the system was validated with some of the main national and international organisations (INTERSOS, UN-HABITAT and the Italian Civil Protection) regarding its practical use in emergency situations and gathering the needs of experts "in the field" to allow a design as close as possible to the real needs of a probable future user. It was thus decided to proceed with the design of a minimum starting accommodation with the following composition: 4 internal modules plus 2 external ones. These measures correspond to an accommodation, even economically sustainable, for a user of 2 to 4 people.

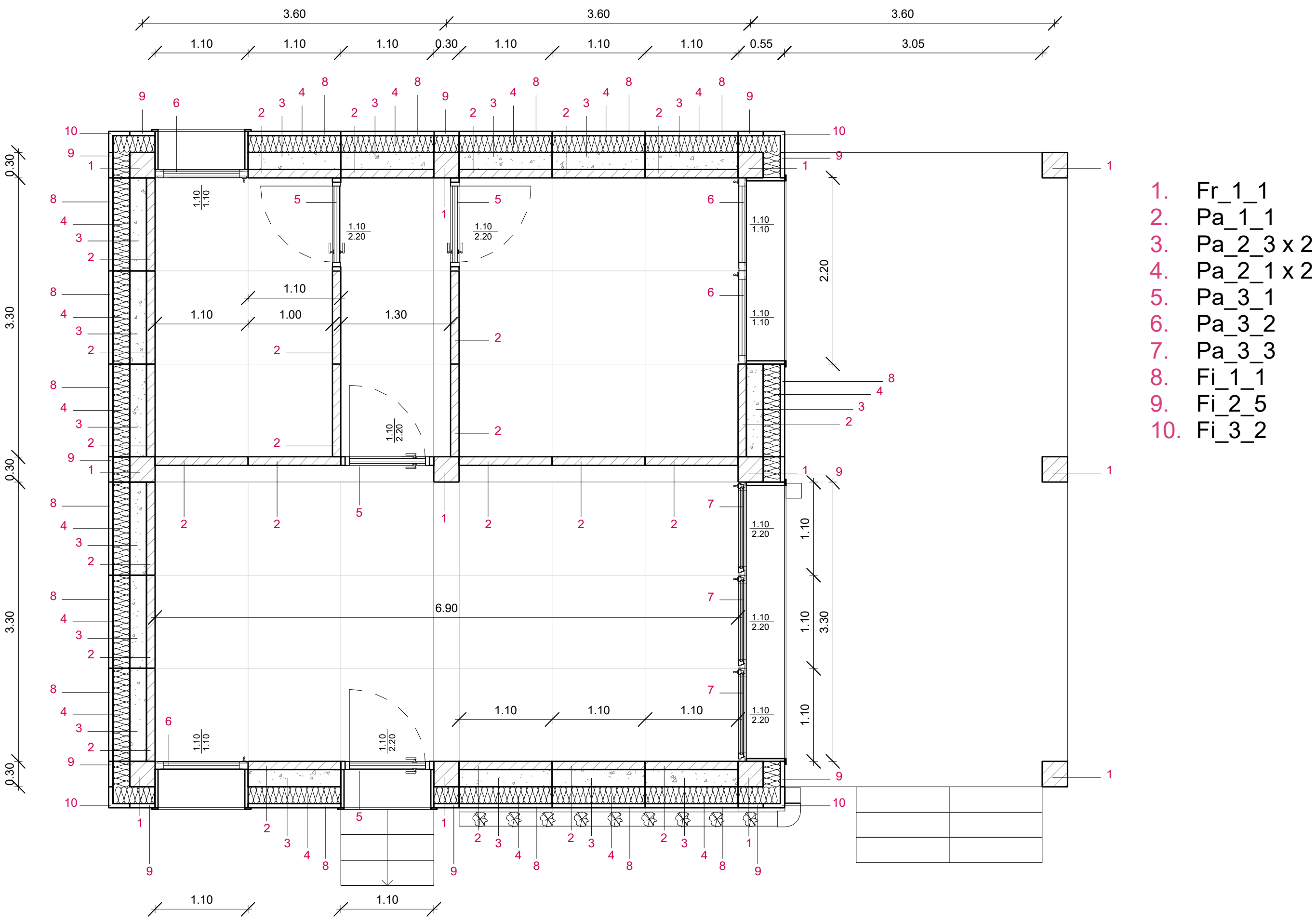


Figure 51 - Plan

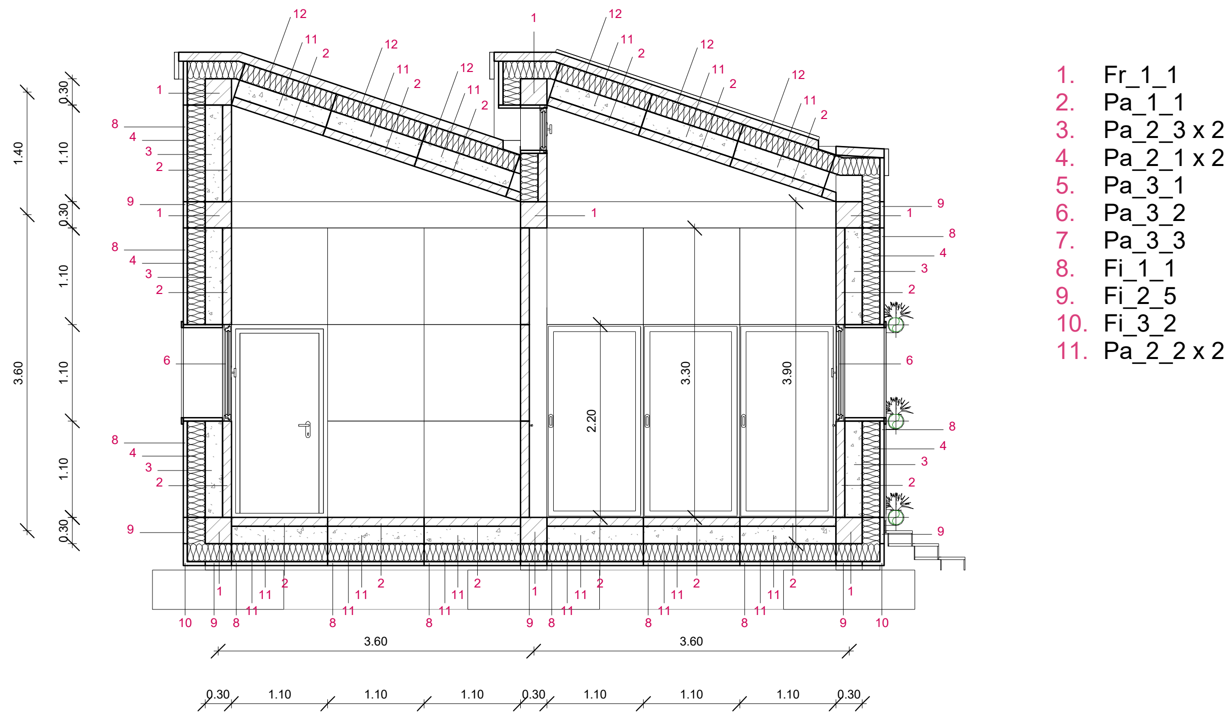


Figure 52 - Section

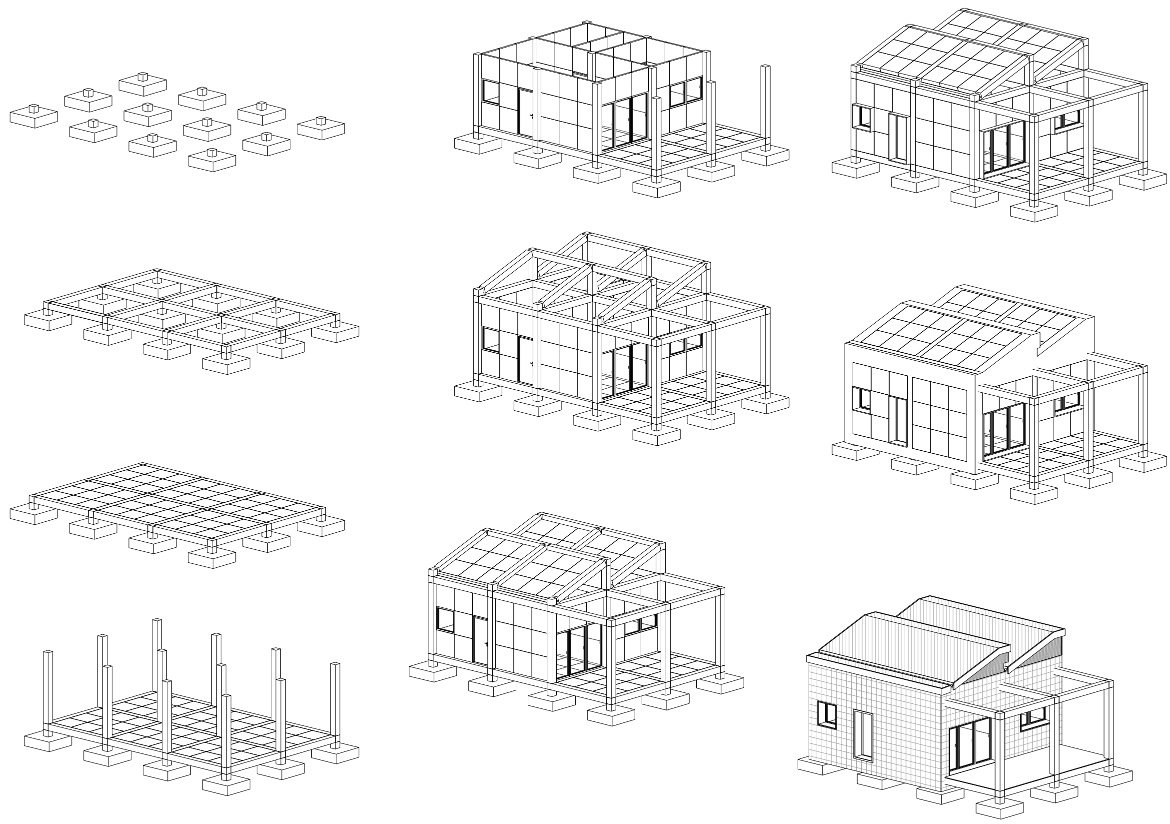


Figure 53 – Assembly steps

5.4.1. **Glocal Impact Network ®**

From the collaboration with GIN (Glocal Impact Network, a company working in the field of international cooperation and development of emerging countries), Liter of Light (an international project of electrification and sustainable lighting of developing areas) and Bloom Project (a project of sustainable and inclusive hydroponic agriculture), an interesting integration project was developed that led to a feasibility study presented to UN-HABITAT (United Nations Agency for Urban Development), which is still in progress for a future international research project, of which we report some original examples of implementation:

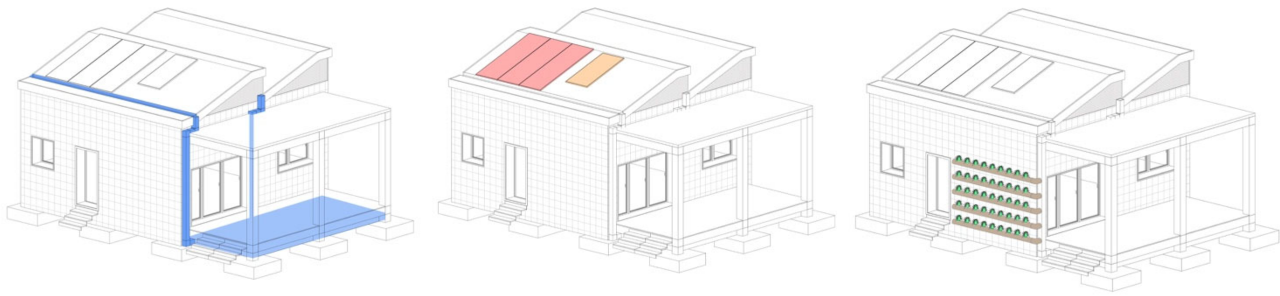


Figure 54 - Applications for the module: a) rain-water system reuse; b) solar energy; c) food production system

- Rain-water reuse and storage system
- PV panels
- Solar panels
- Agritube®: hydroponic system

5.5. GENERAL ARCHITECTURAL DESIGN

The present example condenses the architectural, structural engineering, industrial production, collaboration with national and international organisations and political expertise that make an environmentally, economically and socially sustainable system feasible.

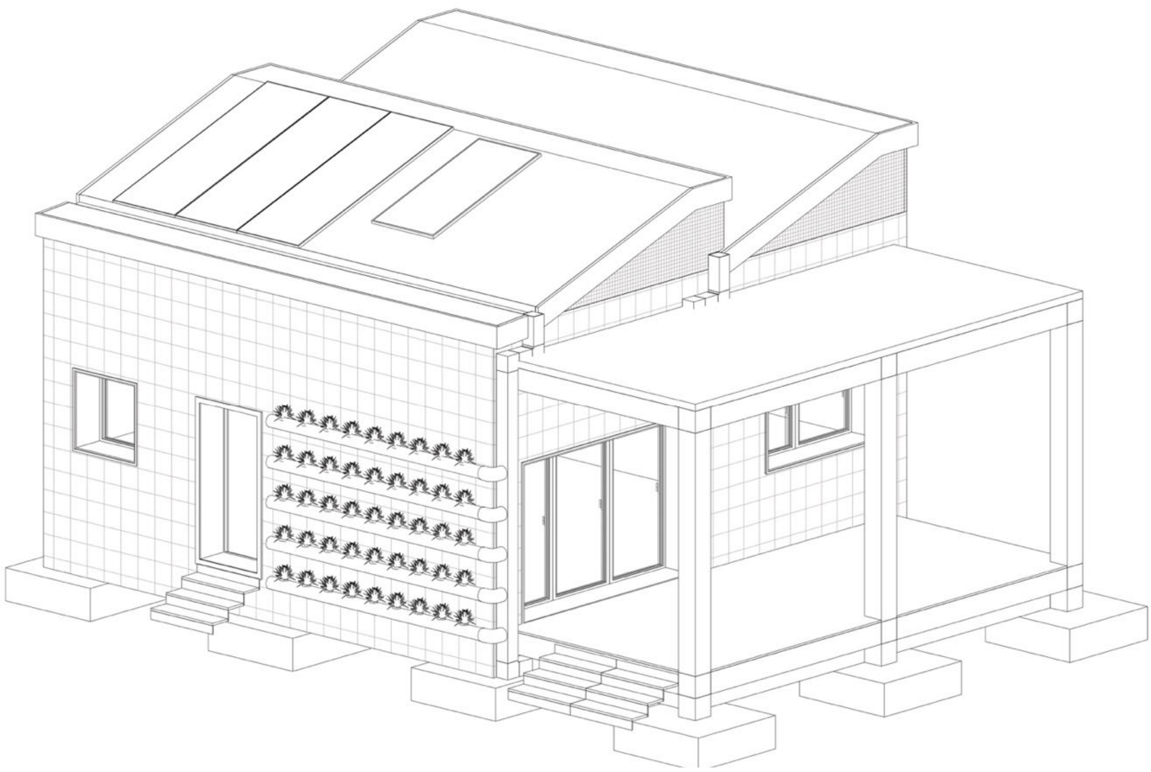
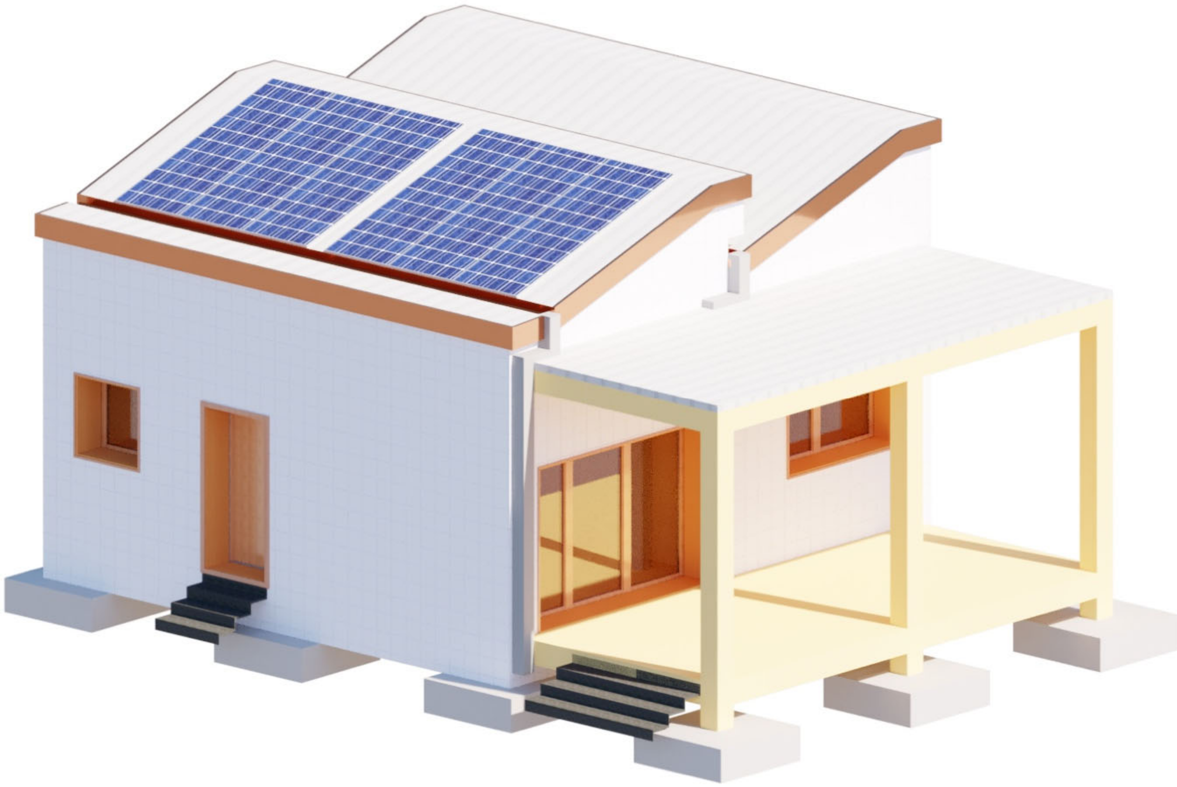


Figure 55 - Final composition of the module



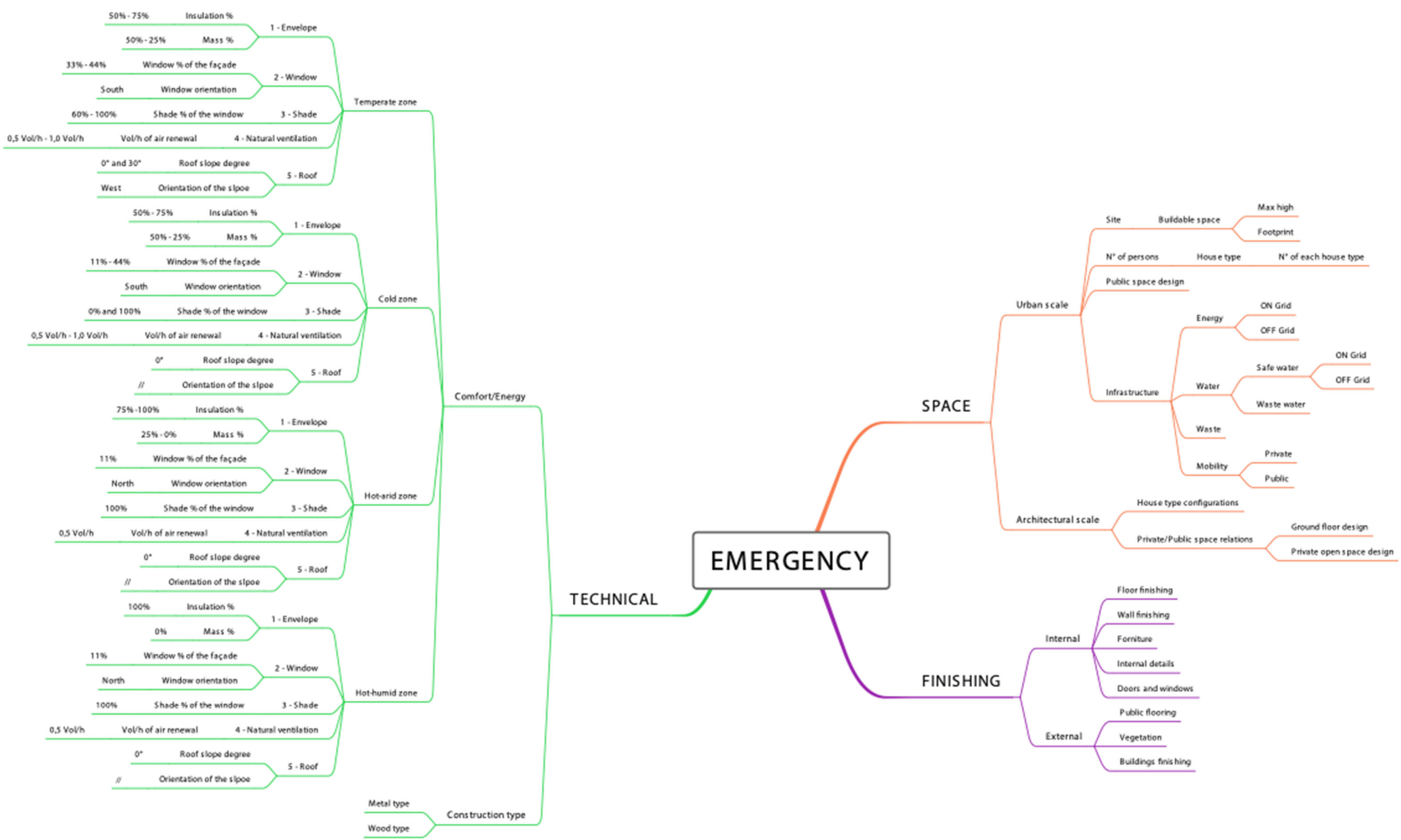
5.6. DECISION MAKING PROCESS

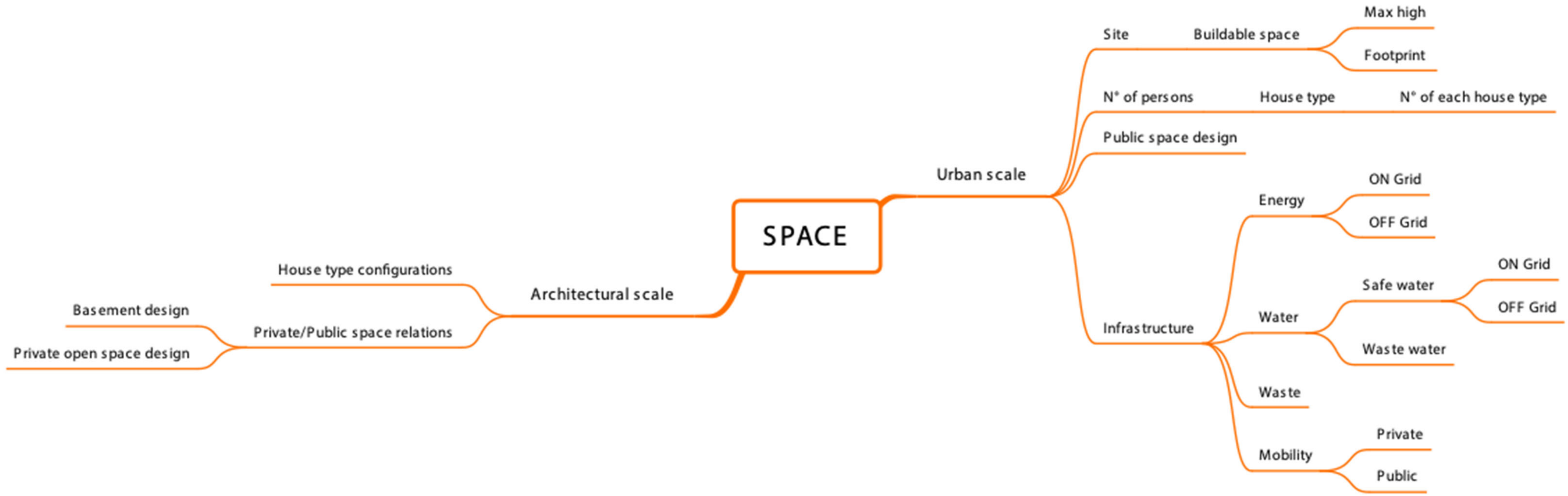
The following is a summary of a hypothetical decision-making process. This diagram is useful to understand how a decision-making process that leads from the need to build houses (for example following a disaster or because there is a desire to regenerate a slum etc.) to the construction of houses would take place. This procedure depends on the situation to situation, therefore, the following scheme is also useful to understand the versatility of the system proposed in this research.

A simple numerical scheme is proposed that represents the temporal progression of decisions and events that lead from the emergency, the need, to the configuration of the module optimized for the situation in question.

1. **Emergency** – Event triggered by the need for housing. That is, the point *zero*. As mentioned in the previous chapters, this trigger can be both very varied in terms of "how" and "where", and in terms of "when". In fact, it can be contingent (e.g. following a disaster or a sudden element of migration etc.) or chronic and long-lasting (e.g. slums or the need to build a new housing district). The need for housing may be temporary or permanent.
   This event, generically defined as an "emergency", is what determines the need to start the whole process. Therefore, it is called the zero point or starting point.
2. **Site identification** – Following the emergence of the need for housing (temporary or permanent), there follows immediately the definition of an area, a site, on which to build this new housing. Therefore, the first step is to identify a geographical area.
3. **Grid** – Once the area of action has been identified, proceed to position the *grid* identified in paragraph 3.1 on this area (Figures 14 - 01. Page 36). This operation will be carried out in such a way as to exploit as much as possible every available space in the area of intervention net of the "incomplete" squares or squares cut from the edge of the lot, so as to have only complete squares at the end. This new lot configuration, made by squares 3,30 m length, identifies the actual usable space.
4. **Sizes** – At this stage, the "size of the emergency must be sized". That is, the number of people to be accommodated must be understood.
5. **Usability of the site** – Constraints on the usability of the site are set. Thus, the percentage of buildability, the waterproofing of the site, the maximum floors (in any case not more than 4 floors above ground), the needs in terms of public space, infrastructures and any specific constraints of the area. This phase is a synthesis of technical, social and regulatory requirements.
6. **Housing** – Choice of housing type. That is, the size of the accommodation according to the future users. This phase determines the size and type of accommodation to be designed (number of rooms, indoor/outdoor relationship and size of buildings...).
7. **Constructive system** – Choice of constructive system (metal or wood) according to the situation. Depending on the location, period and availability, it is decided whether to use the metal or wood system.
8. **Bioclimatic** – Use of the bioclimatic matrix (seen in section 3.3 and 4.6) for the optimal configuration of the individual *modules*.
9. **Budget** – Based on the budget available, the degree of "completeness" of the accommodation is determined. This degree can range from the provision of only the supporting structure (structural frame and floors) to fully finished dwellings including internal and external finishes.
10. **Finishes** – Choice and customization of finishing elements in technical and aesthetic terms. This point is strongly determined by the previous point.

CONCEPTUAL MAP

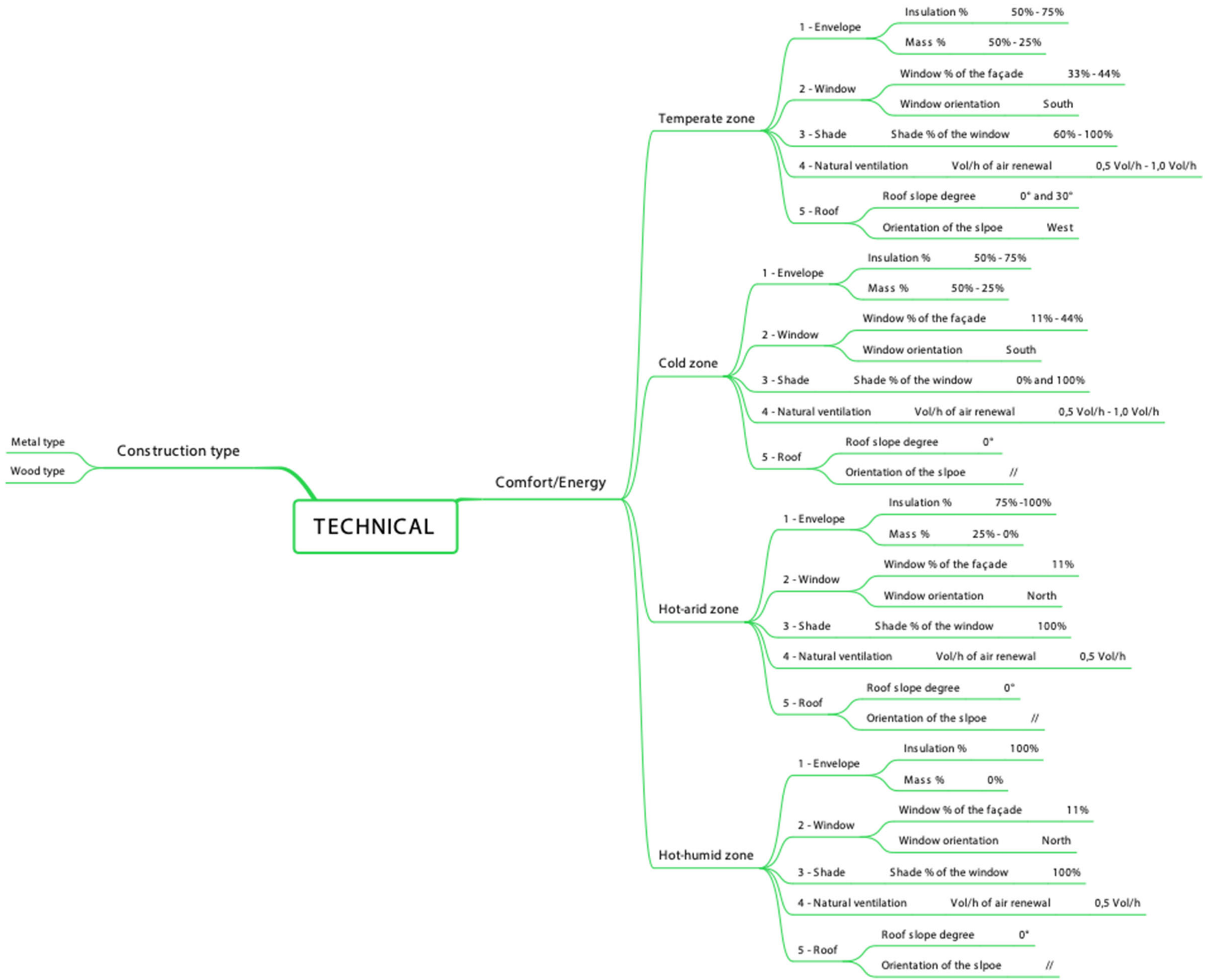


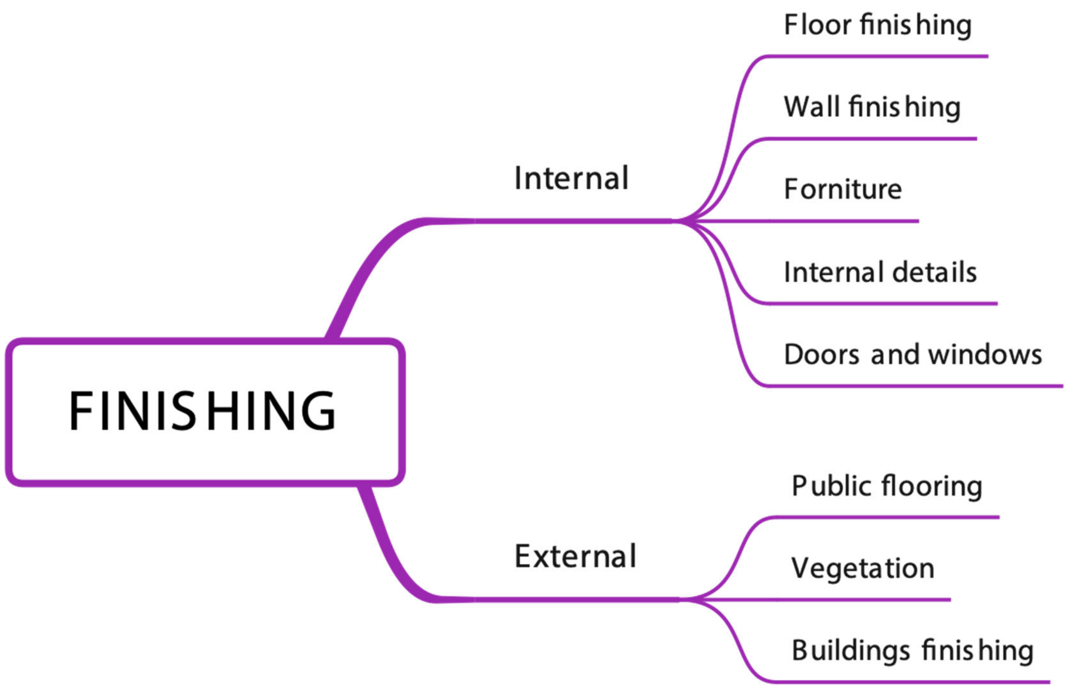


The diagram illustrates the possibilities of "space" configurations. That is, the flow of decisions necessary for the configuration of architectural space on an architectural and urban scale. Following this scheme, the result is a kind of master plan that guides and determines the whole design process to follow-up.

- **Urban scale** - This section identifies the characteristics and constraints of the site and determines the general configuration. On the one hand there are all the spatial prescriptions concerning the dimensions of the future buildings (number of maximum floors, footprint, public space design etc.), on the other hand all the indications concerning the typology (number of people, number and type of accommodations etc.).
  The infrastructure part concerns all the technical context supporting the buildings themselves.
- **Architectural scale** - the architectural choices are more specific: configuration of the housing and configuration of the public/private relationship. The configuration of the house type involves the design of the various types of dwelling by configuring both the rooms that compose it and any open spaces (balconies, loggias, etc.). The configuration of the space/public consists both in designing the "ground connection" of the building and the private open spaces (private garden, parking space, porches etc.). This point is very important as it determines the quality of the dialogue between the public space and the more private and intimate environment of the neighborhood being designed.

In this phase, the technical choices for configuring the module are defined.
The type of construction involves the choice between the metal or wood system (chapter 5). This choice depends on various factors (budget, availability of materials, transport, etc.) and from the design point of view does not involve any variation, in fact the system is designed to guarantee the required design results regardless of the construction system used.
The relationship between comfort and energy needs is one of the main themes of the research. This issue is extensively discussed in (chapter 3) and here the results of paragraph 3.3.5 are reported. They therefore represent the best module configurations in order to maximise the comfort/energy requirements ratio.

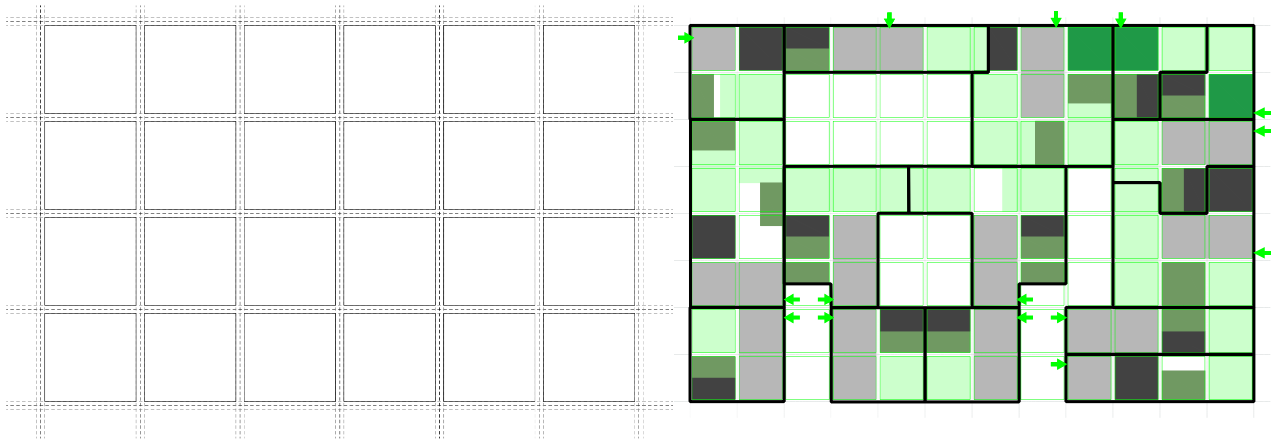




The finishes represent the “aesthetic” choices and are the last “layer” of the entire stratigraphy. The finishing layers also have a technical function, namely that of air and waterproofing the buildings.
The finishing layer is scalable according to the possibilities of the builder: in fact, the whole system is designed to be scalable also in the sense of “completeness”, i.e. it can be realized in different times and by different authors. For example, a public authority can build the buildings up to the structure, floors, windows and equipment, and leave the internal and external finishes to the people who will live in the apartments.

1. Space

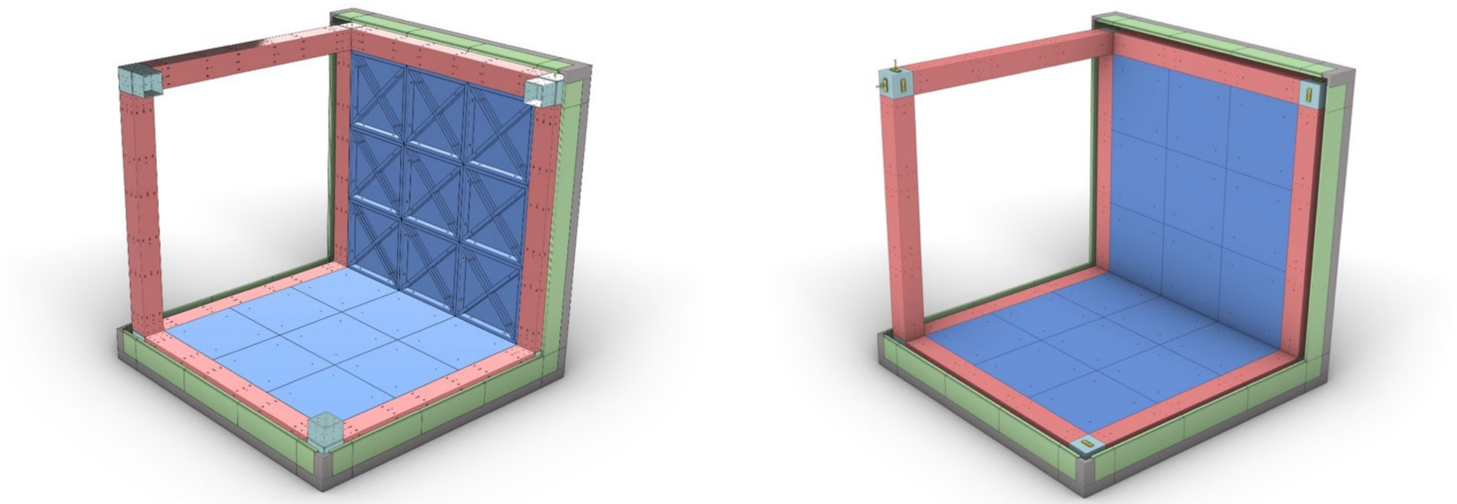
a. Urban (paragraph 3.1 and 4.4)



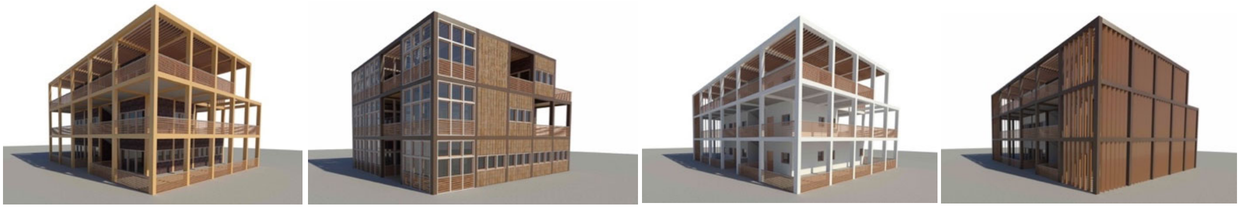
b. Architectural (paragraph 4.1.4)

2. Technical

a. Construction type (Metal paragraph 5.1 and Wood paragraph 5.2. Technical sheet Cap 7)

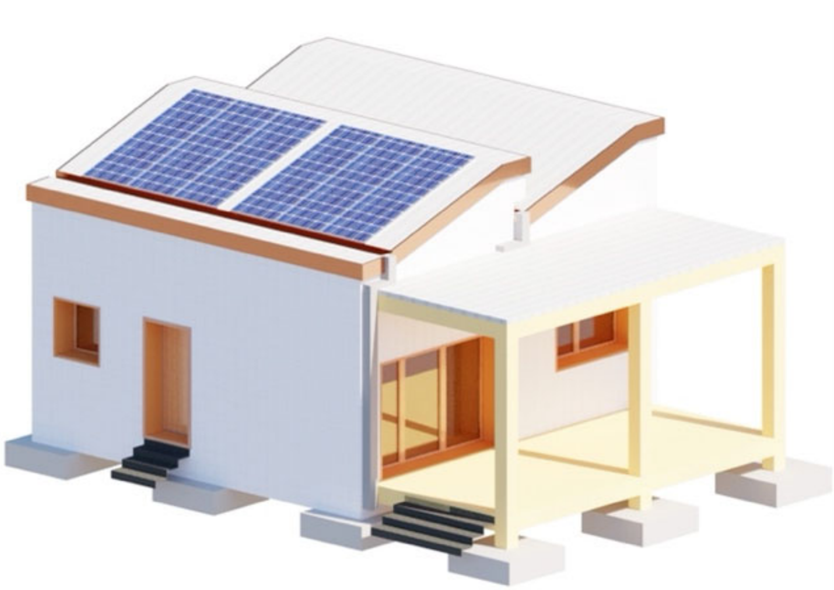


b. Comfort/Energy (Cap 3 and 4)



3. Finishing

a. Internal (Paragraph 5.4 and 5.5)



b. External (Paragraph 4.4)

6. CONCLUSIONS

6.1. METHODOLOGY

The method applied is multi-disciplinary: from the theoretical outline of the study through to the various phases of design, construction and use, an integration of skills and collaborations was sought which, in terms of specific training and quality of information, would lead to a more valid, safer and more efficient product.
All these skills, coordinated in a multidisciplinary work team, are in our opinion indispensable to the design and construction of modern and complex structures, such as the one considered in this thesis, which proposed to obtain a *housing module* for emergency situations, easily assembled and disassembled, usable by an increasing or decreasing number of people, easy to store and transport, able to provide humanly dignified and comfortable shelter with low energy requirements: environmentally, economically and socially sustainable.
Specifically, an integration of different skills was sought in the realisation of the *module*:

6.1.1. **Architectural skills**

Architectural skills led to the development of a project that translated into a space and form the idea of a comfortable and ecologically sustainable home.
The original idea was to provide spaces that could be customised and easily adapted to the most diverse social needs of housing crises: *slums*, urban peripheries, post-disaster emergencies, etc.
Given the "epidemic" numbers of such emergencies and the need to provide humanly dignified and economically sustainable responses shortly, the choice was made to apply off-site construction to emergency architecture, encouraging the industrial sector rather than the traditional building sector for the construction of houses. (PREFABRICATED)
Another requirement imposed by emergency situations (which are often unpredictable) is to consider the time factor: for example, an earthquake suddenly generates the need to provide homes for many people in a very short time. The characteristic of an emergency does not allow for medium or long-term planning; rather the characteristic of an emergency imposes prior planning/preparation, but an immediate temporal response. (MODULAR)
Another factor taken into consideration in this research was the different climate zones in which the emergency event could occur. An indicative system was developed for 4 typical climatic zones which could quickly provide indications on the choice of the optimal *module* composition for that specific climatic zone in order to guarantee comfort conditions while minimising energy requirements. (SUSTAINABILITY)
Another feature considered is that of generating accommodation that can be customised according to needs, both in terms of size (from 2 to n persons) and in terms of quality of space (possibility of choosing the quantity and layout of rooms and services, materials and finishes). (ADAPTABILITY)
Considering all these needs to be met, the minimum size that would satisfy the need for habitable space and at the same time reduce the basic *module* to a minimum has been searched. (Initially, the reasoning was about like a Lego brick: we tried to find the right modular size to satisfy the design requirements, compatibly with the industrial needs of buildings requiring medium/large dimensions. The right compromise between these two composition and production requirements, which would also guarantee sustainability and aesthetics, allow modularity, etc., was 1.20 m for the *sub-module* and 3.60 m for the total *module*, plus 0.30 m for the structural mesh). The starting point was an ideal *sub-module* size of 1.10 m (a size that allows for a standard door of 2.10 m x 0.90 m net span, which with three superimposed *sub-modules* allows for a net inter-floor span of 3.30 m, which is greater than the minimum inter-floor height of 2,70 m and allows for a room of 10.89 m2, which is greater than the minimum size of a standard single room of 9 m^2). The basic choice of the 1.20 m sub-module was, therefore, only determined by the current ease of implementation by the industrial system.
From these dimensions, accommodation for 2 to n persons can be generated, with the possibility of freely choosing the layout and quantity of the rooms. (MODULE SIZE)
The next stage of the architectural project was to shape typical rooms on the basis of the *module* and *sub-module* dimensions (3,30 m and 1,10 m) in the ground plan and then to combine them to form accommodation and buildings. The same procedure used in the plan was then applied in the elevation in order to define the facades and the number of floors of the typical buildings and blocks. (MODULAR BUILDINGS)
Some aspects of the design (e.g., joints and junctions), given the complexity of the proposed system, require further study and more specific solutions, in particular greater fluidity and linearity in the use of *sub-modules* for the management and creation of internal spaces.

6.1.2. **Engineering skills**

Engineering skills have allowed the development of a calculation algorithm on energy efficiency and environmental comfort able to provide the optimal composition of the *module* (the theoretical cube) to maximise the comfort/energy needs ratio of the same.
Five parameters were chosen as the most significant in influencing the energy requirements necessary to maintain comfort conditions in the different climatic zones: 1) the composition of the opaque envelope, 2) the percentage of transparent surface of a façade, 3) the percentage of shading of transparent surfaces, 4) natural ventilation, 5) the inclination of the roof.
Based on these indications it was possible to design a typical building for each of the 4 climate zones considered. This technical aid succeeded in making the architectural design more effective and conscious from the point of view of energy savings, suggesting the architectural and technical choices in the composition of the 4 typical buildings.
It is clear that by using further parameters, the proposed calculation model will become more and more efficient: in a certain sense, it is also modular, and therefore can be increased as needs and resources change

6.1.3. **IT skills**

IT skills have enabled the computer processing of hundreds of thousands of data, translated into useful information for *module* design in the various climate zones.
The algorithm elaborated can be, with the relative in-depth studies and subsequent specific studies, proposed as a computer *application* that can be used by design studios and a valid tool for optimizing the energy efficiency of buildings. In this regard, it has been considered that ad hoc *Artificial Intelligence* and *Machine Learning* systems, studied and instructed in this regard, may allow even more data to be introduced, selecting, however, only the information considered most useful for design.
This potential for processing a program at the service of design has attracted the attention of a number of specialized companies in the sector who have seen the possibility of commercial use and dissemination of technical information and could be a subject for future development.

6.1.4. **Industrial skills**

The *module* is firstly and foremost a product designed to be produced as mass-produced as possible. It was therefore necessary both to identify sizes, shapes and materials suitable for industrial production, and to envisage an industrial production process and assume ways of assembling the individual "pieces" together.
The first step in this sense was the identification of usable construction systems: wood and metal. On the basis of the materials (corresponding to the production, construction and assembly systems), the shapes of the *module* were adapted to elements which were the precursor to the actual parts.
The parts that make up the *module* are a) beam and pillar; b) structural connection joint; c) fixed and movable panel (window, door and patio door); d) panel joint; f) foundations.
Each of these pieces has been designed for both the timber system (solid elements and interlocking metal joints) and the metal system (hollow box and sheet metal elements with screw and bolt joints).
The proposed systems were then further developed on an industrial and construction basis: specifically, a concrete implementation process was initiated through a local company that makes prefabricated steel houses.
This phase, in addition to testing the concrete implementation of the *module* with all its components, also produced an initial estimate of production costs that meet the economic sustainability required among the objectives.
Also, this point can, of course, be developed with subsequent studies and allow collaborations with companies in the sector, which have already shown interest in the proposed *modular system*.

6.1.5. **Emergency stakeholders**

Continuous and direct contact with experts in the field has enabled the production of a system and the usage of a methodology closely linked to the practical context and applicability. Through interviews, conferences, meetings and comparisons, it was possible to identify the practical needs of those who live and deal with these emergencies on a daily basis and, above all, to validate with those experts the practical usefulness and applicability of the research.
National and international experts in the field of emergencies observed and analysed, validated and gave their technical contribution and experience to the process that led to the production of this research document, considered interesting and applicable to emergency needs.

Each of the organisations consulted and involved has contributed its own specific aspect of enrichment and reflection:

- UN agencies: importance of the issue of transport and storage (WFP); identification of optimal dimensions, usable materials, production processes and the importance of the circular economy, number of floors, cost range and numbers of housing emergencies on the African continent (UN-HABITAT).
- INTERSOS: identification of the problems of transport, management and timing of the use of materials for emergencies; the specific problems of some areas of the world linked to emergencies (war zones, places with particular topographical and social conditions, the management of water and environmental problems in the area etc.); the economic funds allocated; the political and governmental management linked to emergencies; the cooperation of the various actors and institutions among themselves and among the populations involved in the emergency.
- Italian Civil Protection: focus on emergency issues on the national territory; in-depth case study of the post-earthquake response in L'Aquila in 2008; identification of the dimensions, costs and housing and construction problems encountered; problems in logistical and political management; hints on the management of the post-earthquake in central Italy in 2016 and 2017; possible future developments linked to the use of recycled plastic in the system.
- Glocal Impact Network: evaluation of the community impacts in the South of the world of the system in question; integration of the housing construction system with GIN products and services (Agritube - hydroponic agriculture; Liter of Light - electrification and sustainable lighting services); evaluation of the integration of the system towards larger scale approaches and public space (collaboration with City Space Architecture); collaboration with industries in the construction and IT sector for the development of both the construction production system and that linked to the potential of the calculation algorithm (COGI, X-Lam Dolomiti, RI Group ... for the industrial sector; IBM ... for the IT sector).

6.2. CONCLUSIONS

The multidisciplinarity of the research was sought and achieved in a very satisfactory manner: it represents one of the main objectives obtained by this research.

The Italian University, in line with the European academic world, is also keen to encourage interdisciplinary exchange between the various research specialisations and the relationship/communication between academia, industry and the political/social world.

It has been demonstrated that the *module* - as imagined, conceived and designed - is feasible in practice.

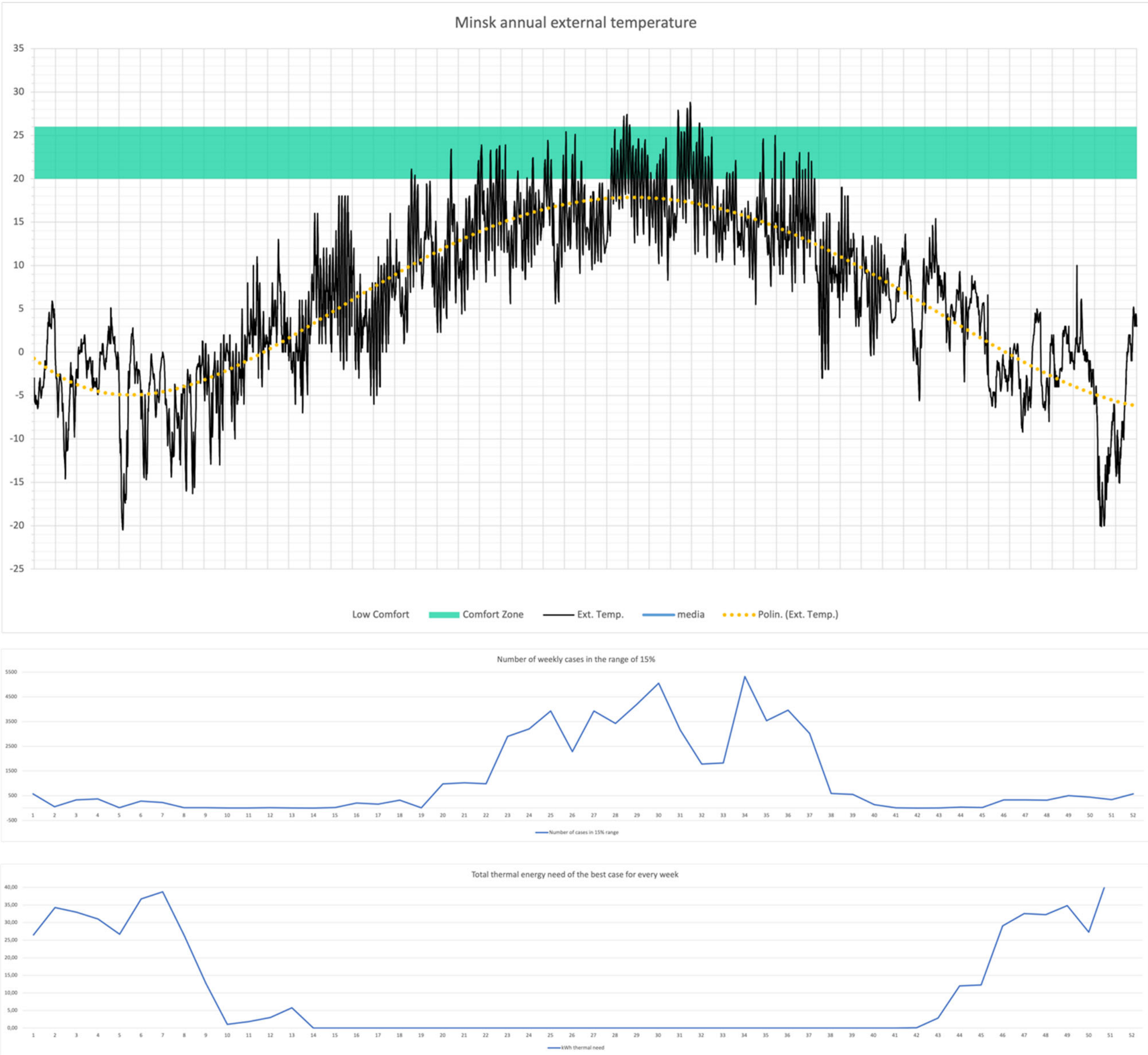
It meets the required environmental expectations; the market demonstrates interest in it; and it can be economically viable (even profitable though).

More complex *modules or* modules for uses other than housing can be developed.

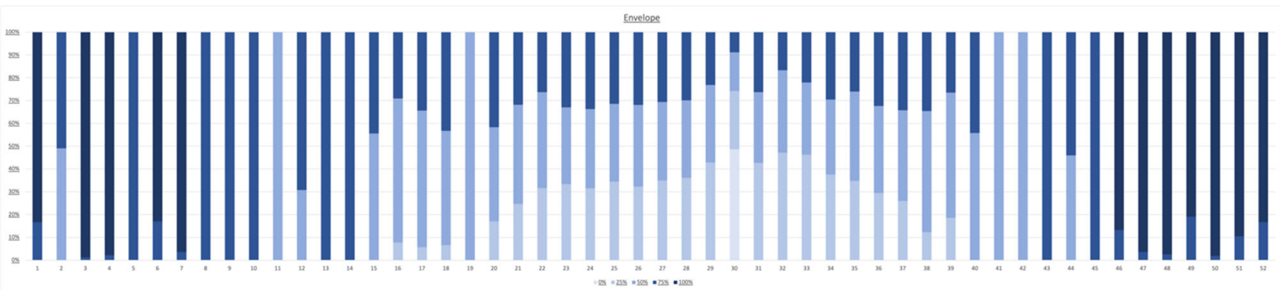
7. Graphs and sheets

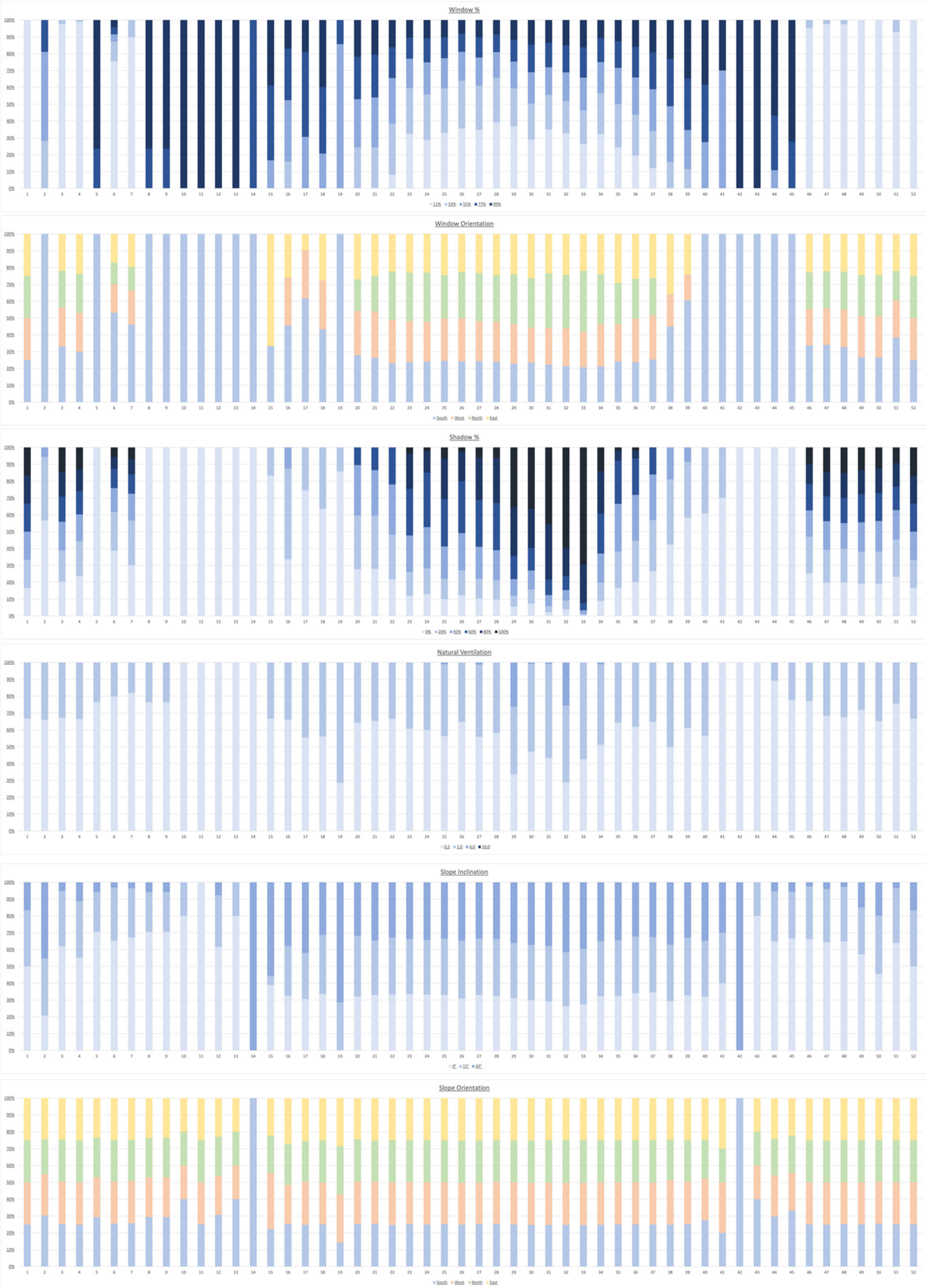
7.1. Chapter 3 Graphs

7.1.1. Minsk



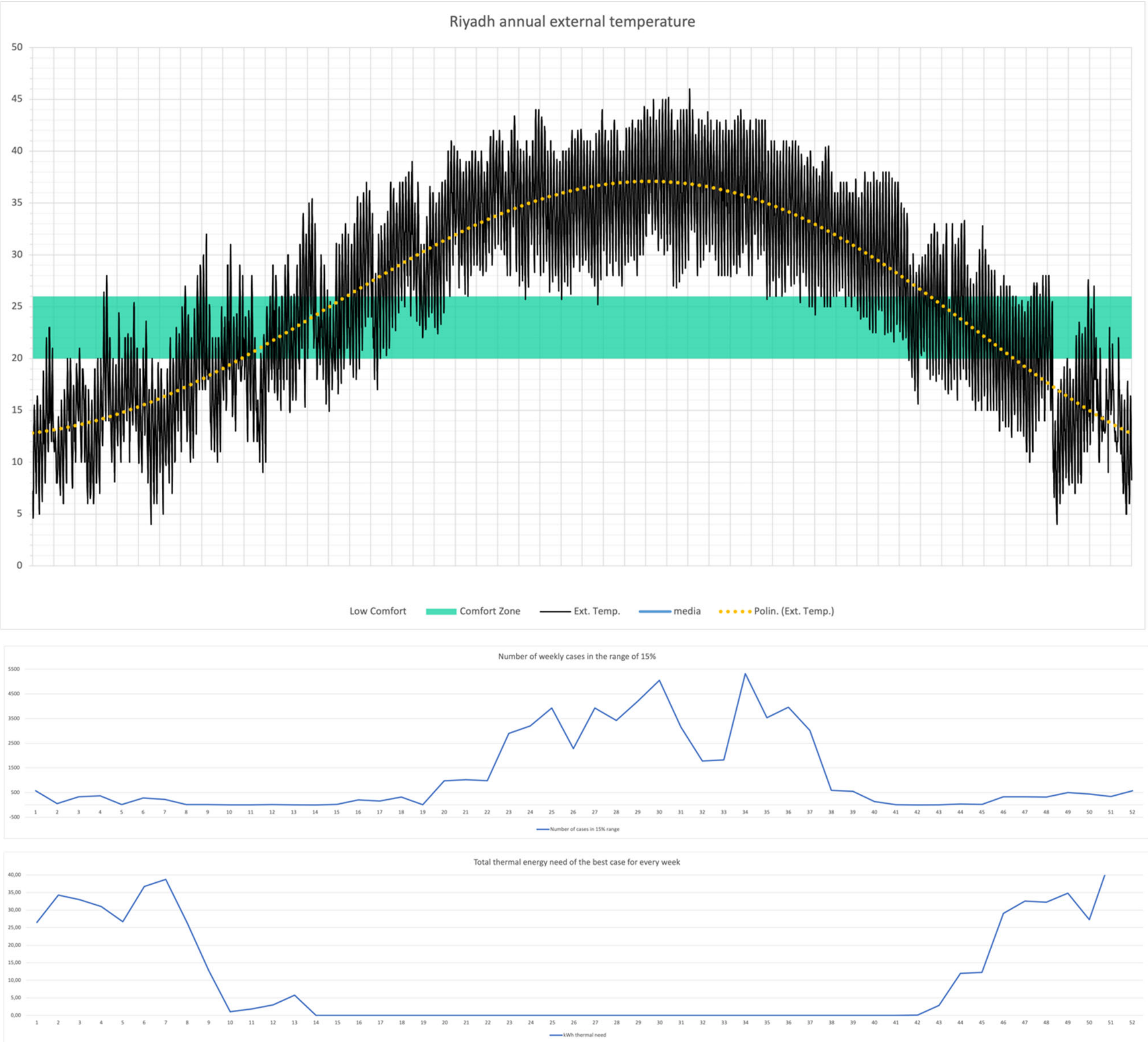
Graph 1 – From the top: Minsk external temperature and comfort zone; Annual number of weekly cases inside the range of the 15% from the absolute best case; Total energy need of the weekly best case



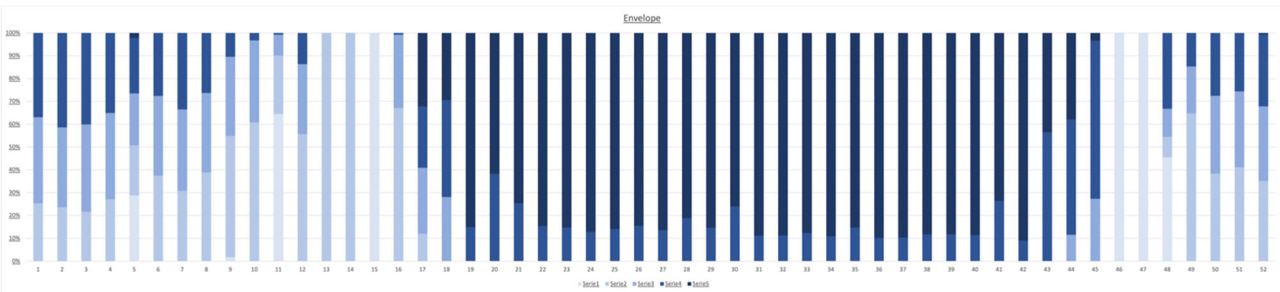


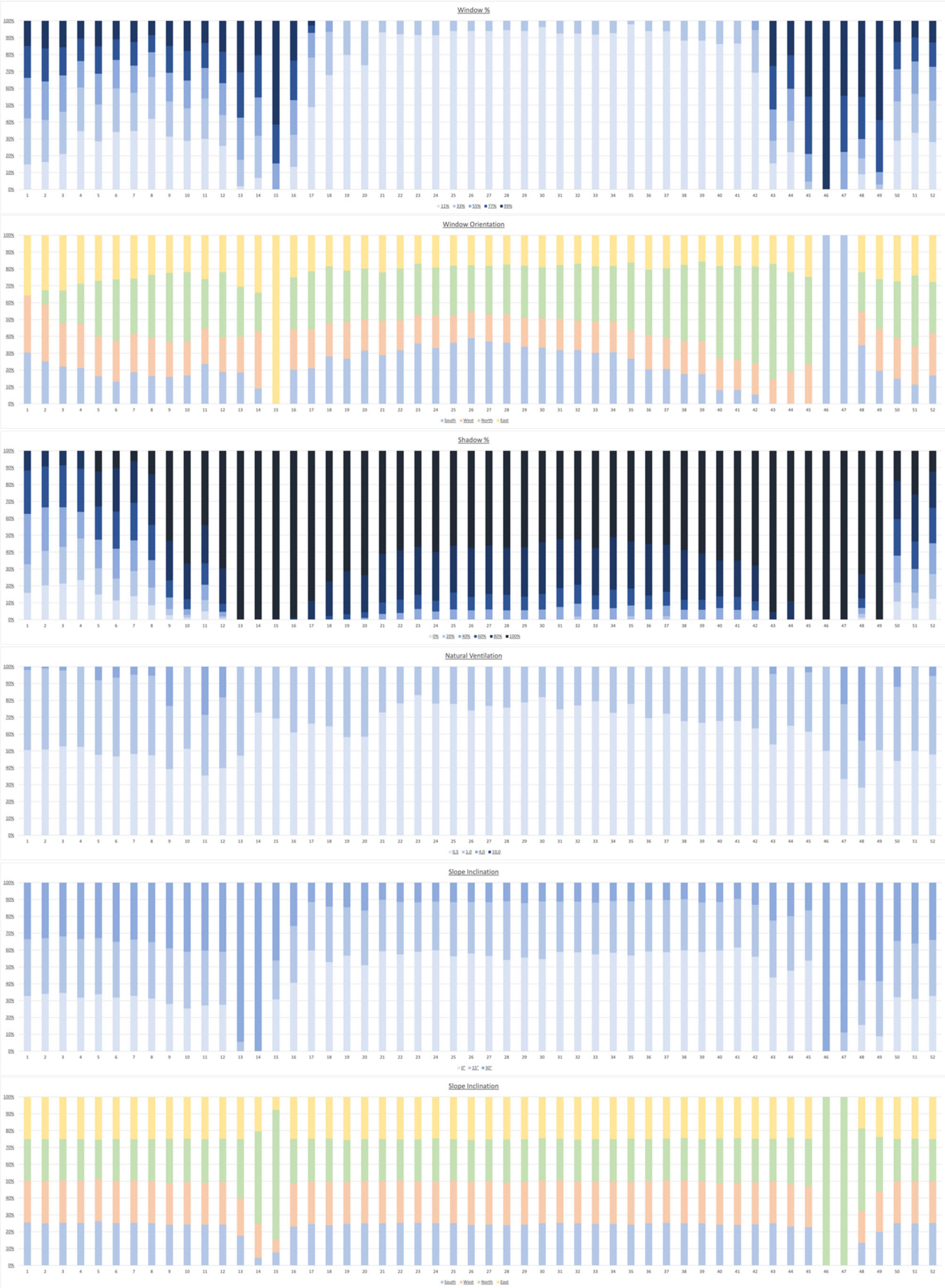
Graph 2 – Graph of the better combination of each parameter for every week of one year. From the top: Envelope (% of Insulation VS Thermal Mass); Window % (size of the window in one façade); Window Orientation (orientation of the façade with the window); Shadow % (% of the shadow of the window); Natural Ventilation (number of Vol/h changing); Slope Inclination (degree of the slope inclination); Slope Orientation (orientation of the slope inclined)

7.1.2. **Riyadh**



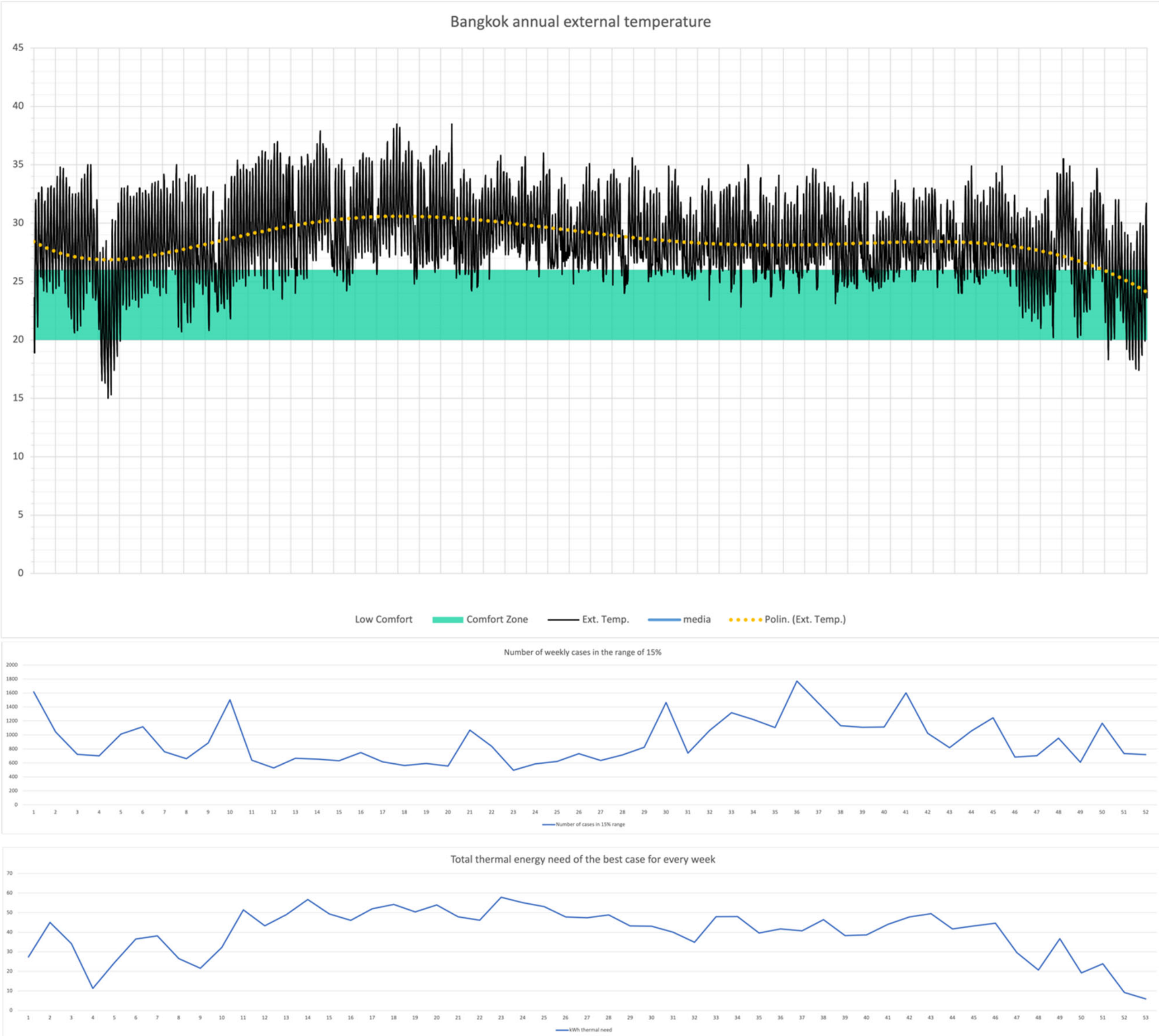
Graph 3 – From the top: Riyadh external temperature and comfort zone; Annual number of weekly cases inside the range of the 15% from the absolute best case; Total energy need of the weekly best case



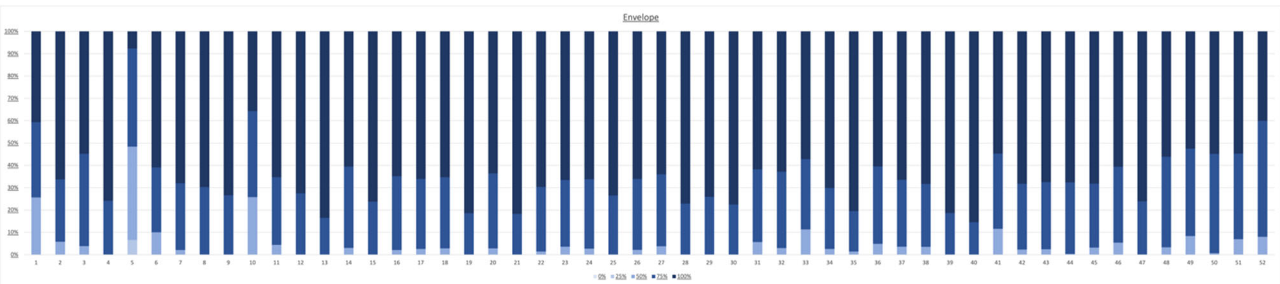


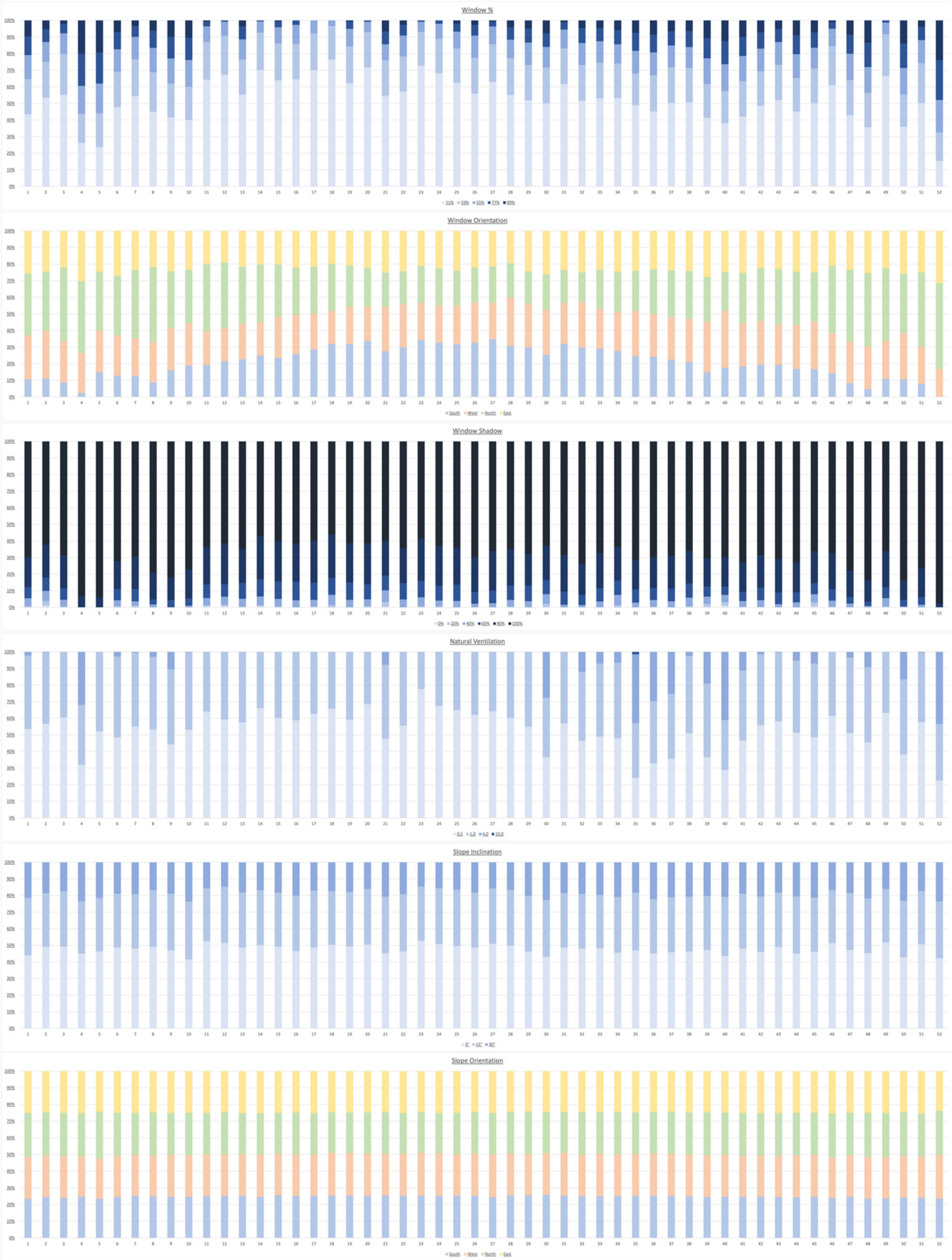
Graph 4 – Graph of the better combination of each parameter for every week of one year. From the top: Envelope (% of Insulation VS Thermal Mass); Window % (size of the window in one façade); Window Orientation (orientation of the façade with the window); Shadow % (% of the shadow of the window); Natural Ventilation (number of Vol/h changing); Slope Inclination (degree of the slope inclination); Slope Orientation (orientation of the slope inclined)

7.1.3.**Bangkok**



Graph 5 – From the top: Bangkok external temperature and comfort zone; Annual number of weekly cases inside the range of the 15% from the absolute best case; Total energy need of the weekly best case





Graph 4 – Graph of the better combination of each parameter for every week of one year. From the top: Envelope (% of Insulation VS Thermal Mass); Window % (size of the window in one façade); Window Orientation (orientation of the façade with the window); Shadow % (% of the shadow of the window); Natural Ventilation (number of Vol/h changing); Slope Inclination (degree of the slope inclination); Slope Orientation (orientation of the slope inclined)

7.2. CHAPTER 7 SHEETS

7.2.1. Metal Technical Drawing

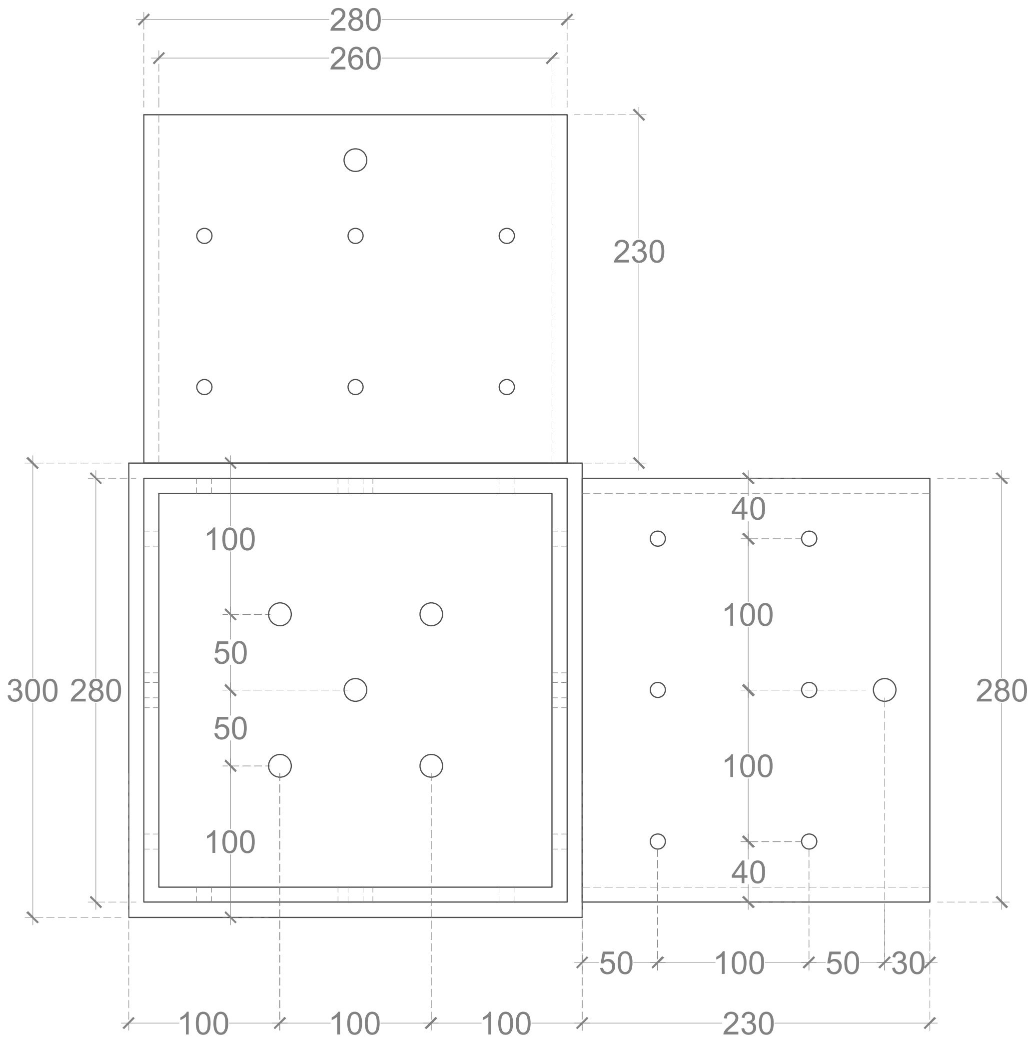
AM 01

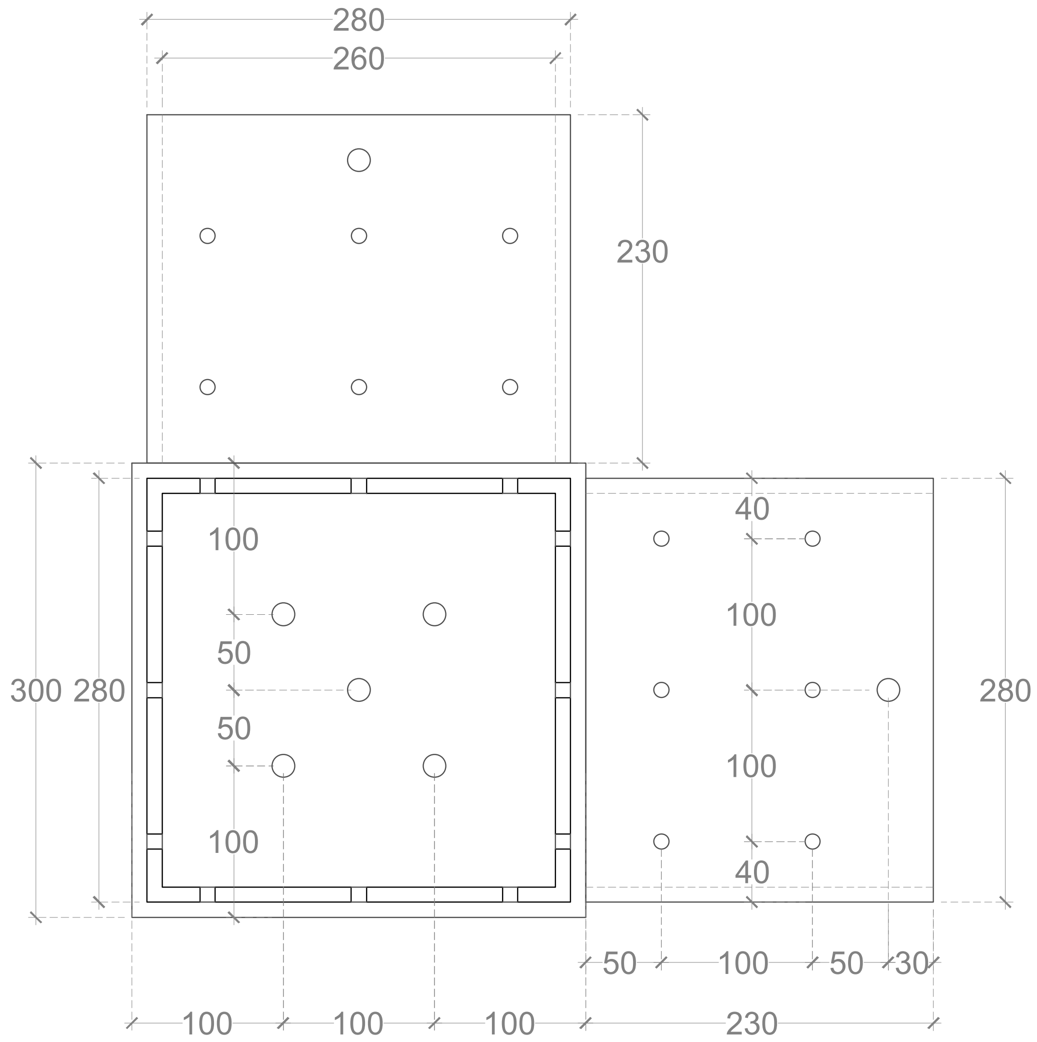
METAL SYSTEM

COMPONENTS

SCALE 1:5

Jn_1_1
Frame structural Joint





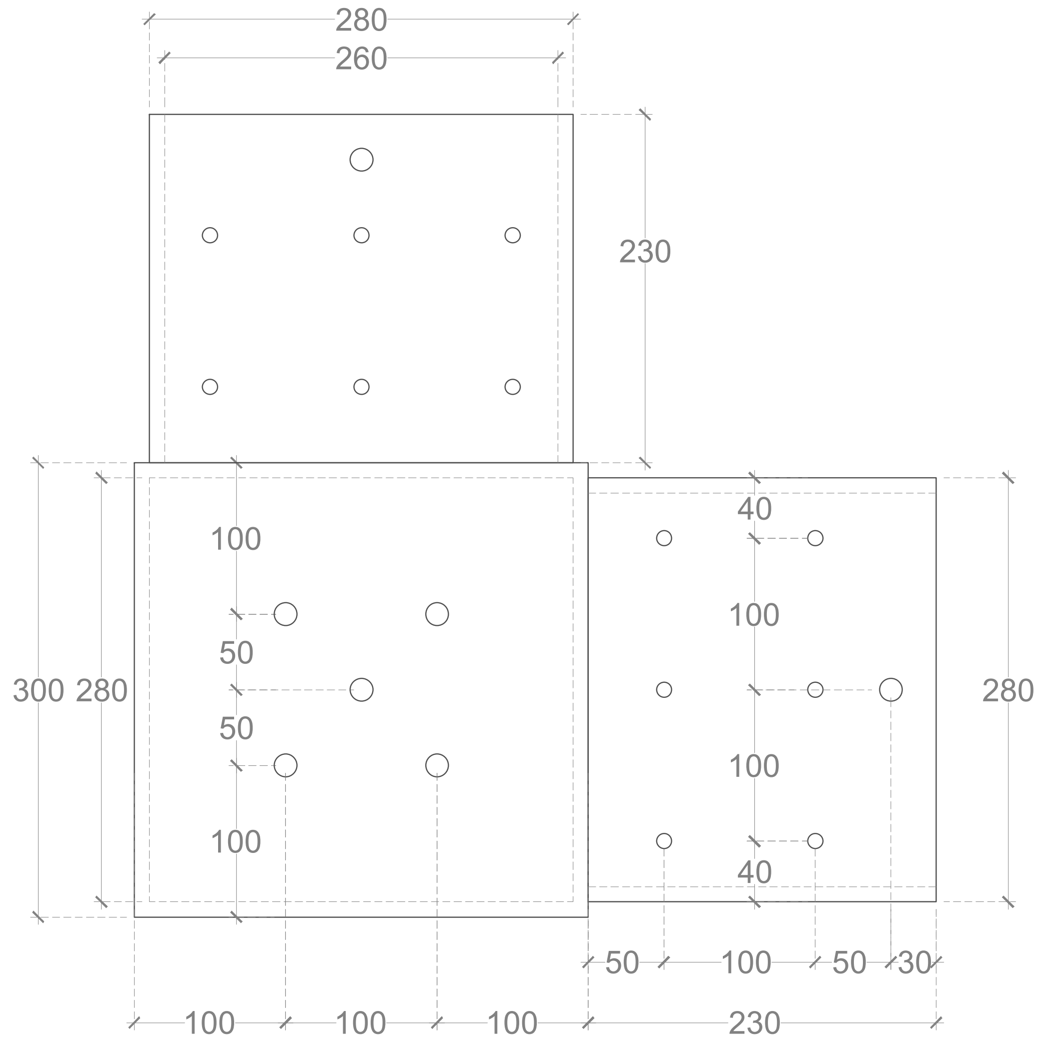
AM 02

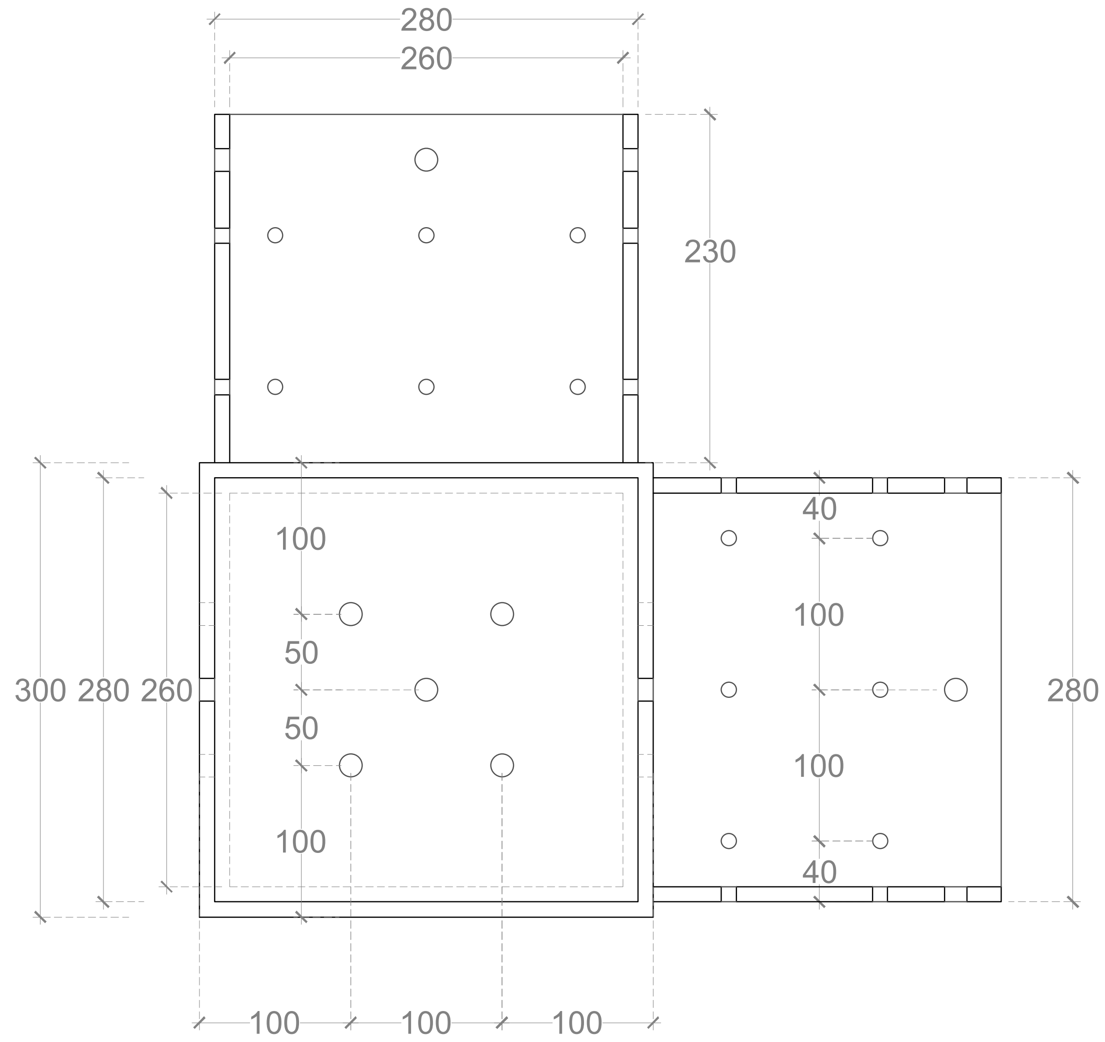
METAL SYSTEM

COMPONENTS

SCALE 1:5

Jn_1_1
Frame structural Joint





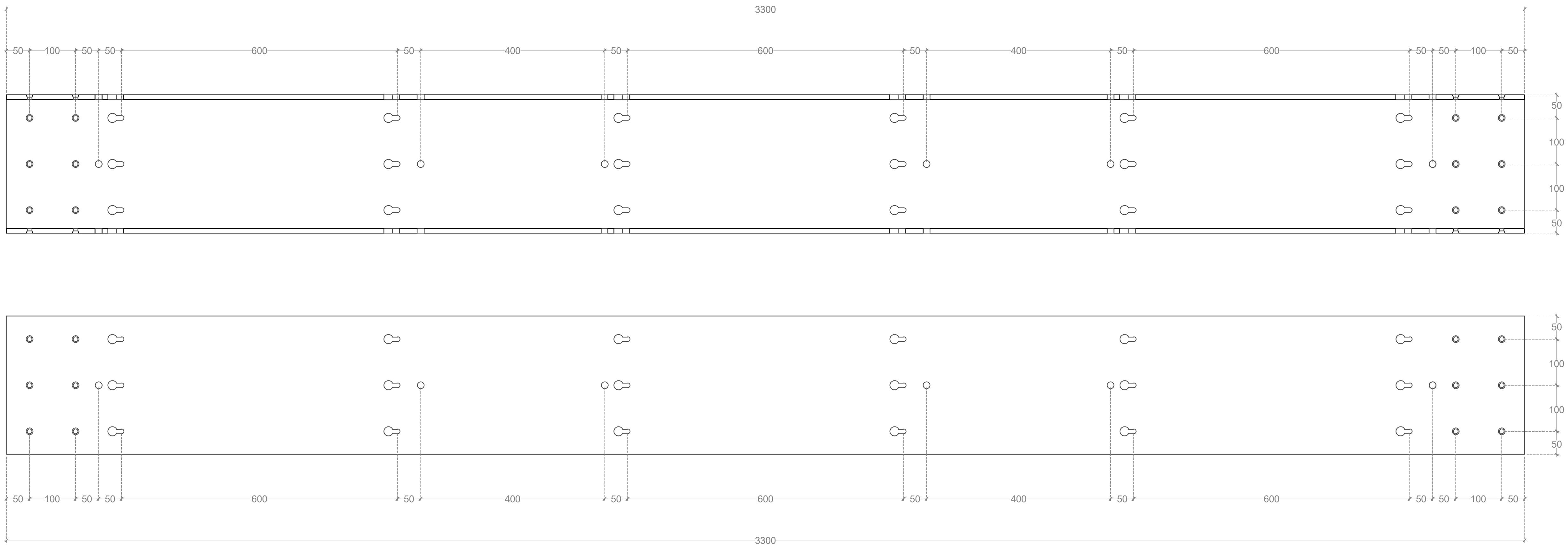
AM 03

METAL SYSTEM

COMPONENTS

SCALE 1:10

Fr_1_1
beam/column



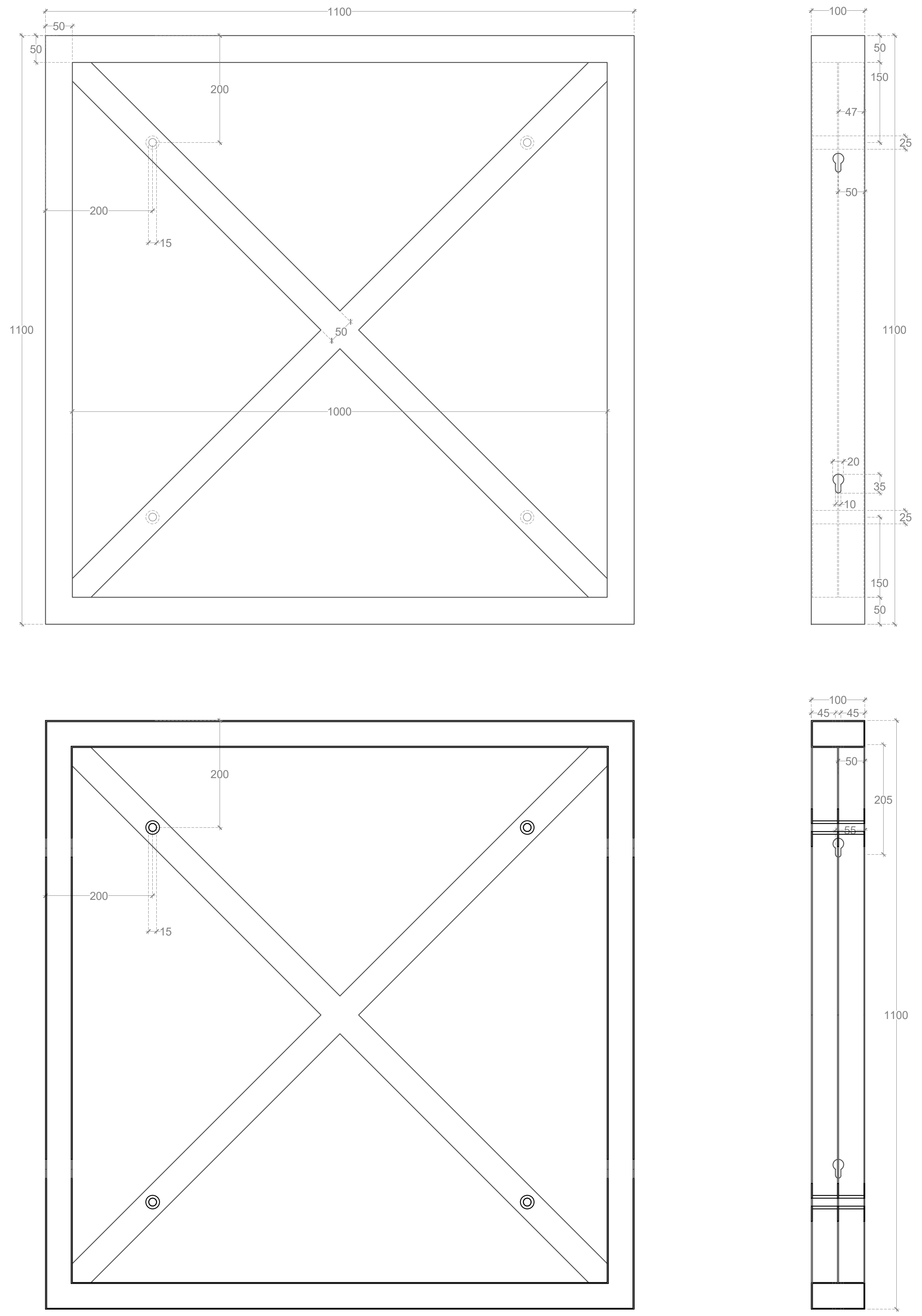
AM 04

METAL SYSTEM

COMPONENTS

SCALE 1:10

Pa_1_1
Panel cladding



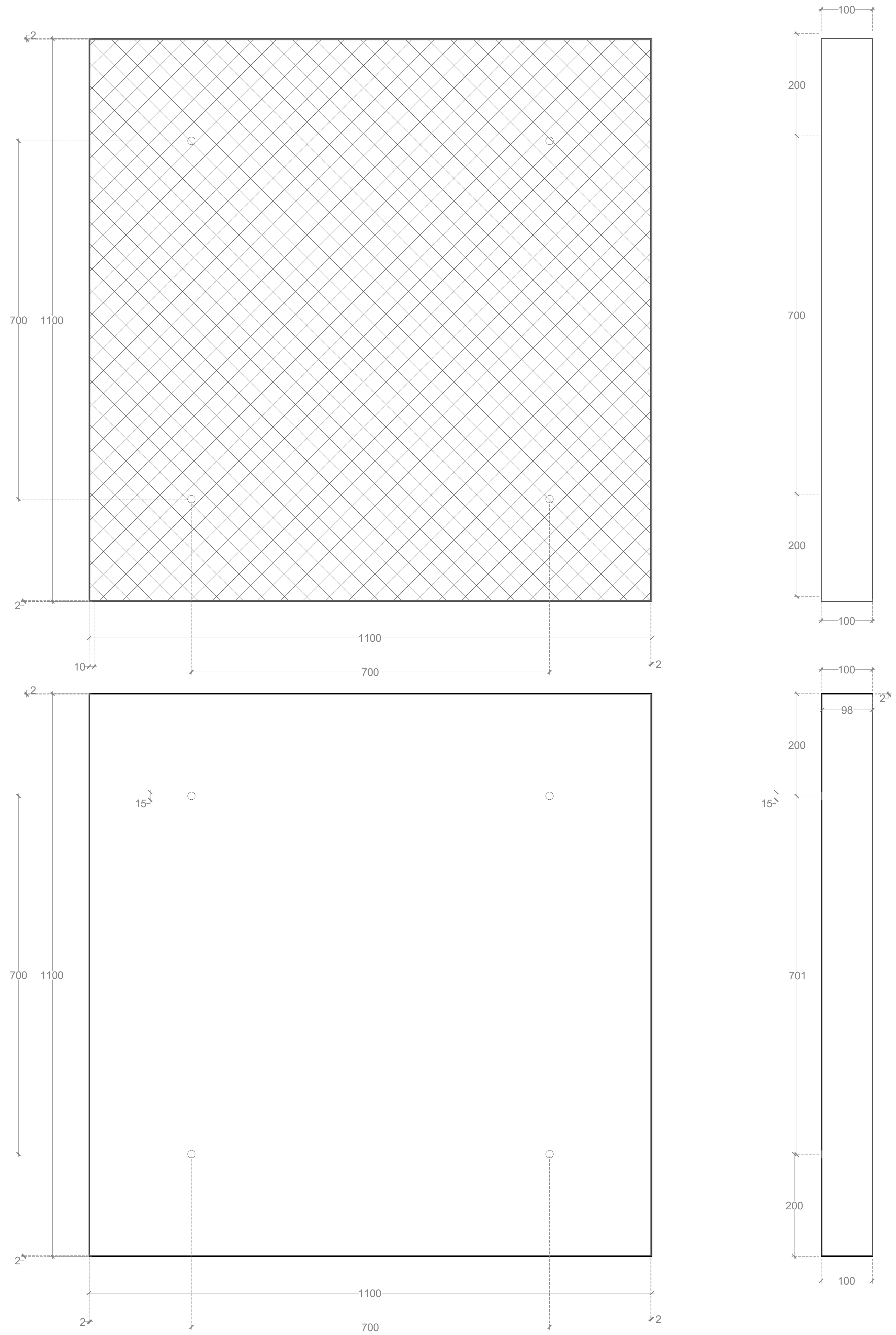
AM 05

METAL SYSTEM

COMPONENTS

SCALE 1:10

Pa_2_1
Panel cladding - Insulation wall



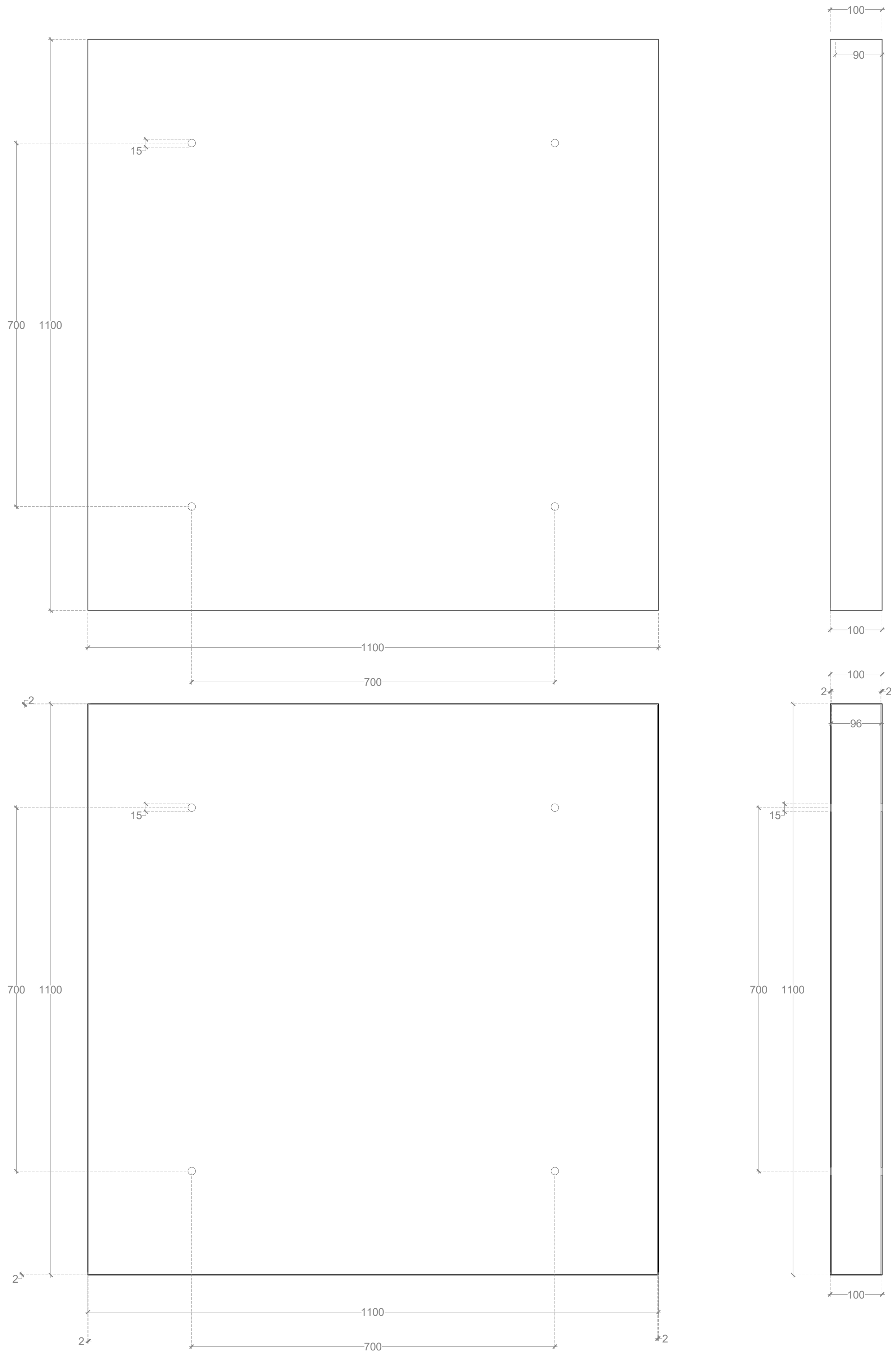
AM 06

METAL SYSTEM

COMPONENTS

SCALE 1:10

Pa_2_2
Panel cladding - Insulation/
Thermal Mass floor



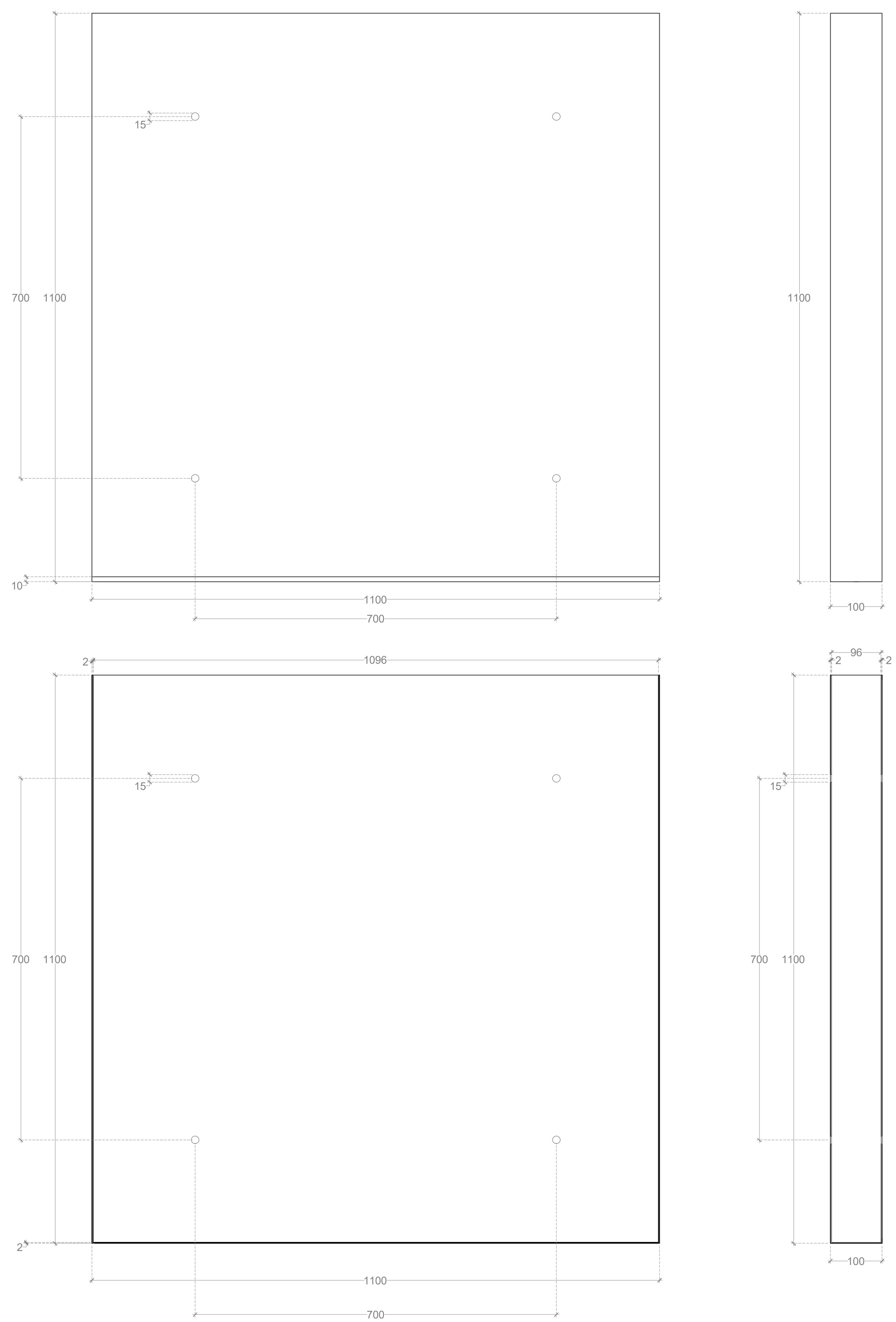
AM 07

METAL SYSTEM

COMPONENTS

SCALE 1:10

Pa_2_3
Panel cladding



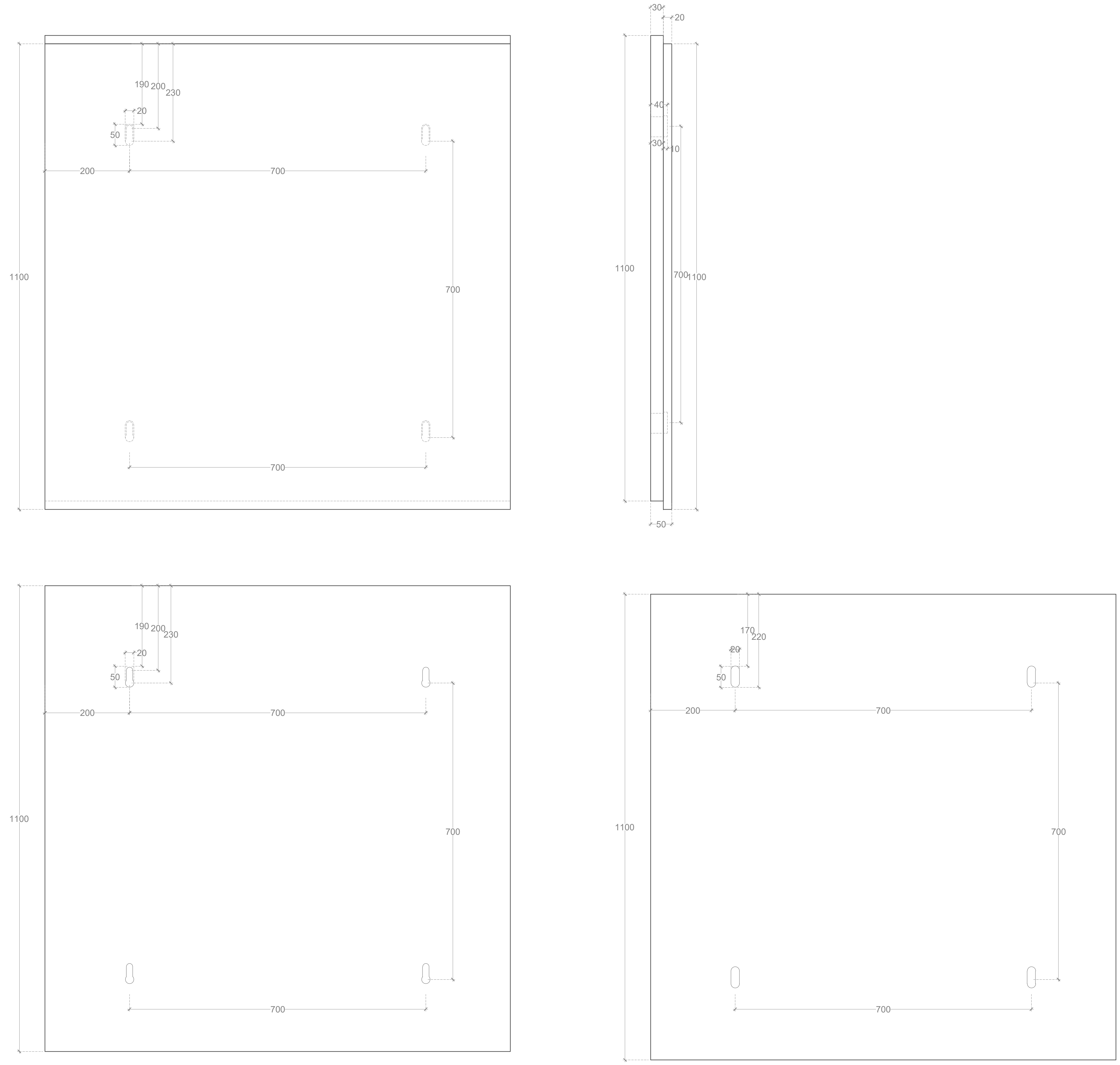
AM 08

METAL SYSTEM

COMPONENTS

SCALE 1:10

Fi_1_1
Finishing Panel



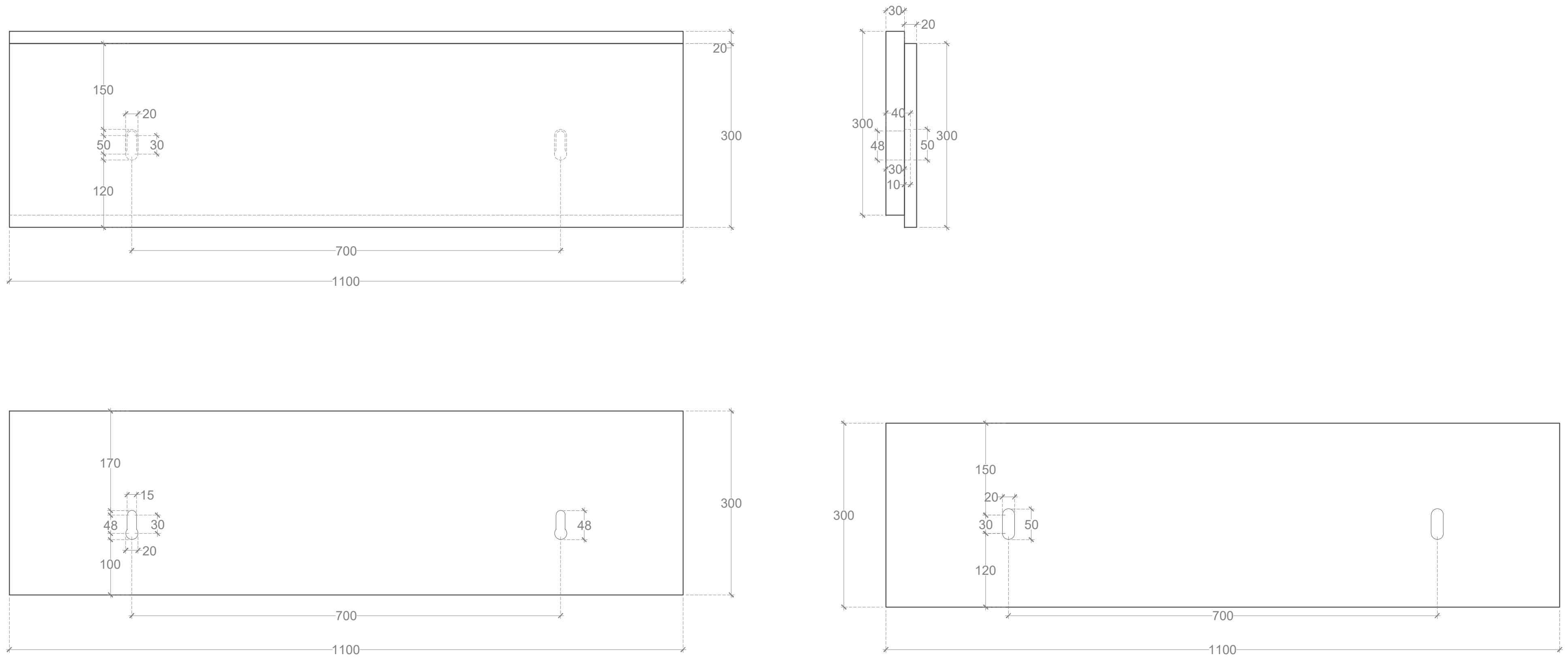
AM 09

METAL SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_1
Finishing Panel - frame border 01



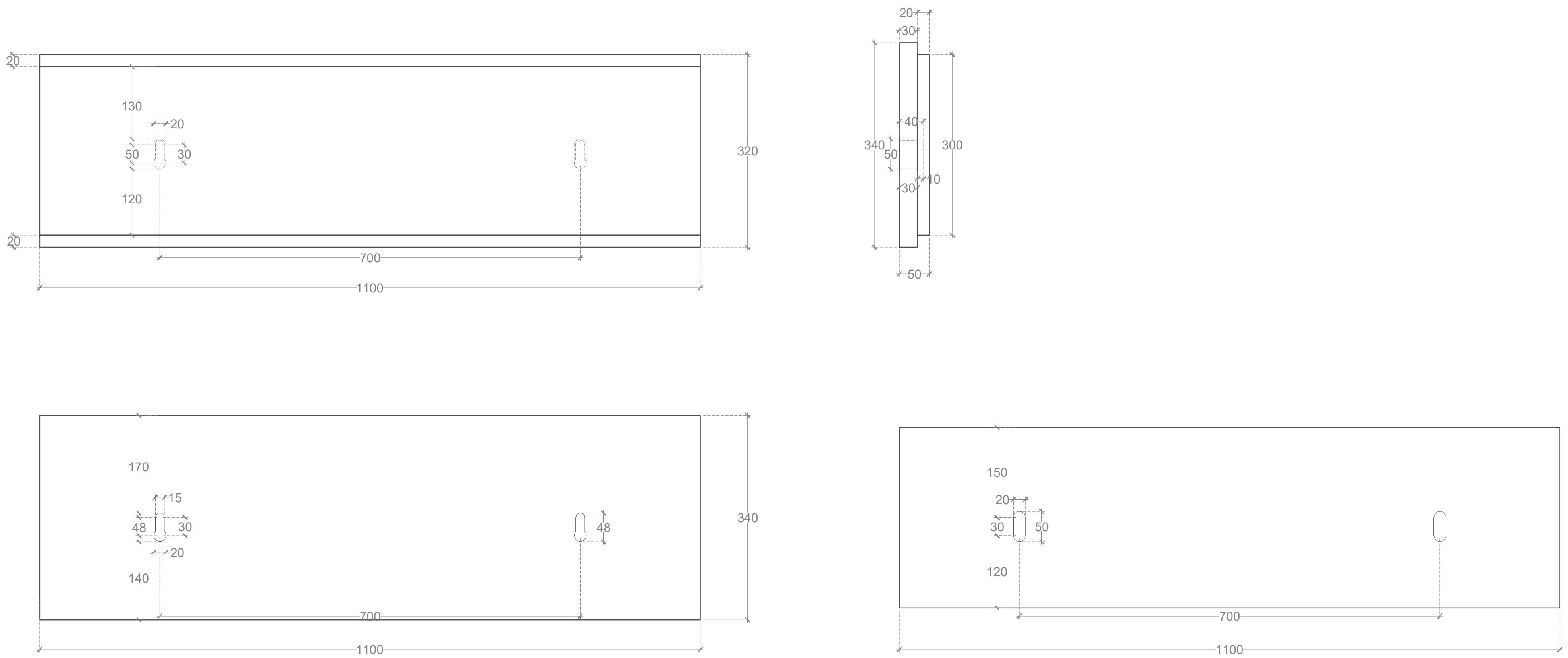
AM 10

METAL SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_2
Finishing Panel - frame border 02



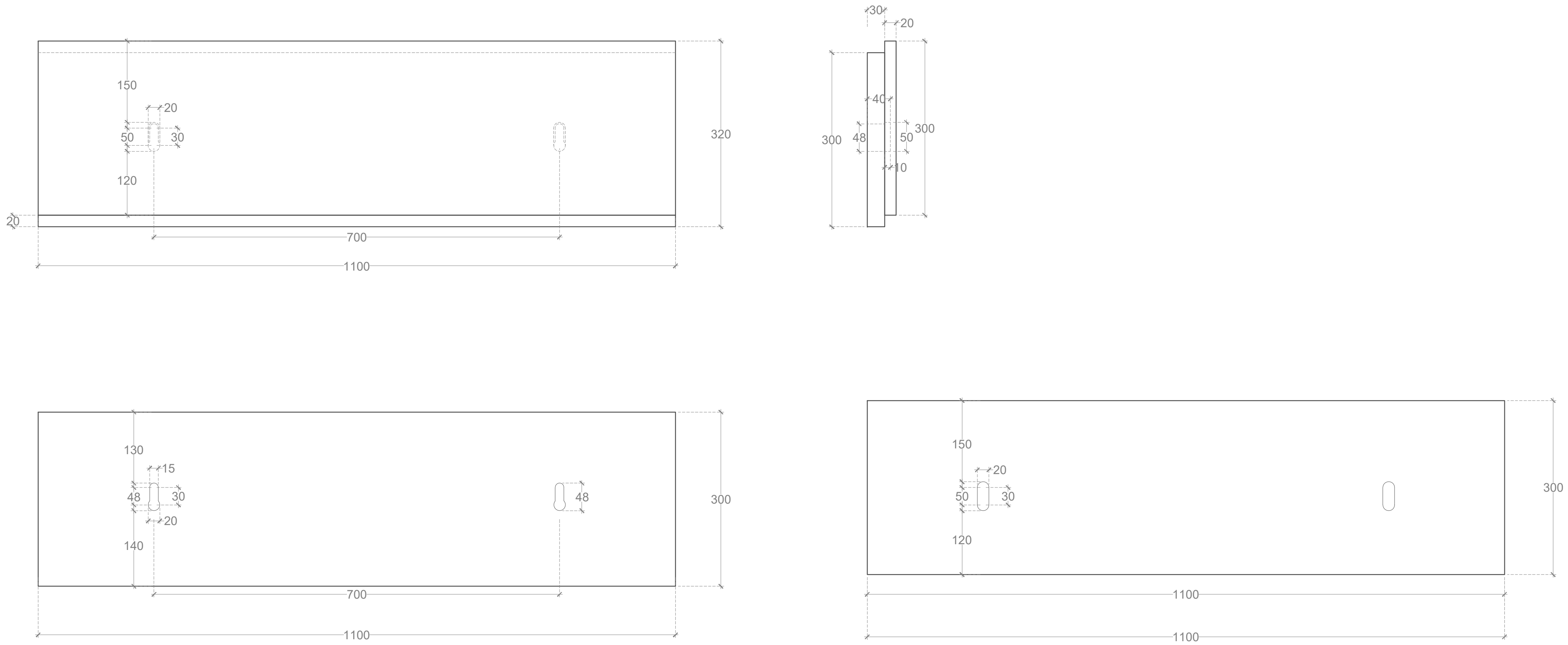
AM 11

METAL SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_3
Finishing Panel - frame border 03



AM 12

METAL SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_4
Finishing Panel - long frame border horizontal

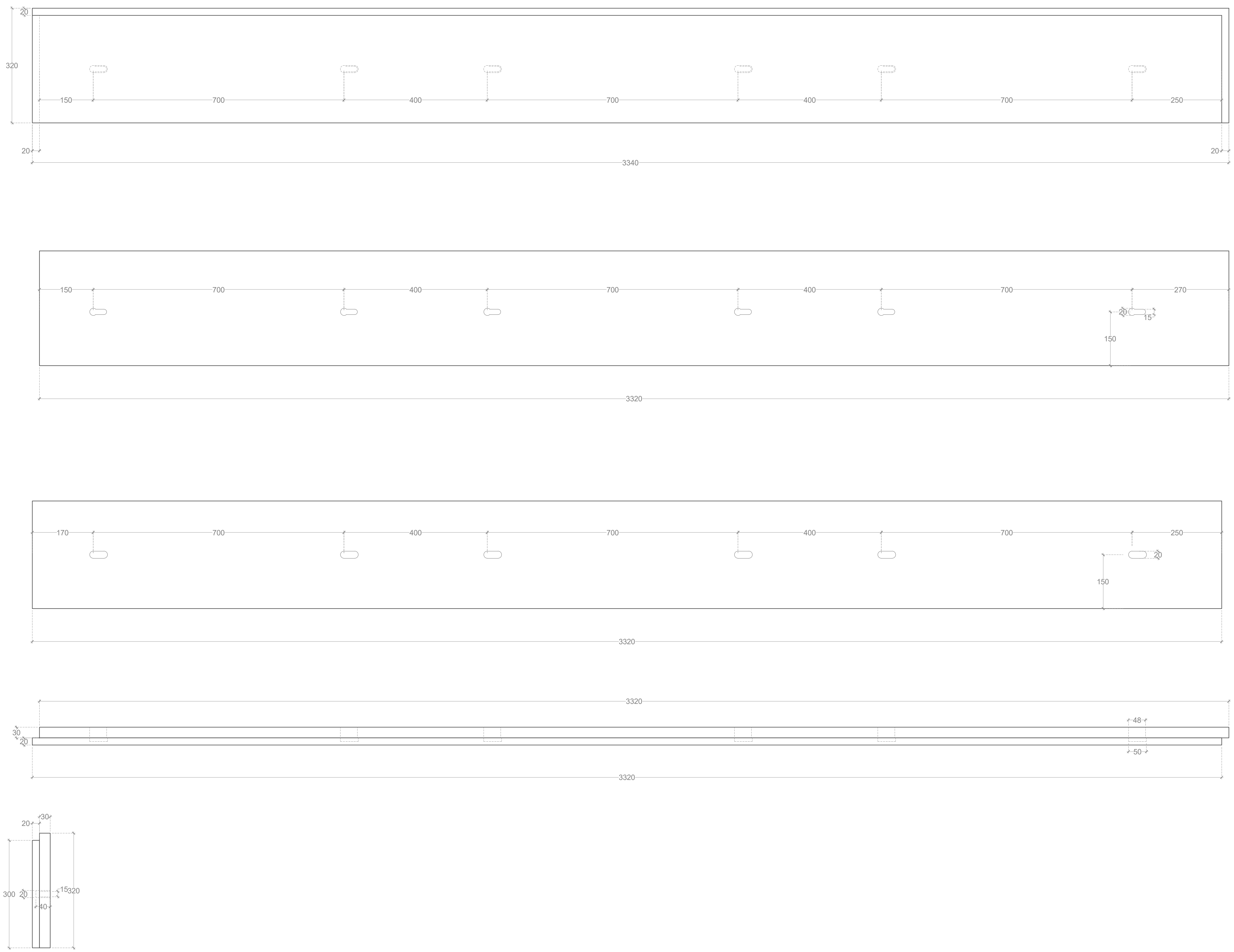
AM 13

METAL SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_5
Finishing Panel - long frame border vertical



AM 14

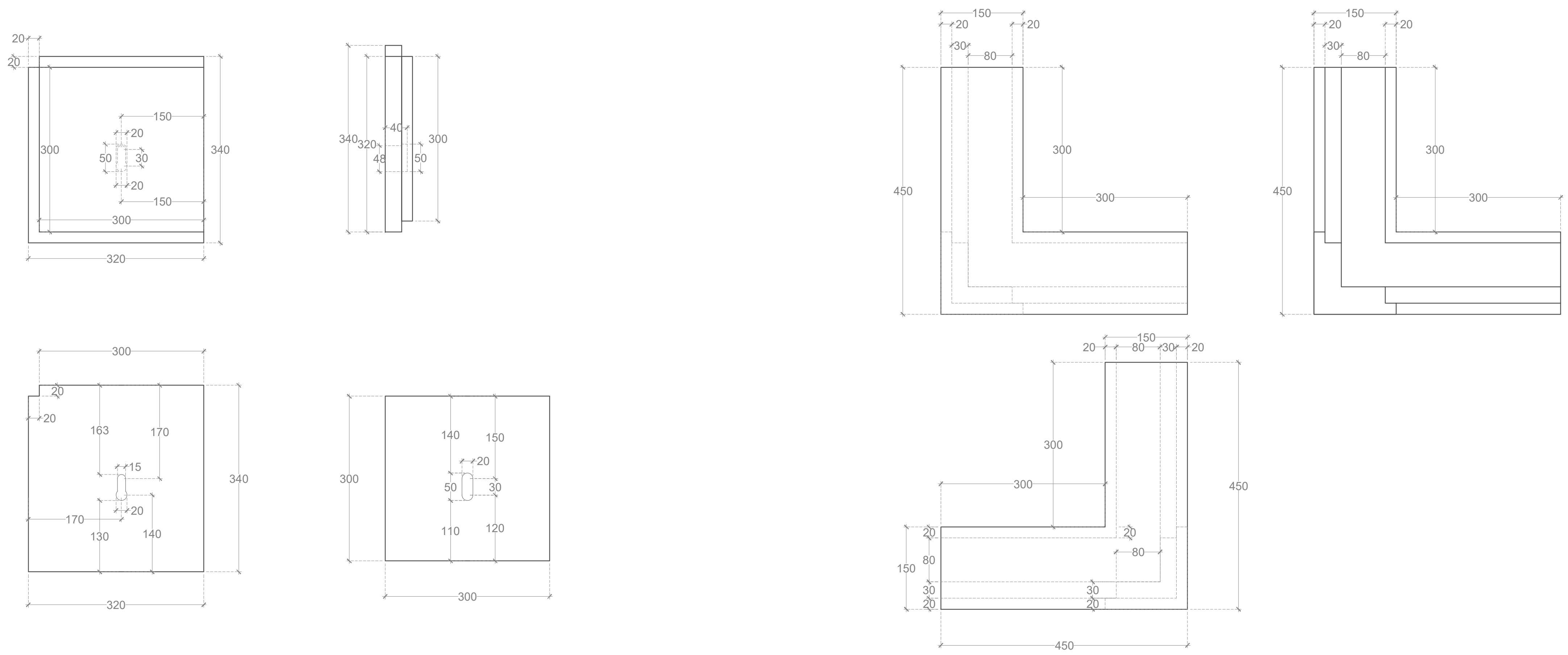
METAL SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_6
Finishing Panel - joint border

Fi_3_1
Finishing Panel - angolar border



AM 15

METAL SYSTEM

COMPONENTS

SCALE 1:10

Fi_3_2
Finishing Edge - edge border

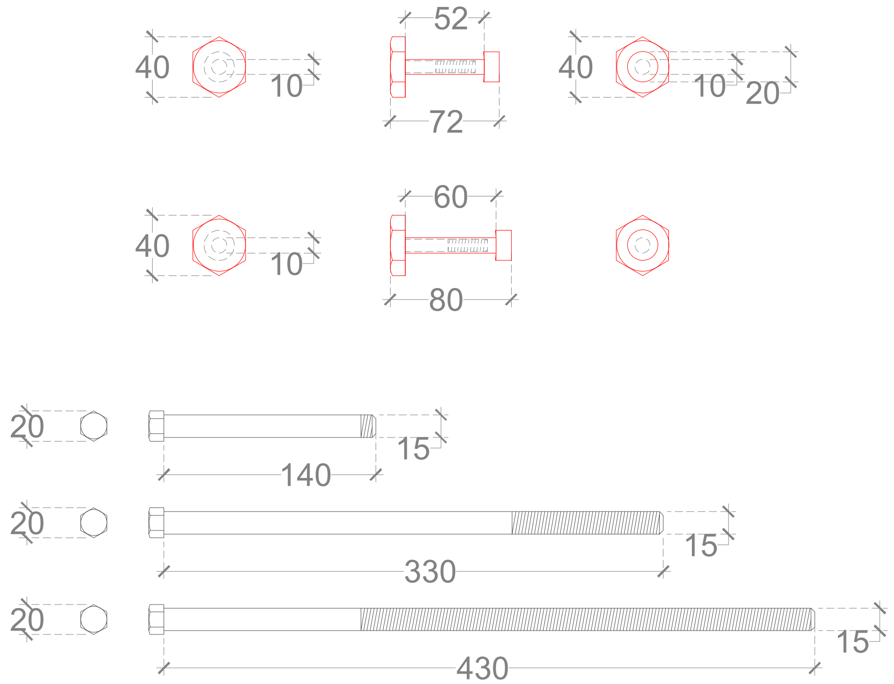
AM 16

METAL SYSTEM

COMPONENTS

SCALE 1:5

Metalware



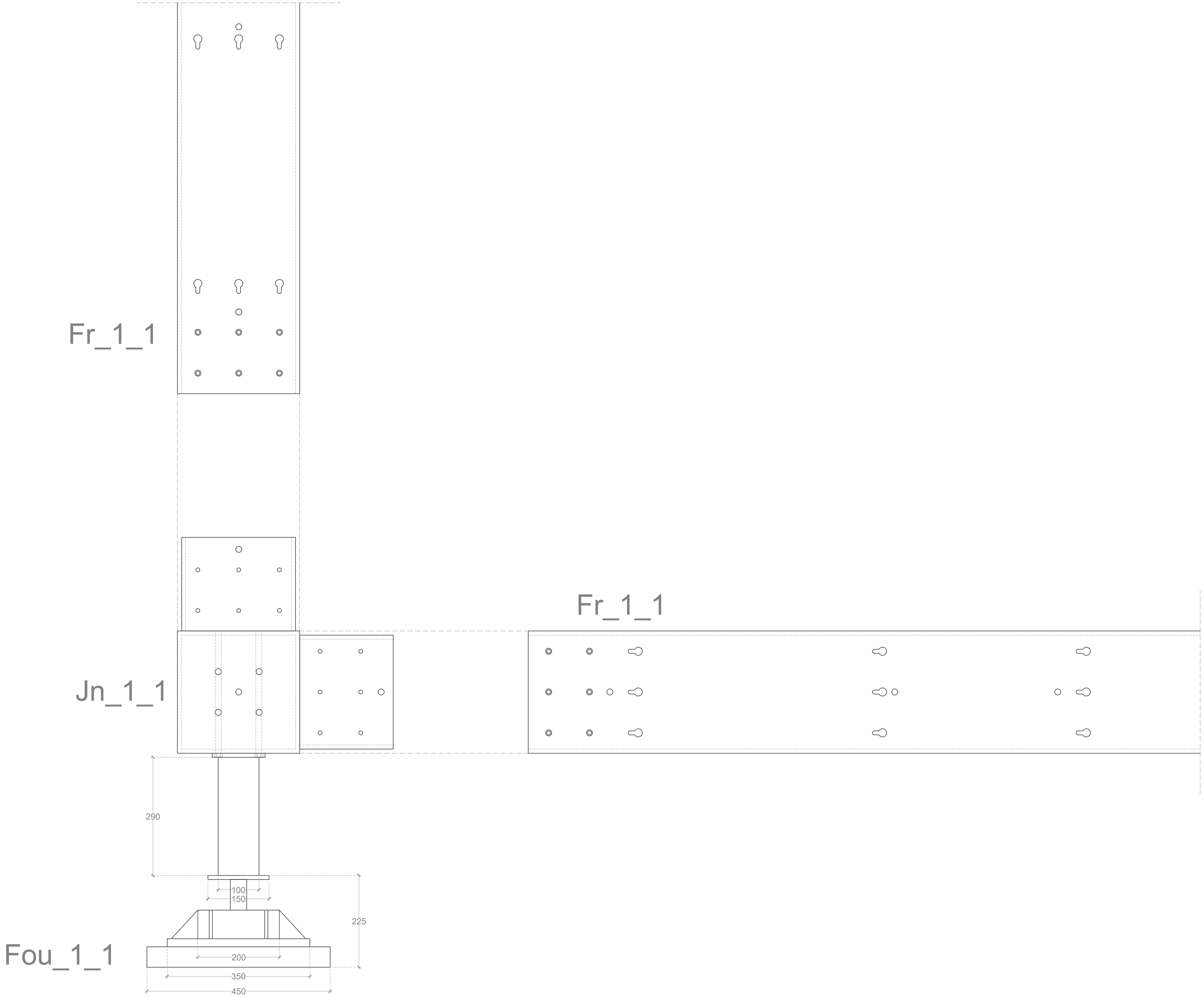
BM 01

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Detail connection:
Joint (Jn_1_1)
Beam (Fr_1_1)
Column (Fr_1_1)
Foundation (Fou_1_1)



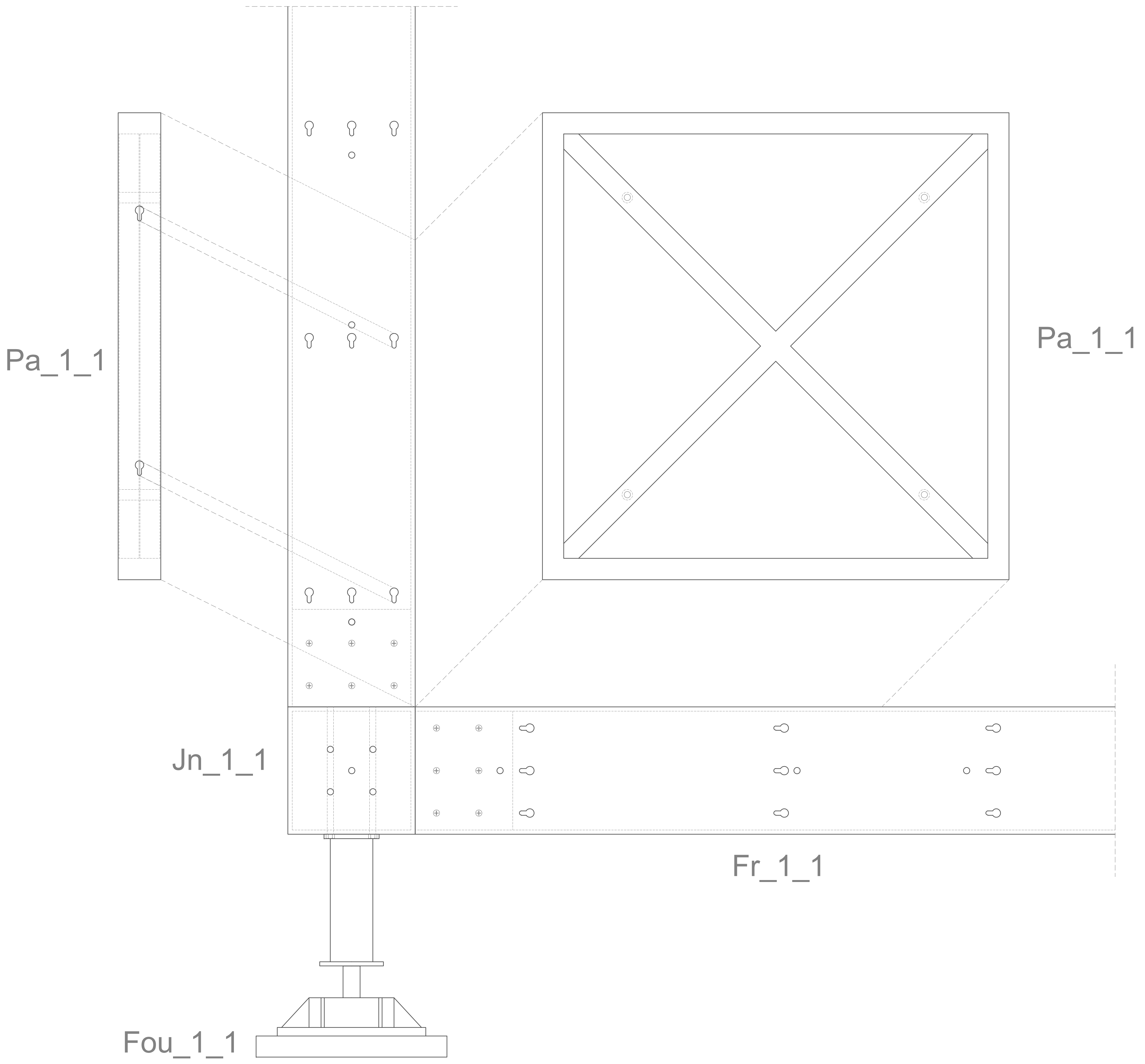
BM 02

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Detail connection:
Joint (Jn_1_1)
Beam (Fr_1_1)
Column (Fr_1_1)
Foundation (Fou_1_1)
Panel (Pa_1_1)



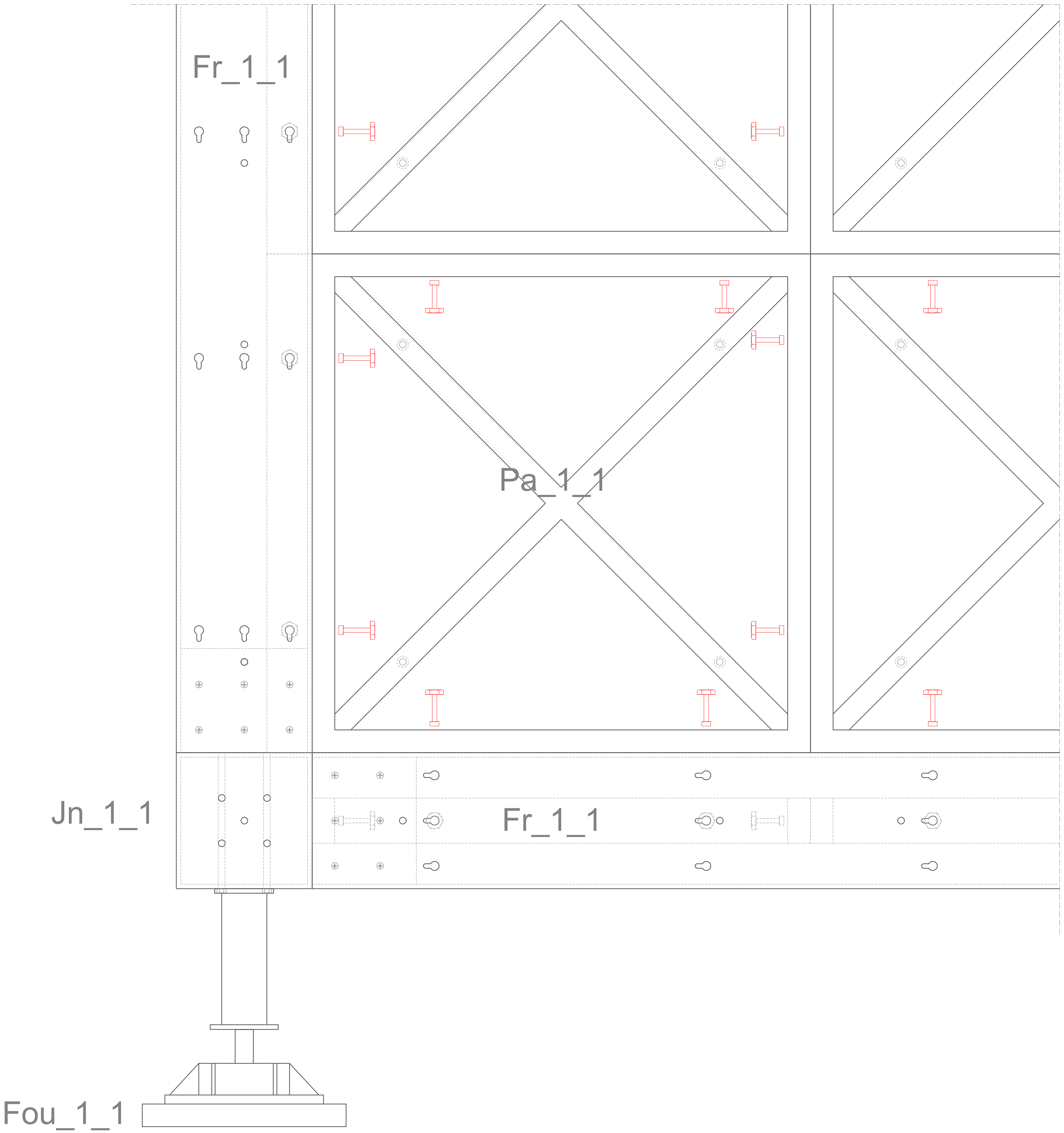
BM 03

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 01



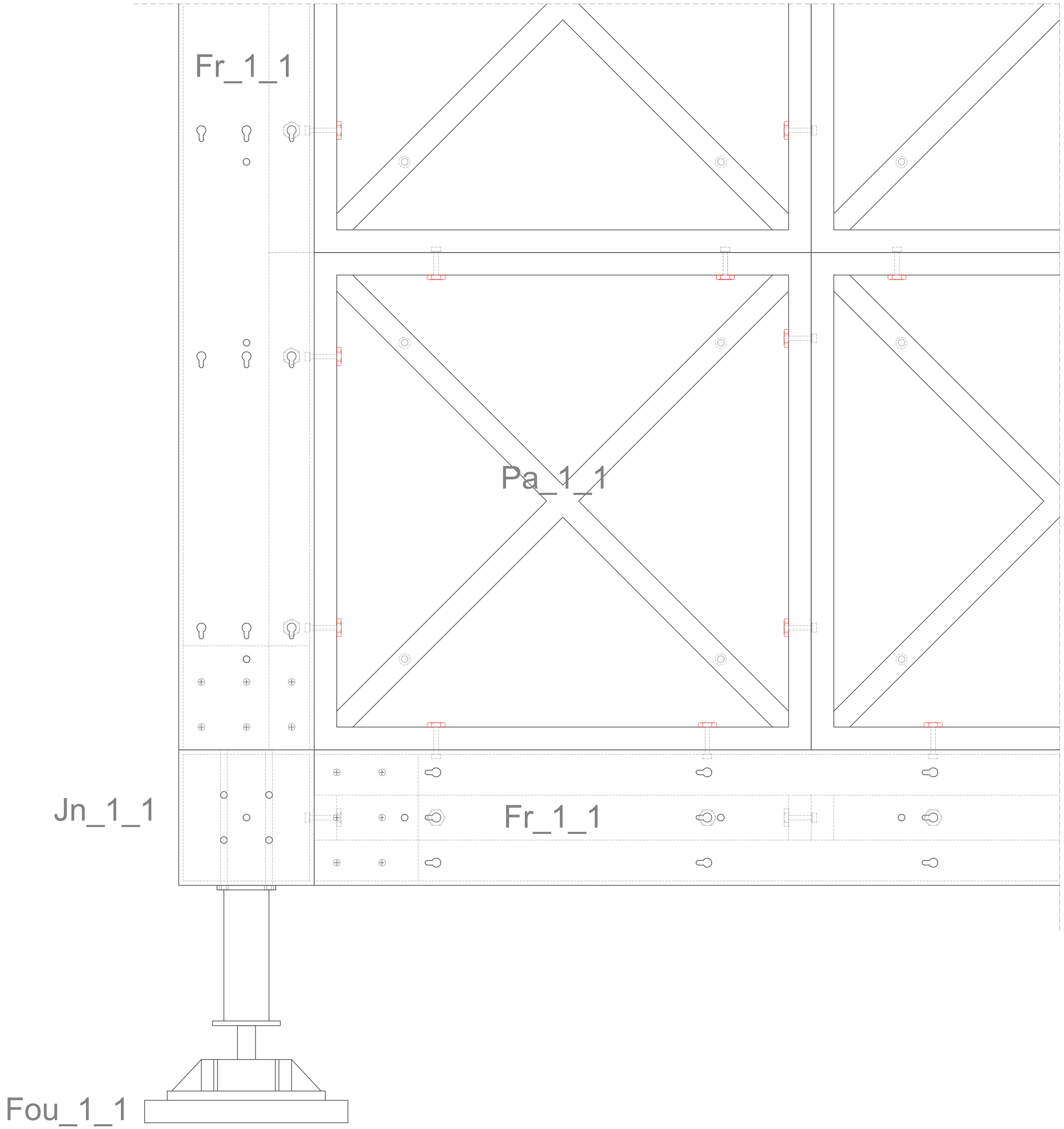
BM 04

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 02



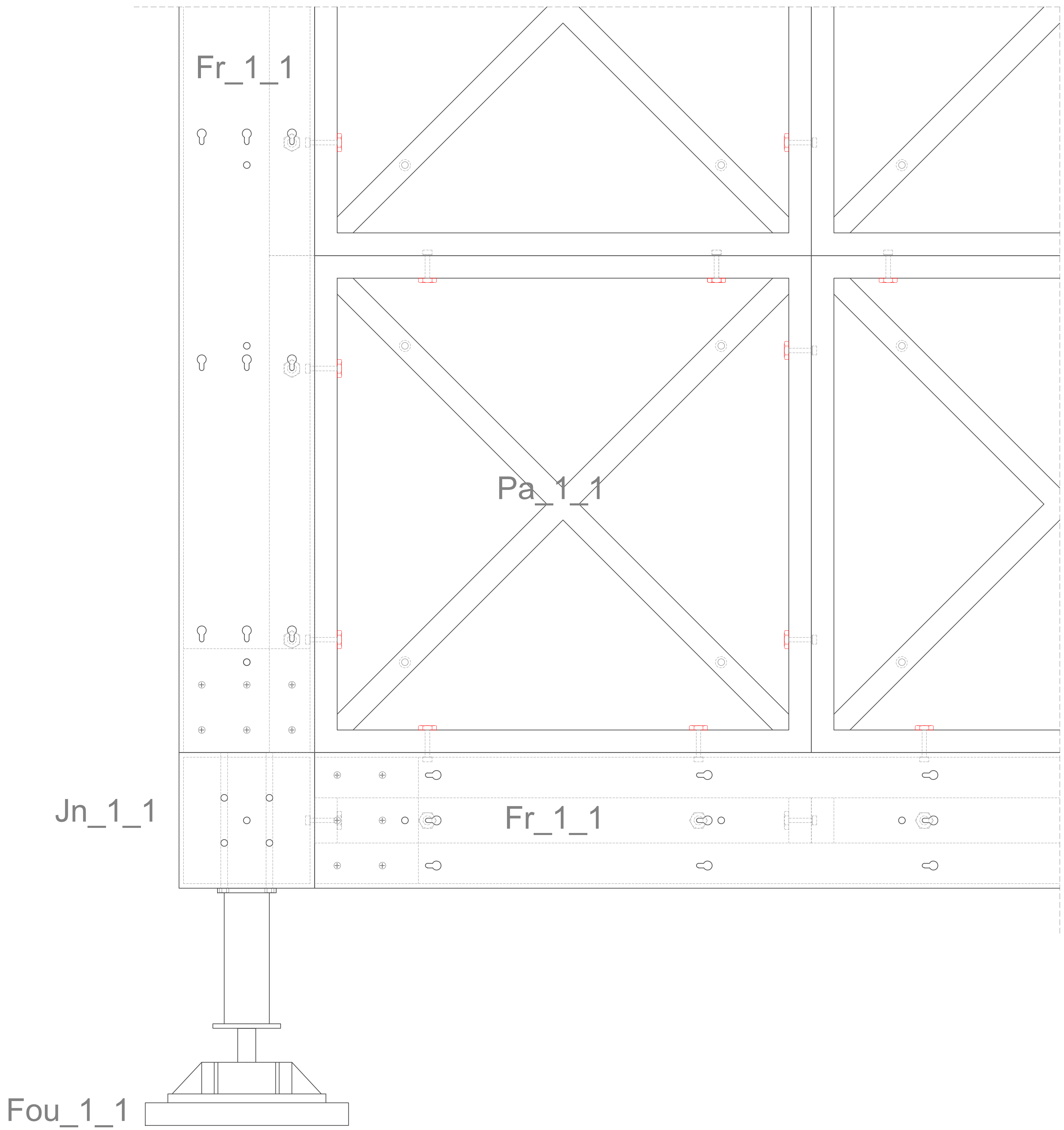
BM 05

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 03



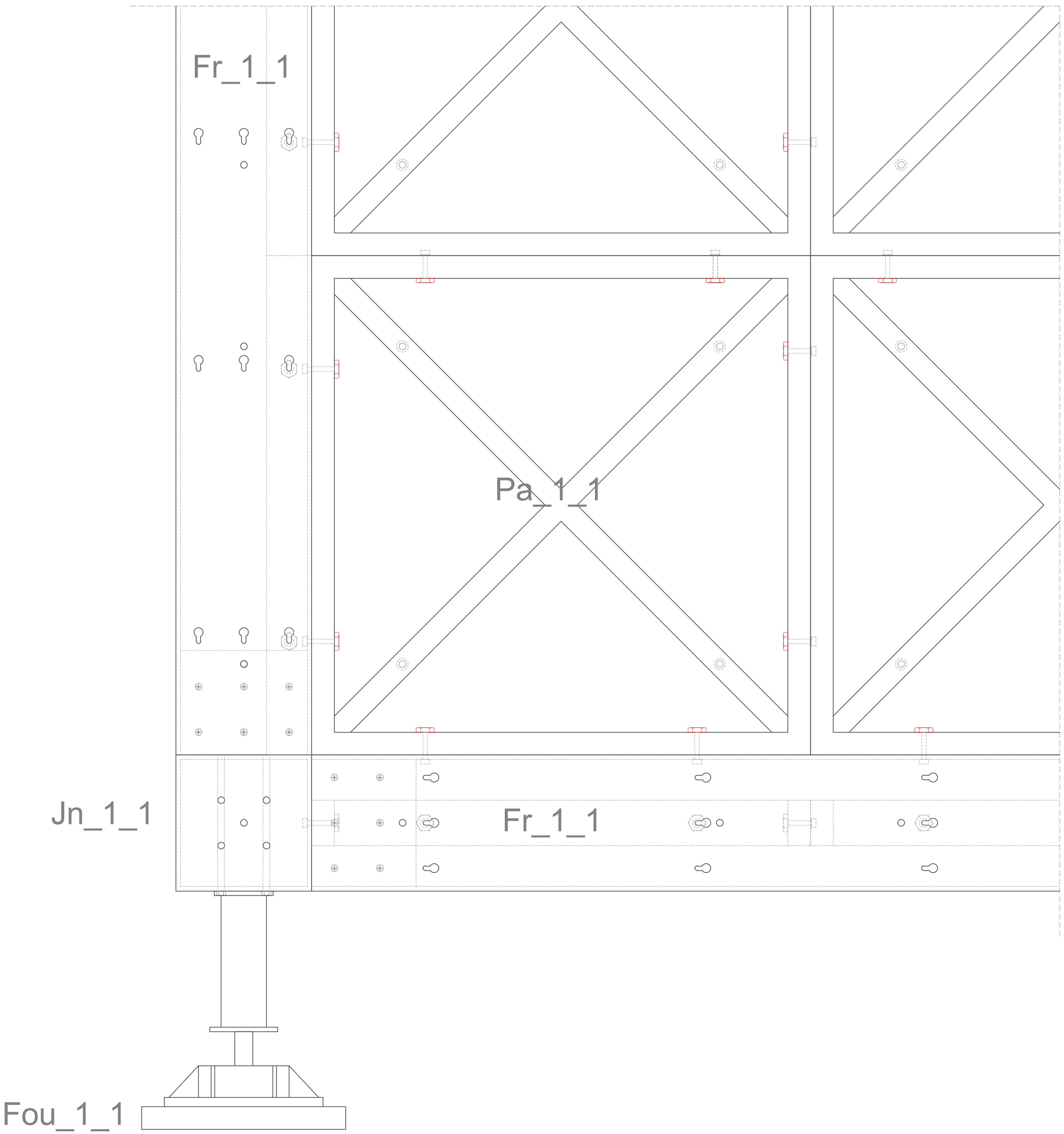
BM 06

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 04



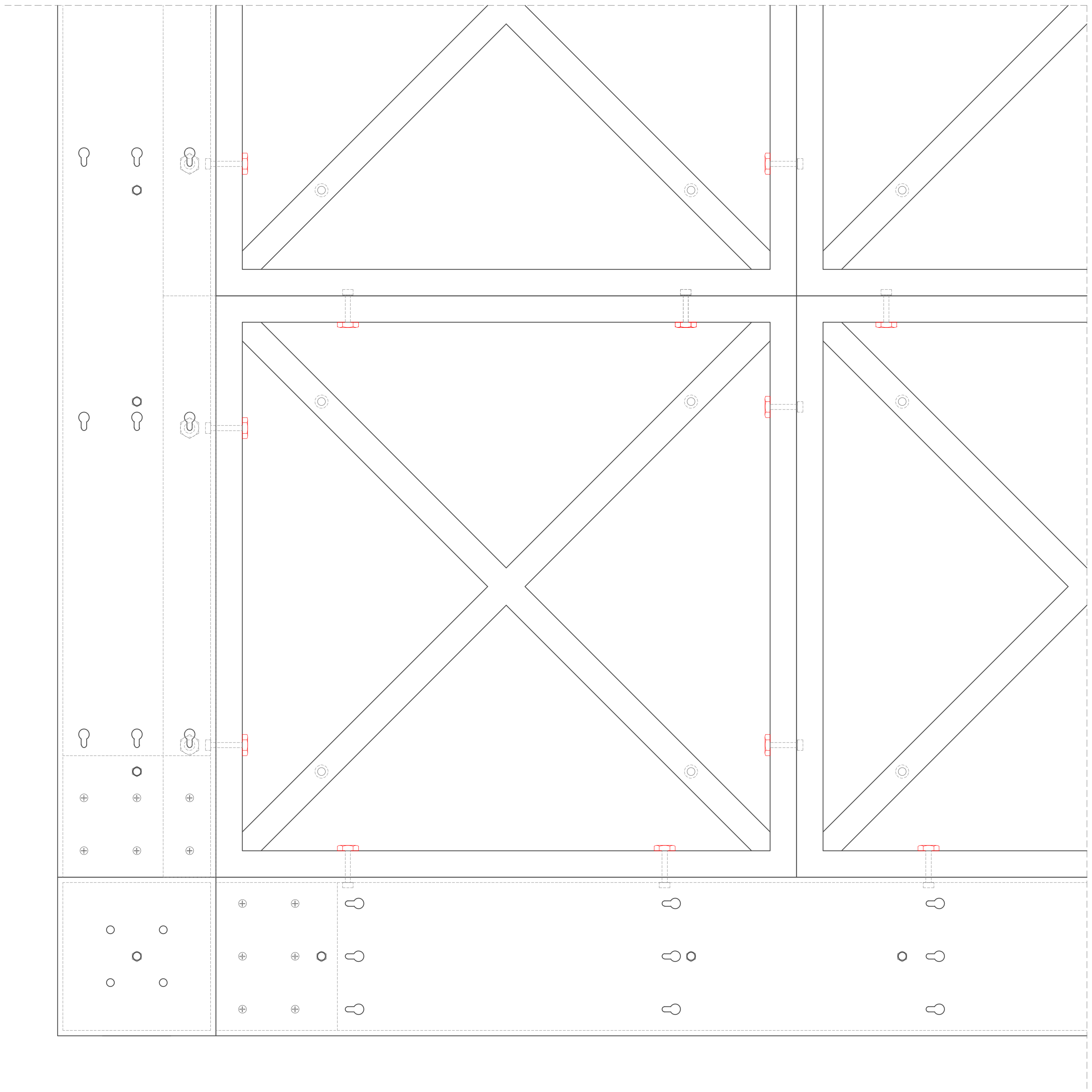
BM 07

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 05



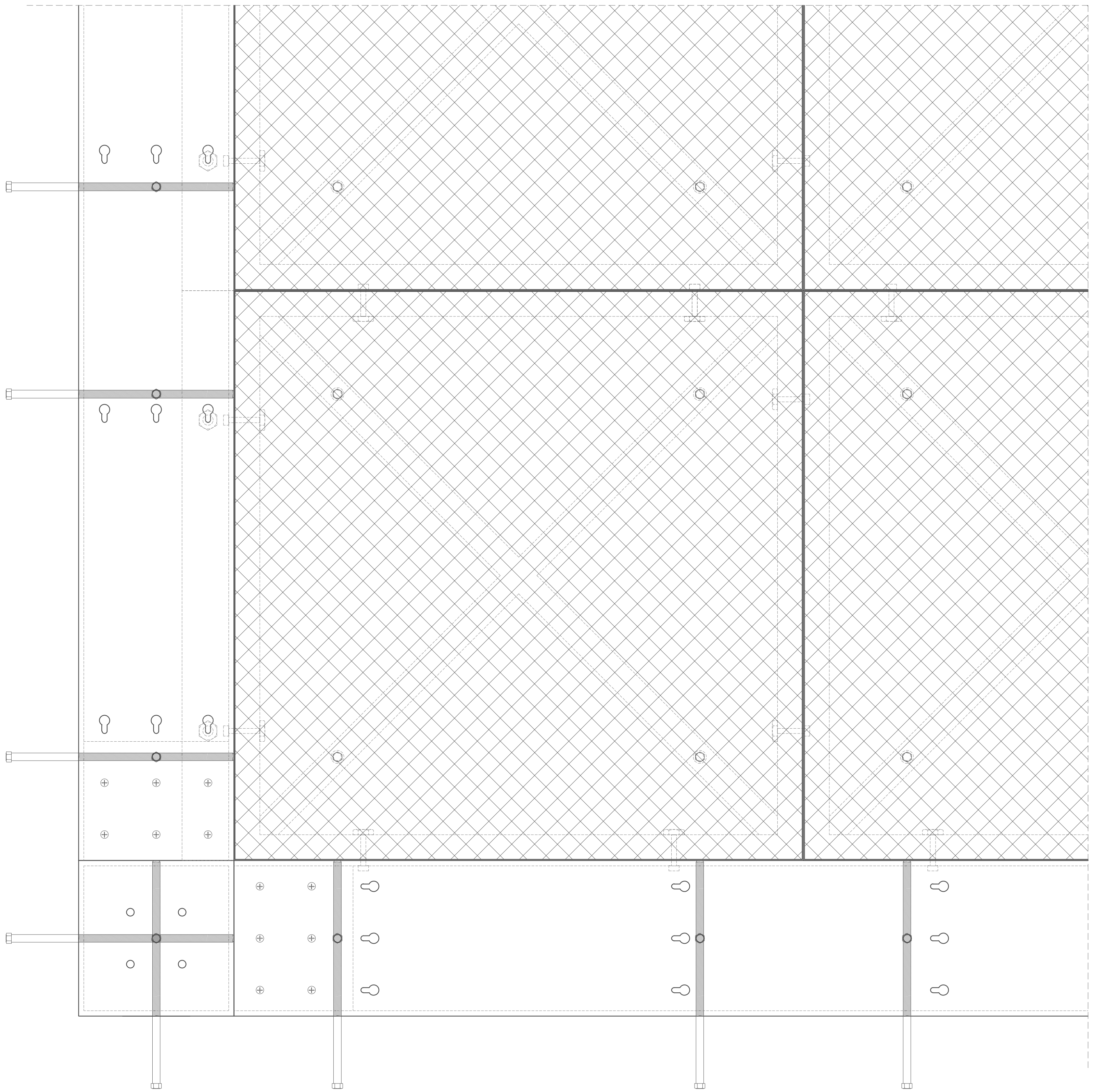
BM 08

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 06



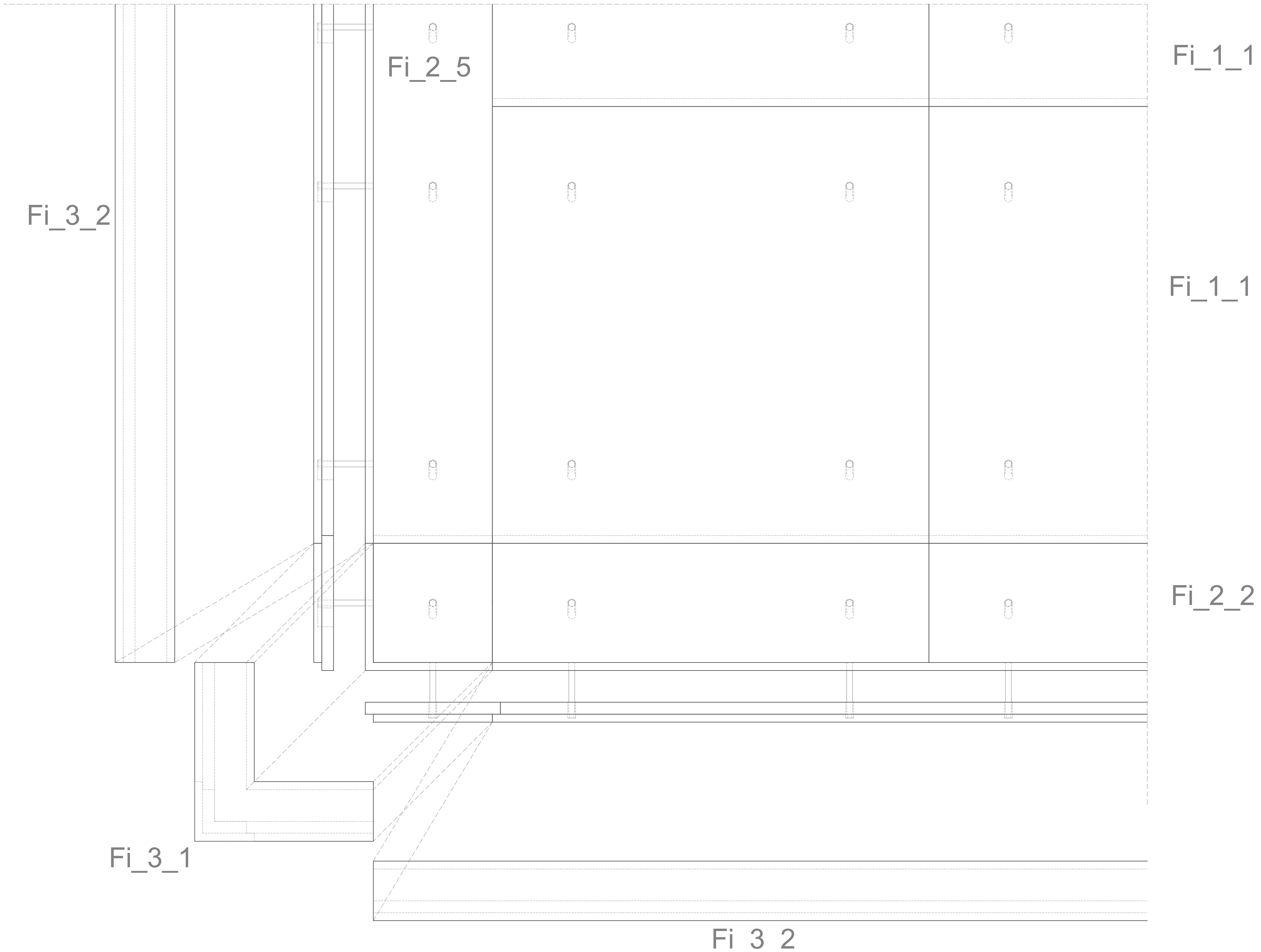
BM 09

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Finishing assembly sequence



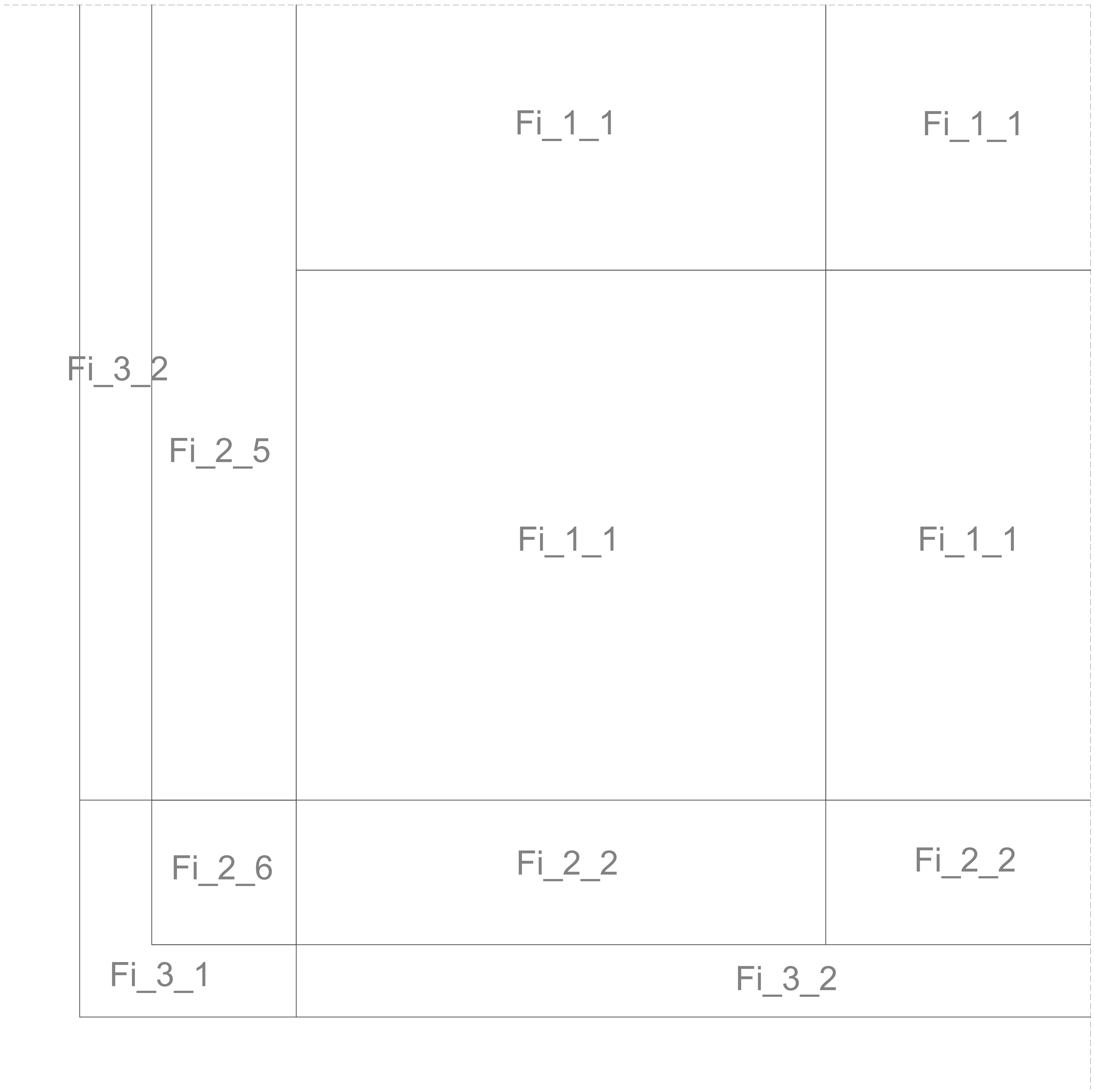
BM 10

METAL SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Finishing complete



7.2.2. **Assembly Instructions – Metal**

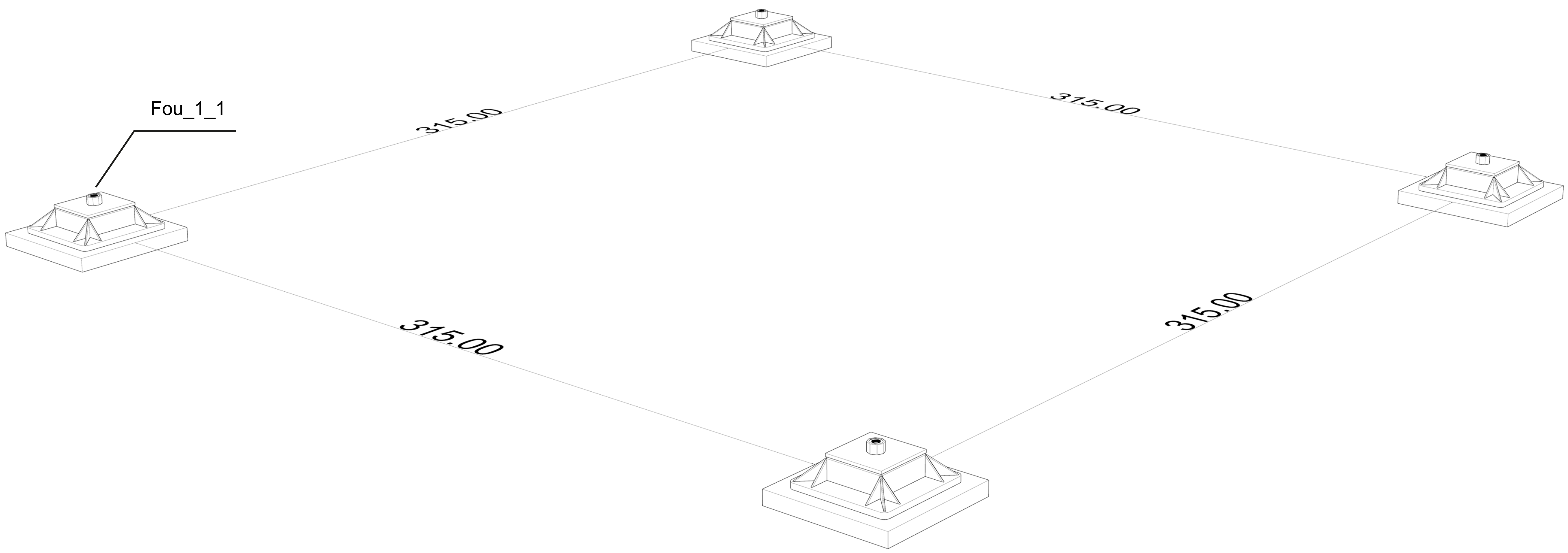
CM 01

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_1

Foundations placement



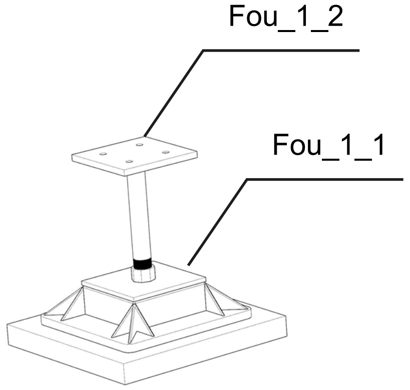
CM 02

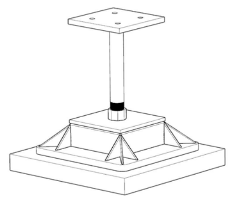
METAL SYSTEM

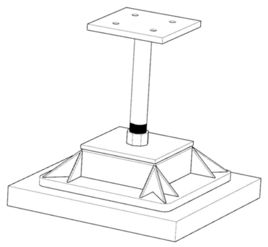
ASSEMBLY INSTRUCTIONS

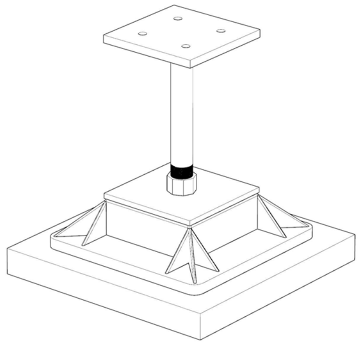
Fou_1_1
Fou_1_2

Framework-foundations junctions

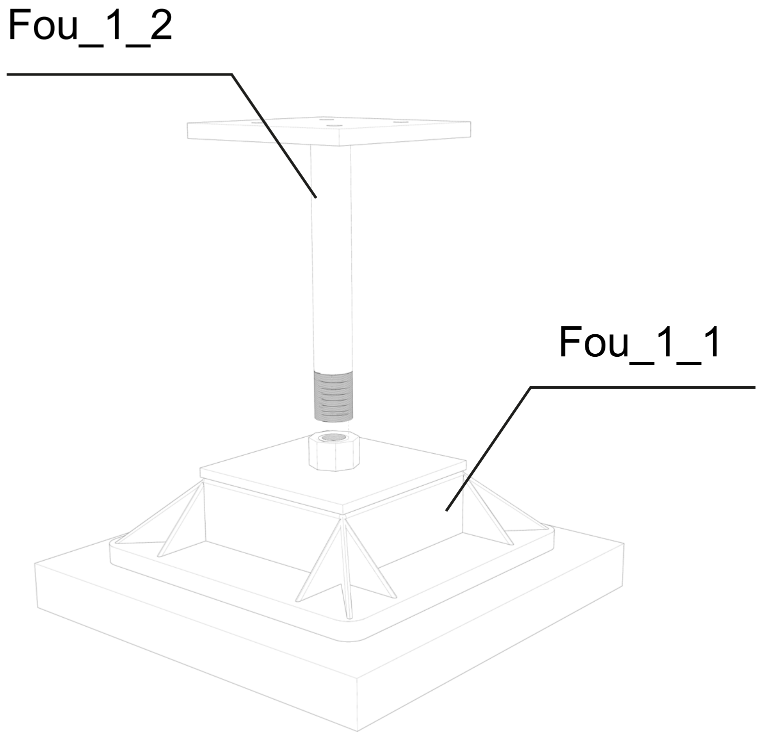








DETAILS



CM 03

METAL SYSTEM

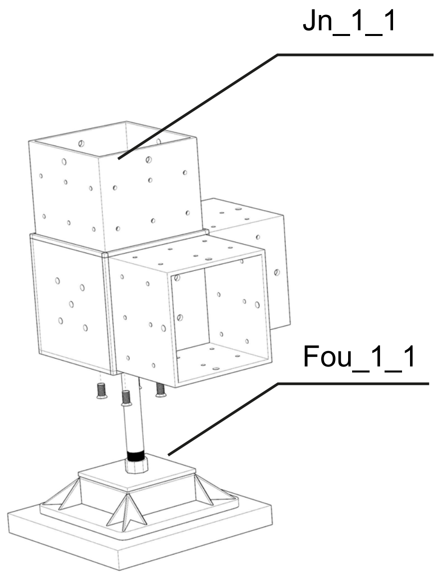
ASSEMBLY INSTRUCTIONS

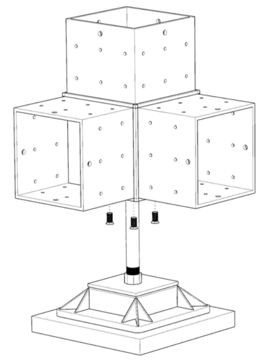
Fou_1_2

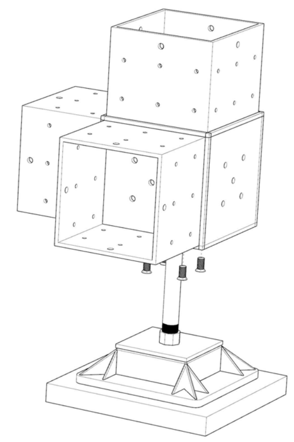
Fou_1_1

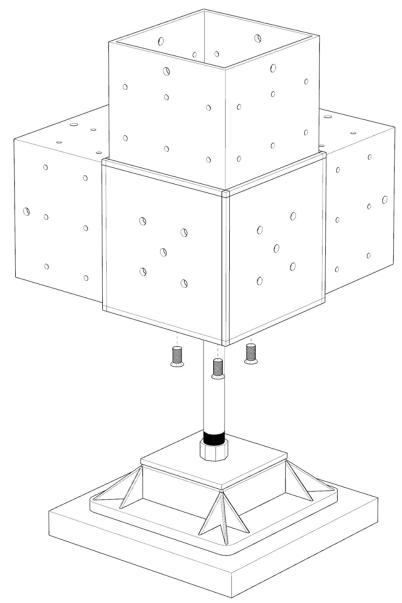
Jn_1_1

Structural junctions

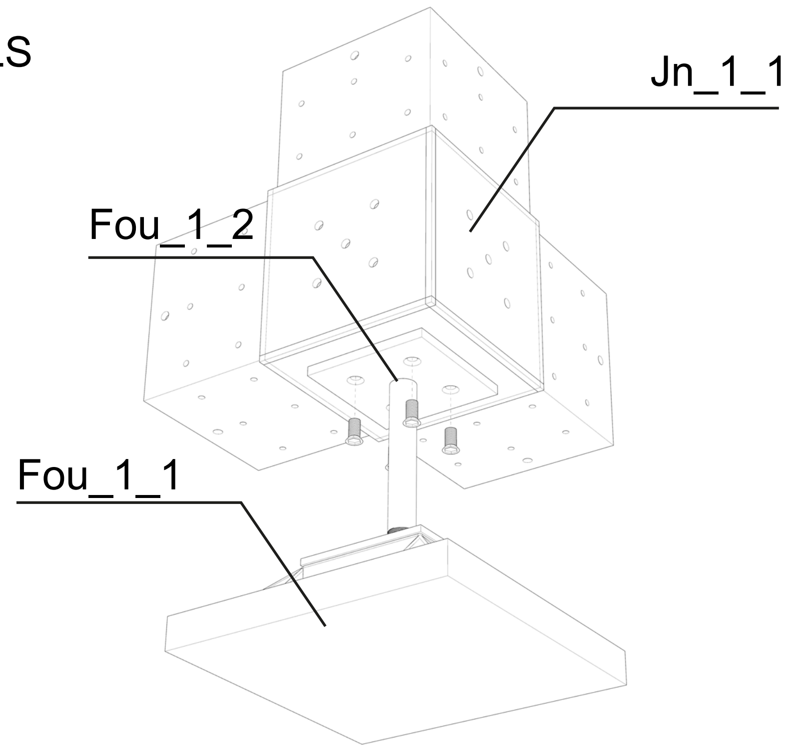








DETAILS



CM 04

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

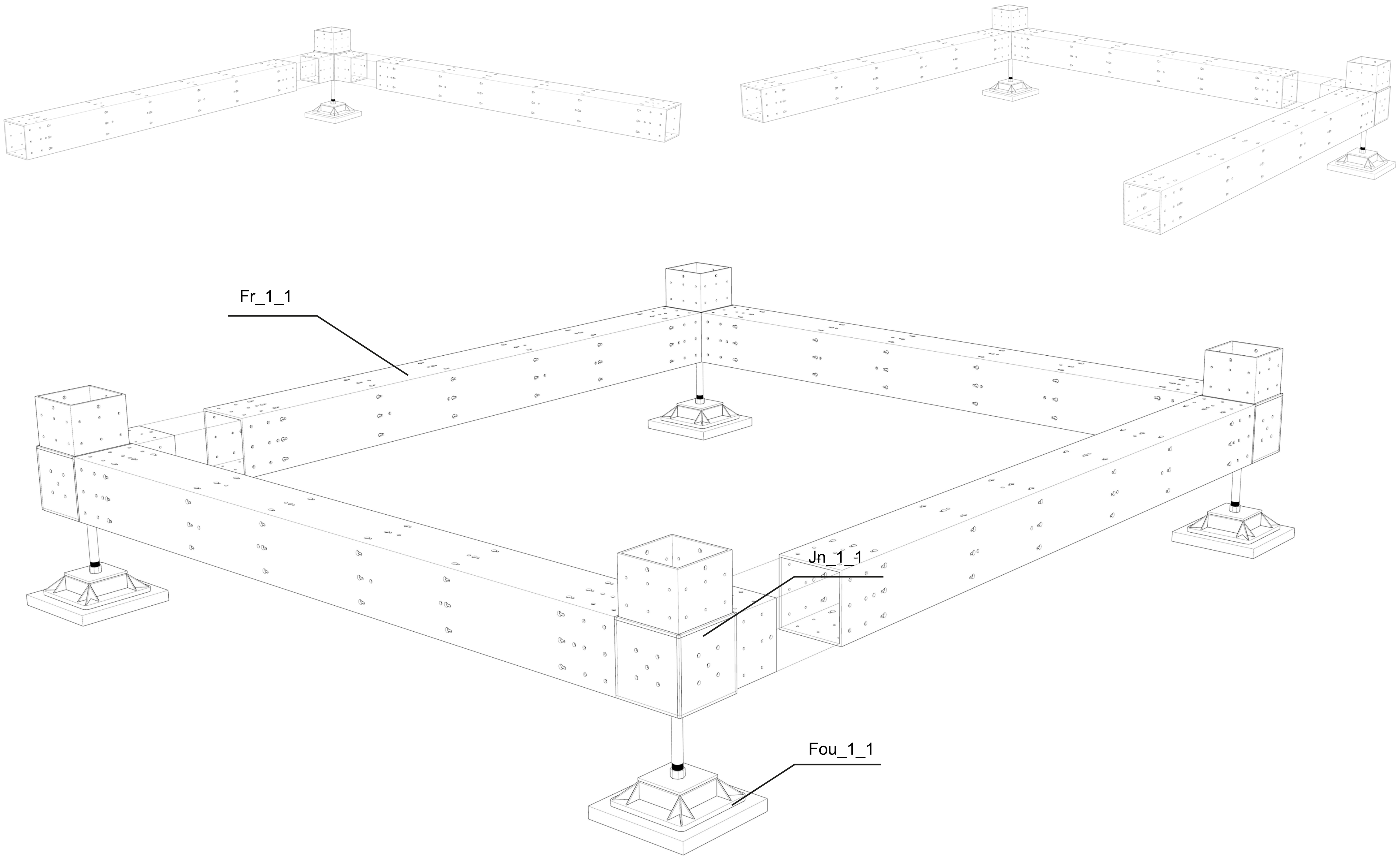
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Beeams framework assembly



CM 05

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

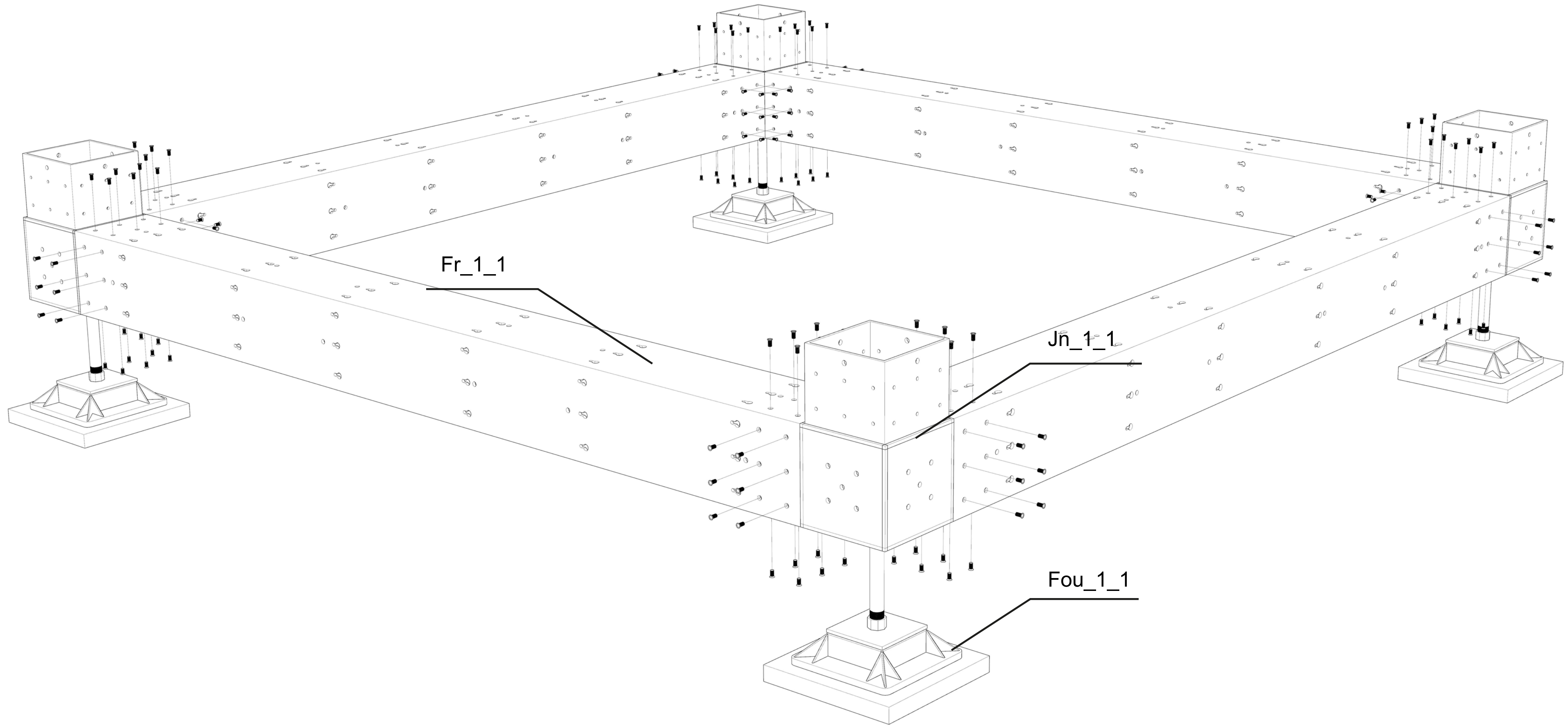
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Base framework



CM 06

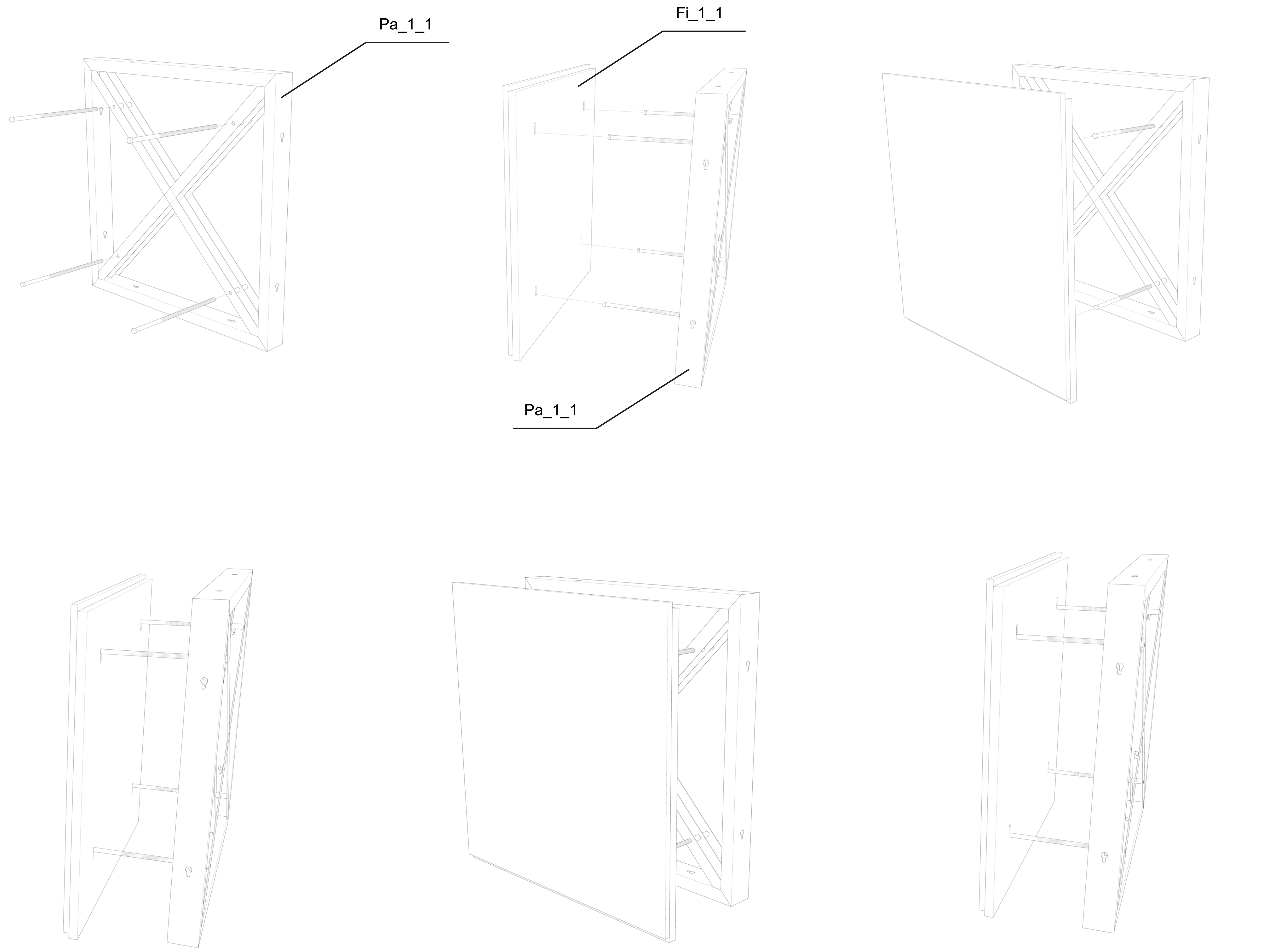
METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Pa_1_1

Fi_1_1

Panel + finishing assembly



CM 07

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

Fou_1_1

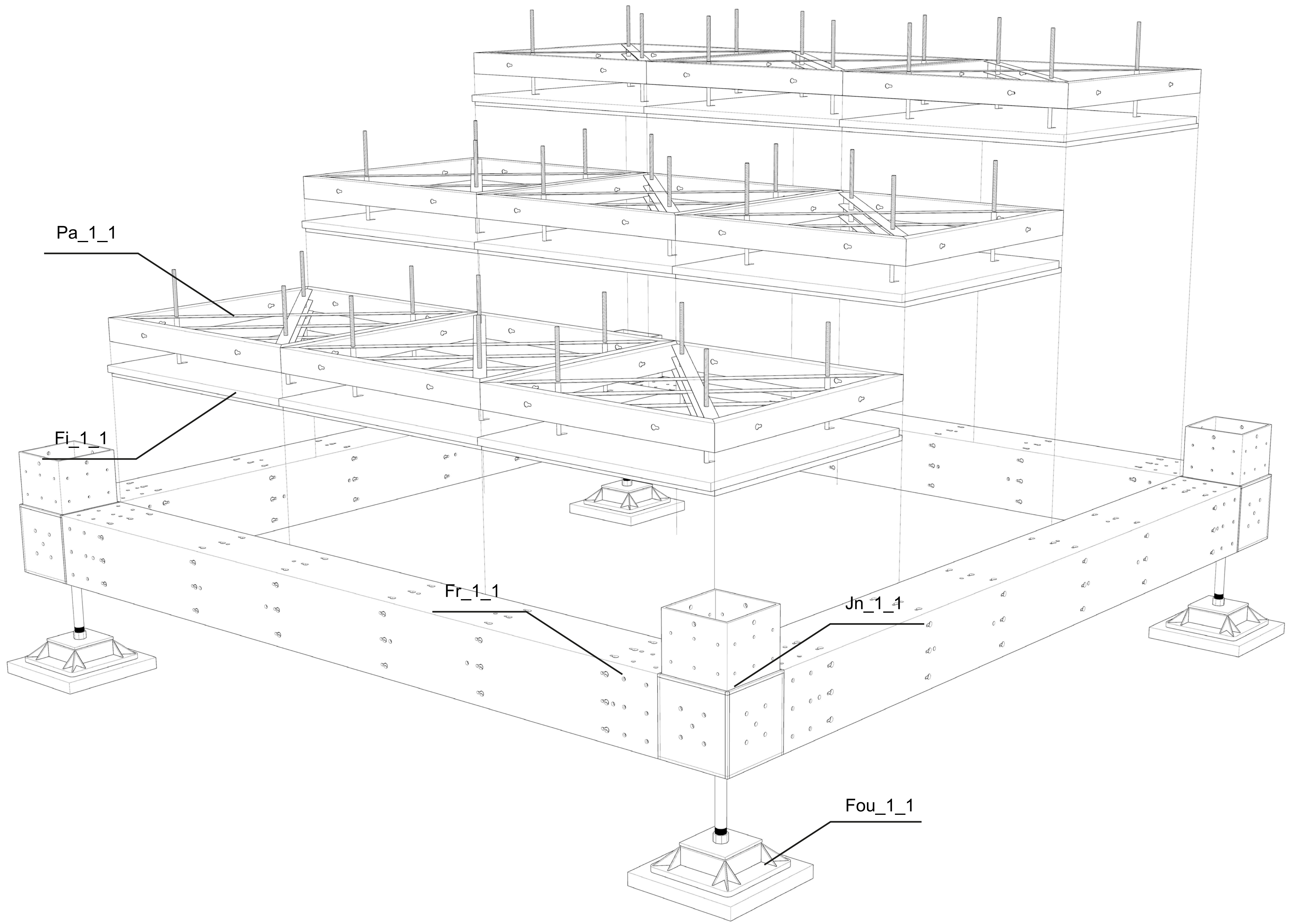
Jn_1_1

Fr_1_1

Pa_1_1

Fi_1_1

Floor structural panel + external finishing



CM 08

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

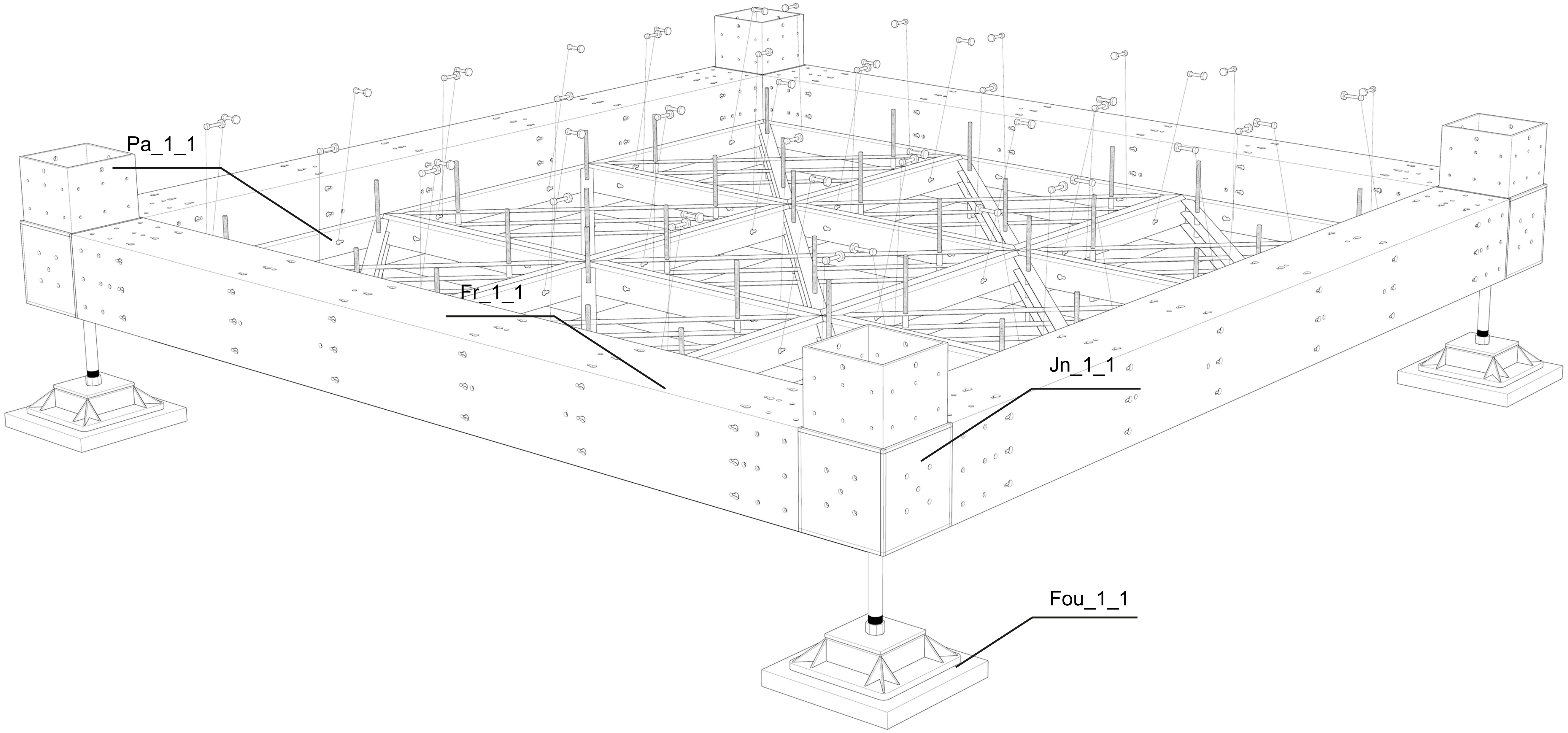
Fou_1_1

Jn_1_1

Fr_1_1

Pa_1_1

Metalware junction of the floor panel



CM 09

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

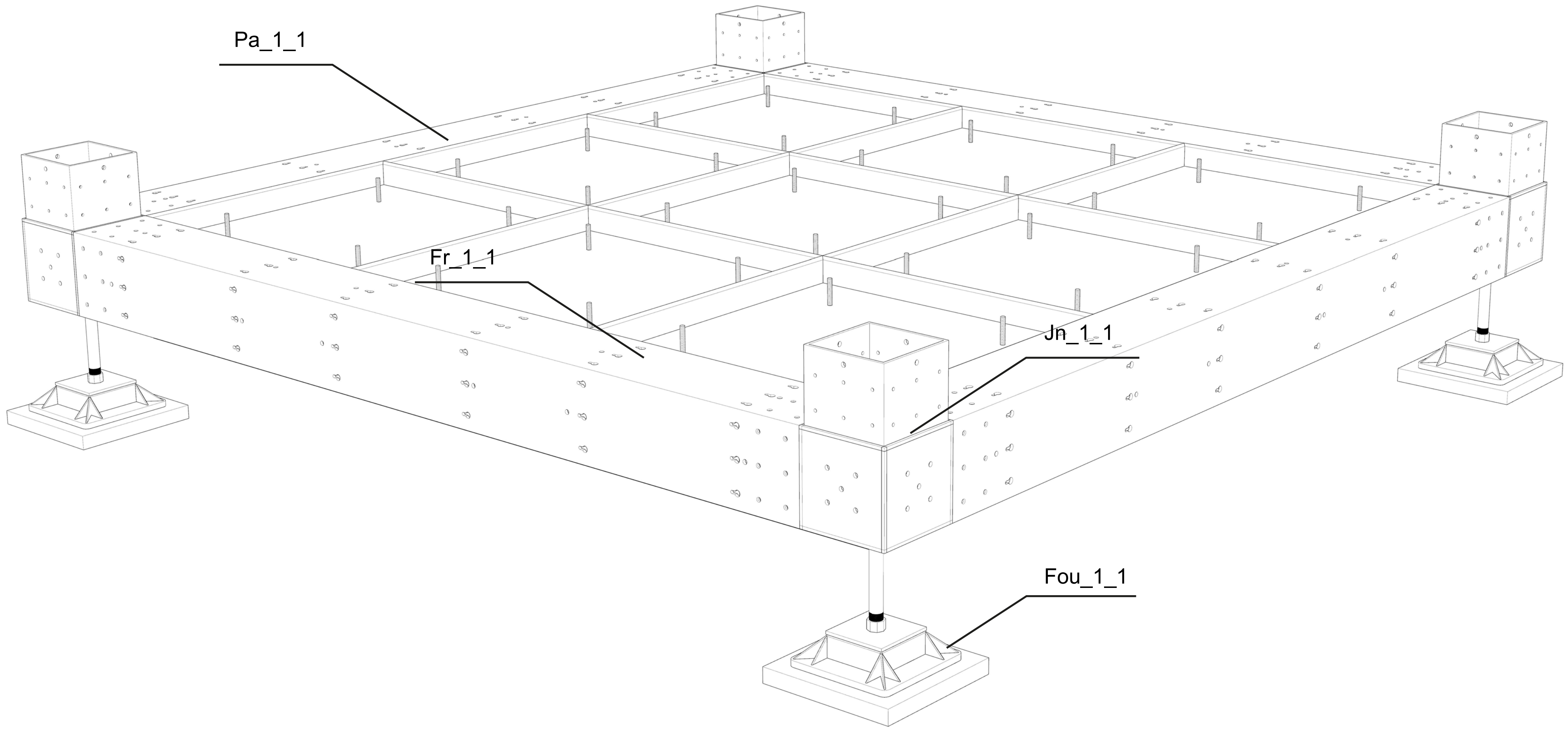
Fou_1_1

Jn_1_1

Fr_1_1

Pa_1_1

Panel cladding - Insulation/
Thermal Mass floor



CM 10

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

Fou_1_1

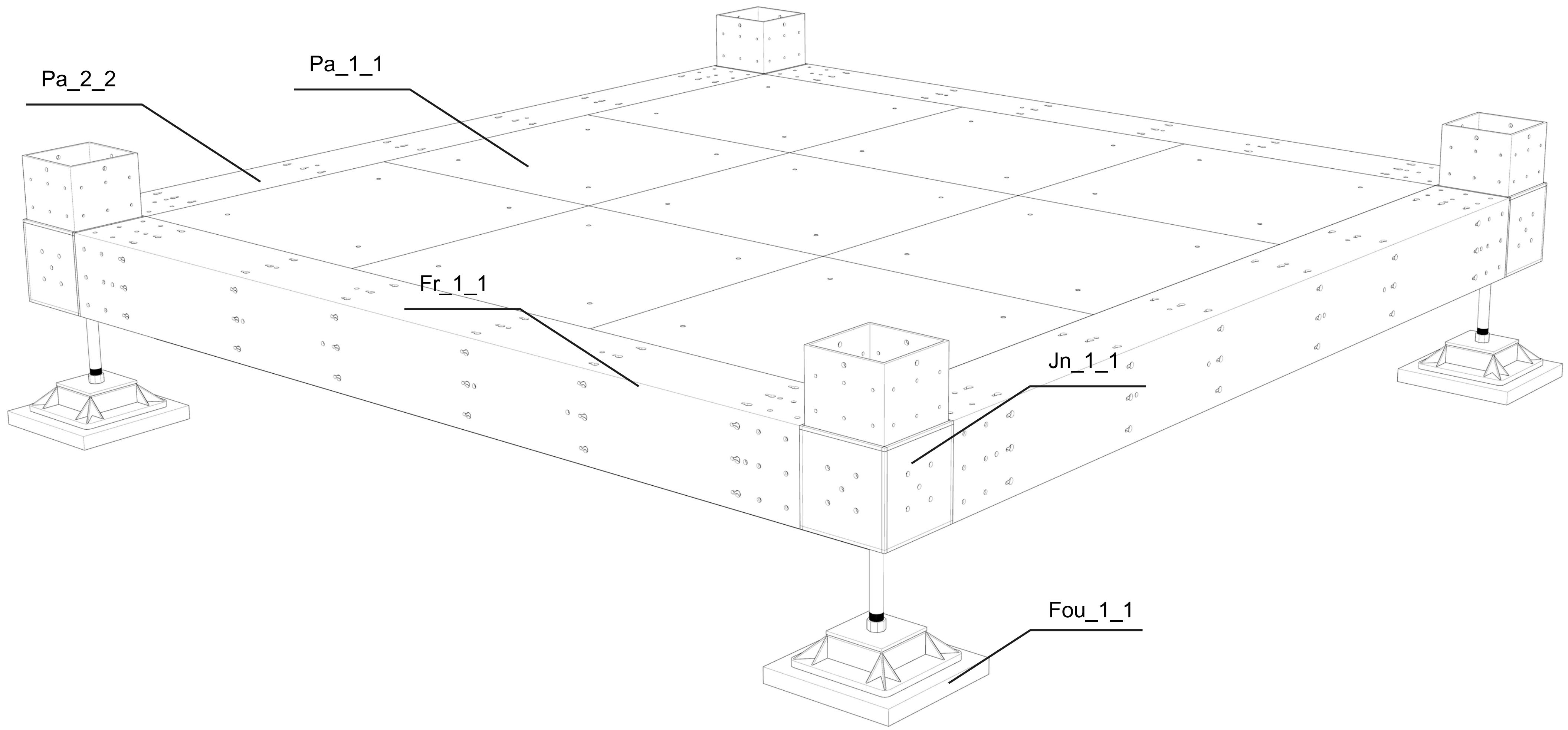
Jn_1_1

Fr_1_1

Pa_1_1

Pa_2_2

Internal finishing of the floor



CM 11

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

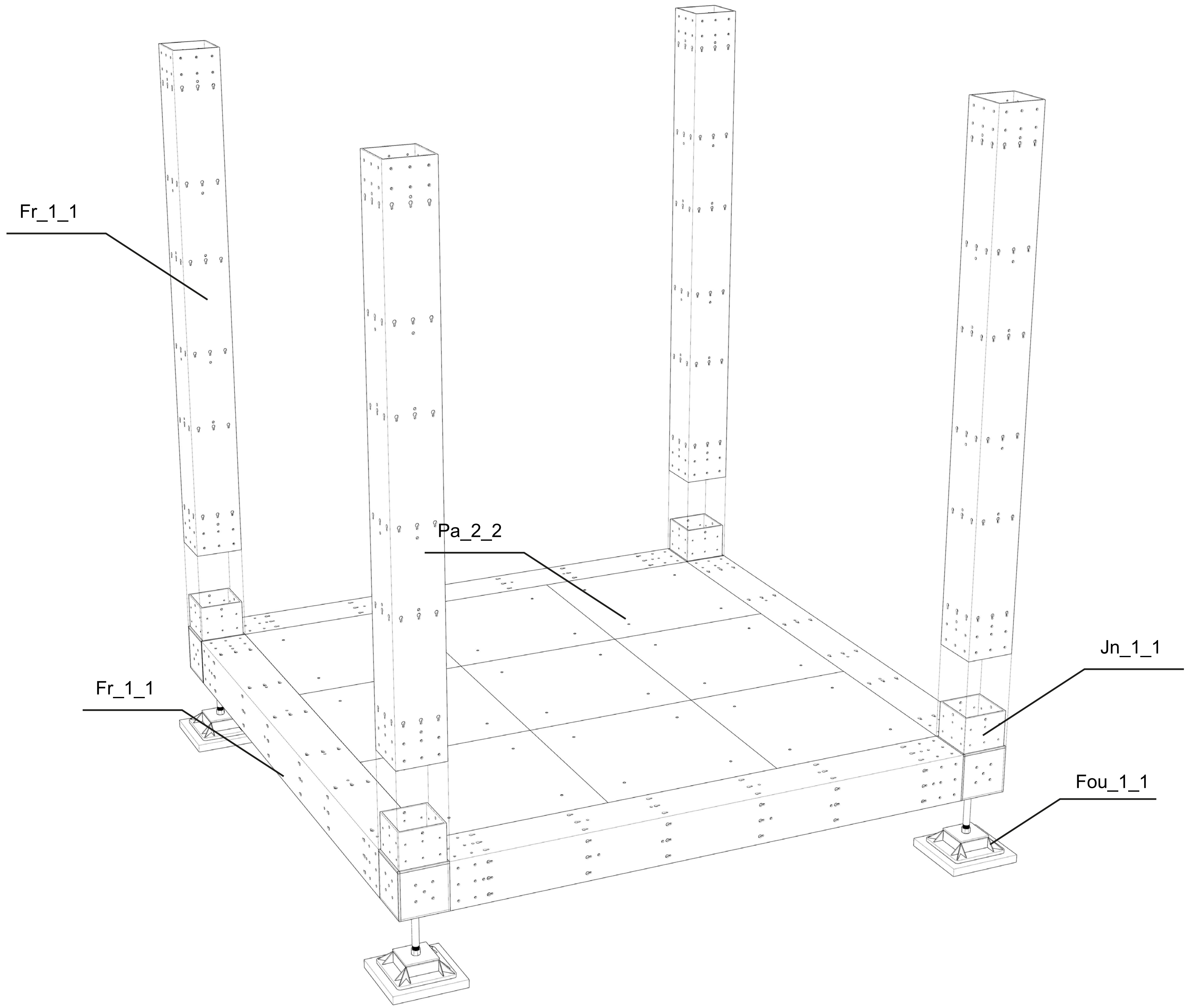
Fou_1_1

Jn_1_1

Fr_1_1

Pa_2_2

Columns



CM 12

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

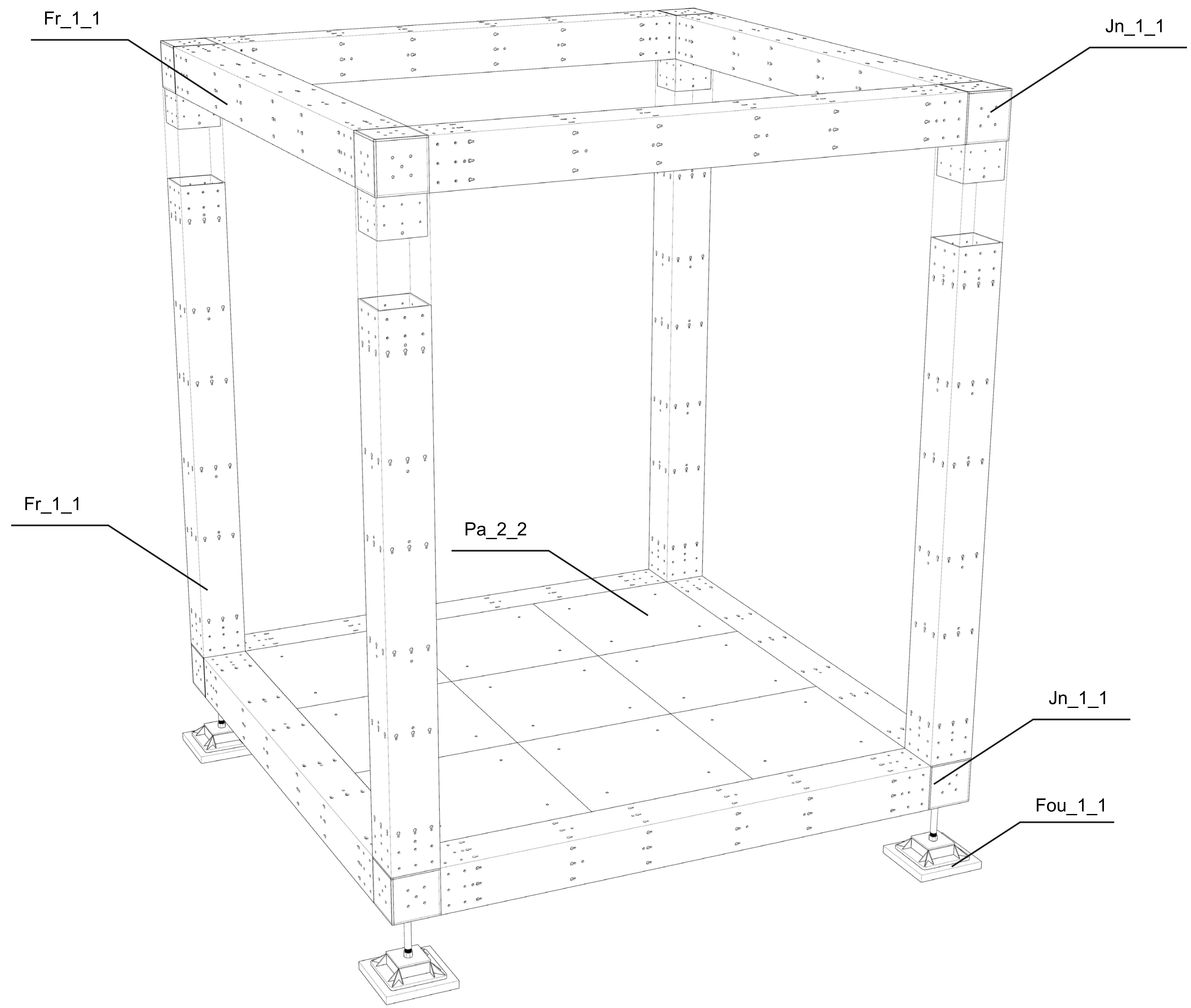
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Upper framework



CM 13

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

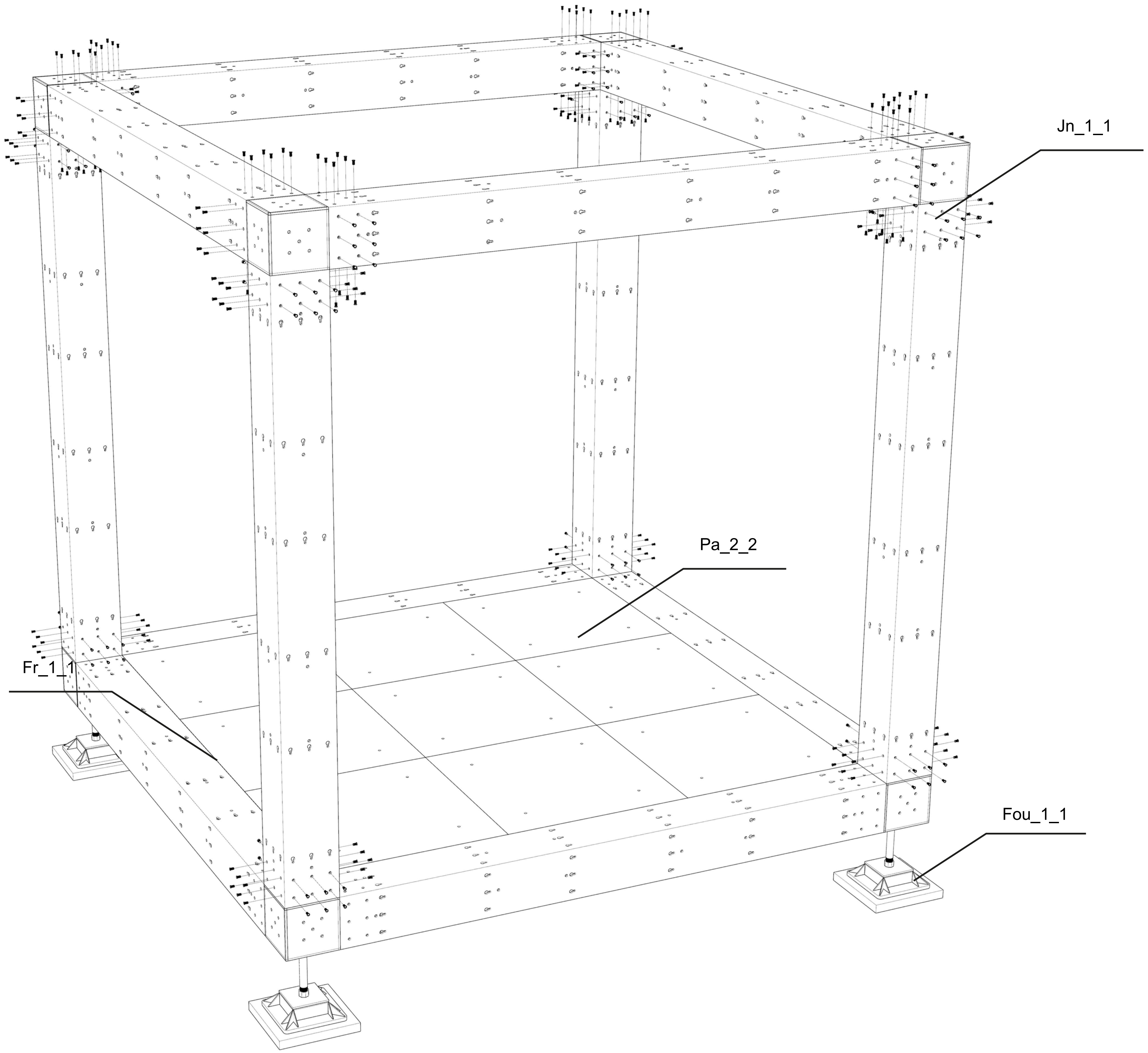
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1 Framework

locking



CM 14

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

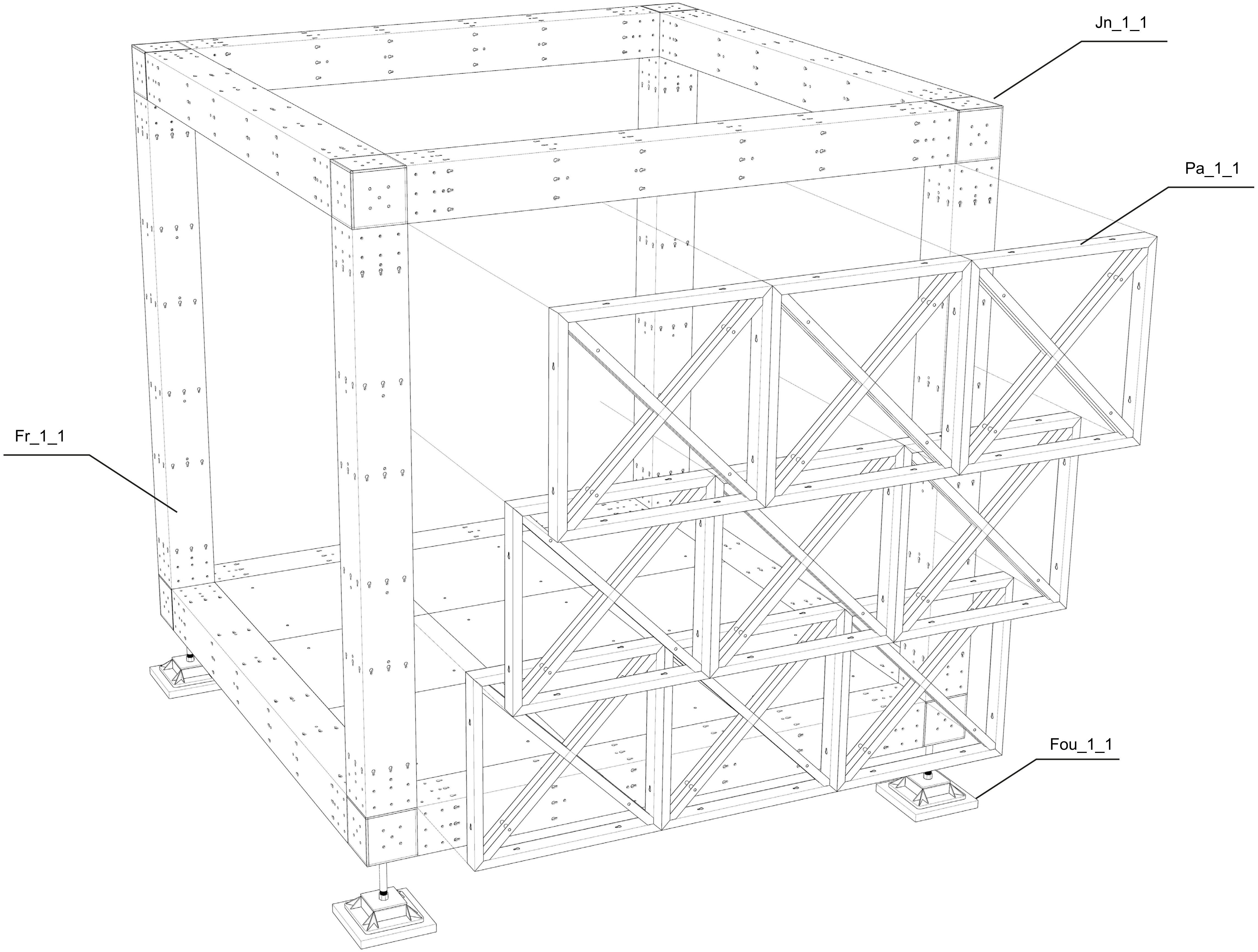
Fou_1_1

Jn_1_1

Fr_1_1

Pa_1_1

Wall panel



CM 15

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

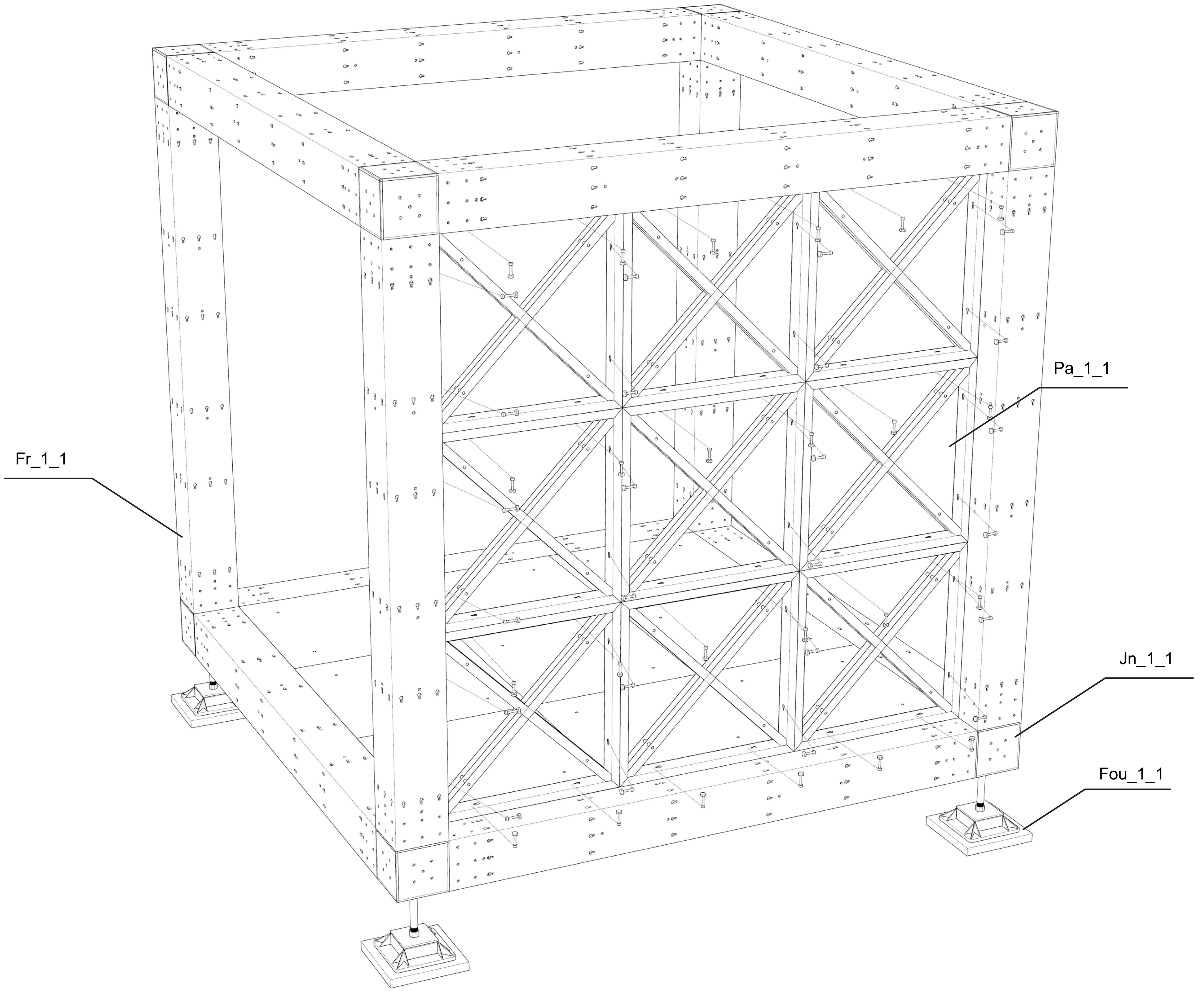
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Metalware junction of the wall panel



CM 16

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

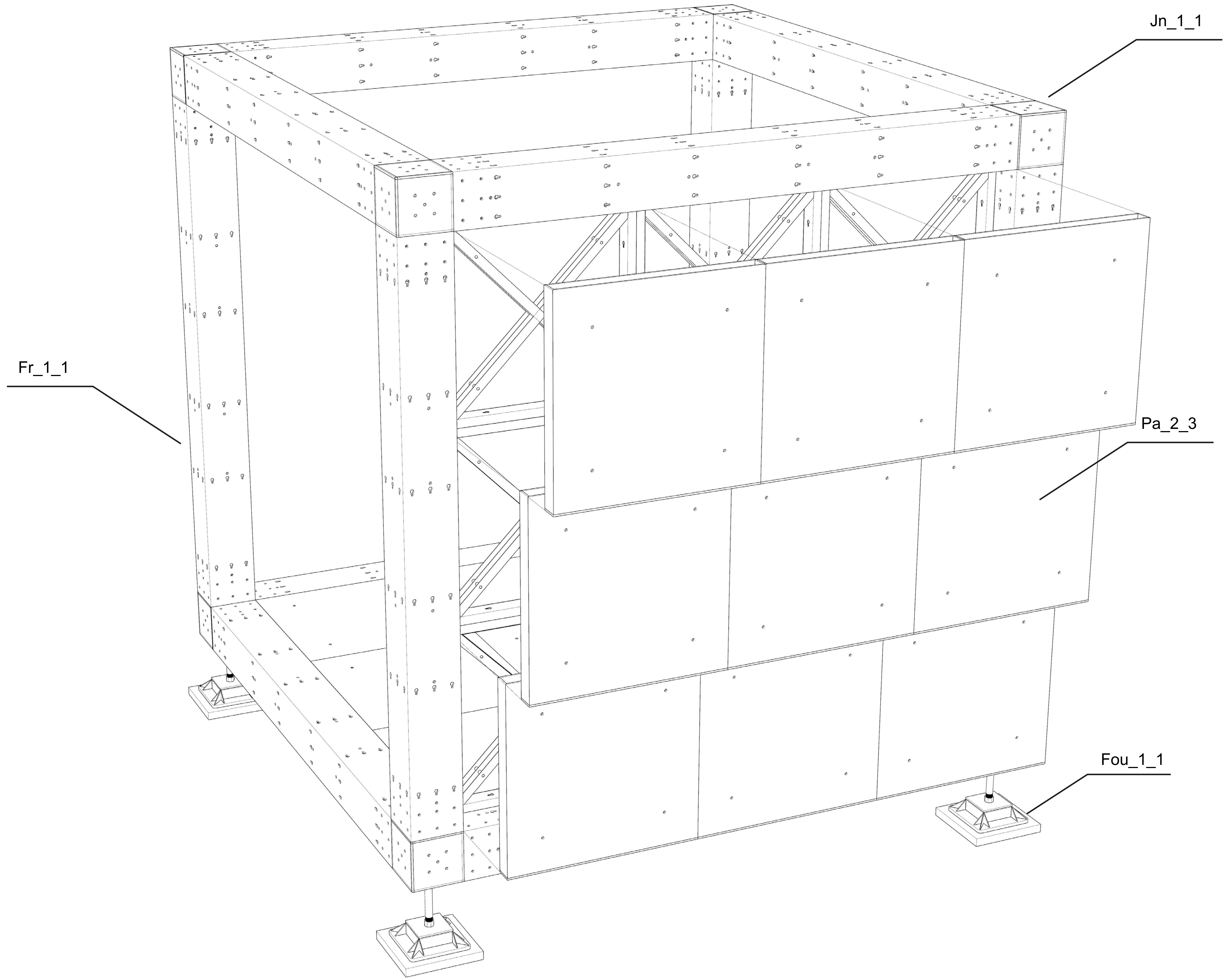
Fou_1_1

Jn_1_1

Fr_1_1

Pa_2_3

Panel cladding Thermal Mass wall



CM 17

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

Fou_1_1

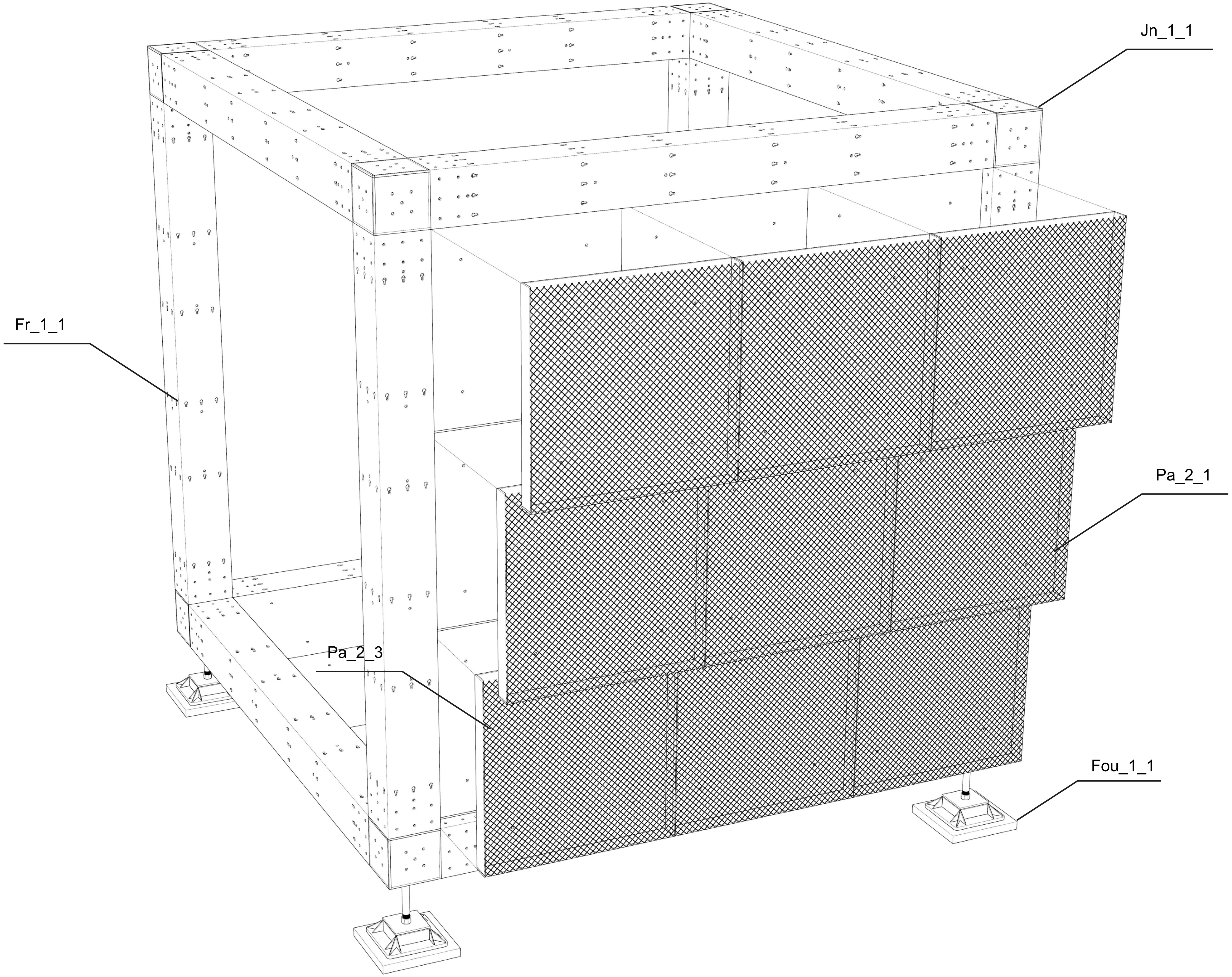
Jn_1_1

Fr_1_1

Pa_2_3

Pa_2_1

Panel cladding Insulation wall



CM 18

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

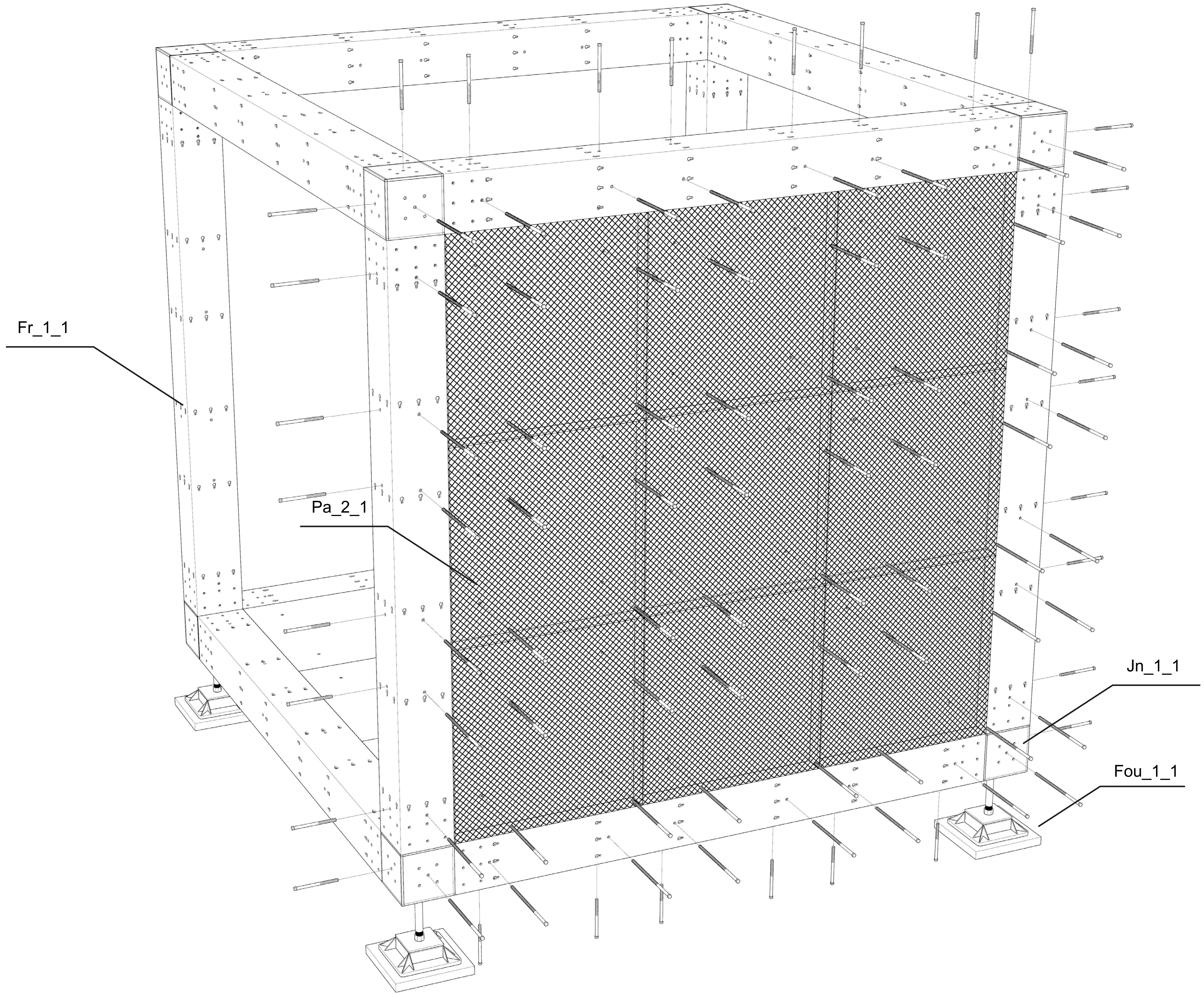
Fou_1_1

Jn_1_1

Fr_1_1

Pa_2_1

Metalware finishing structure

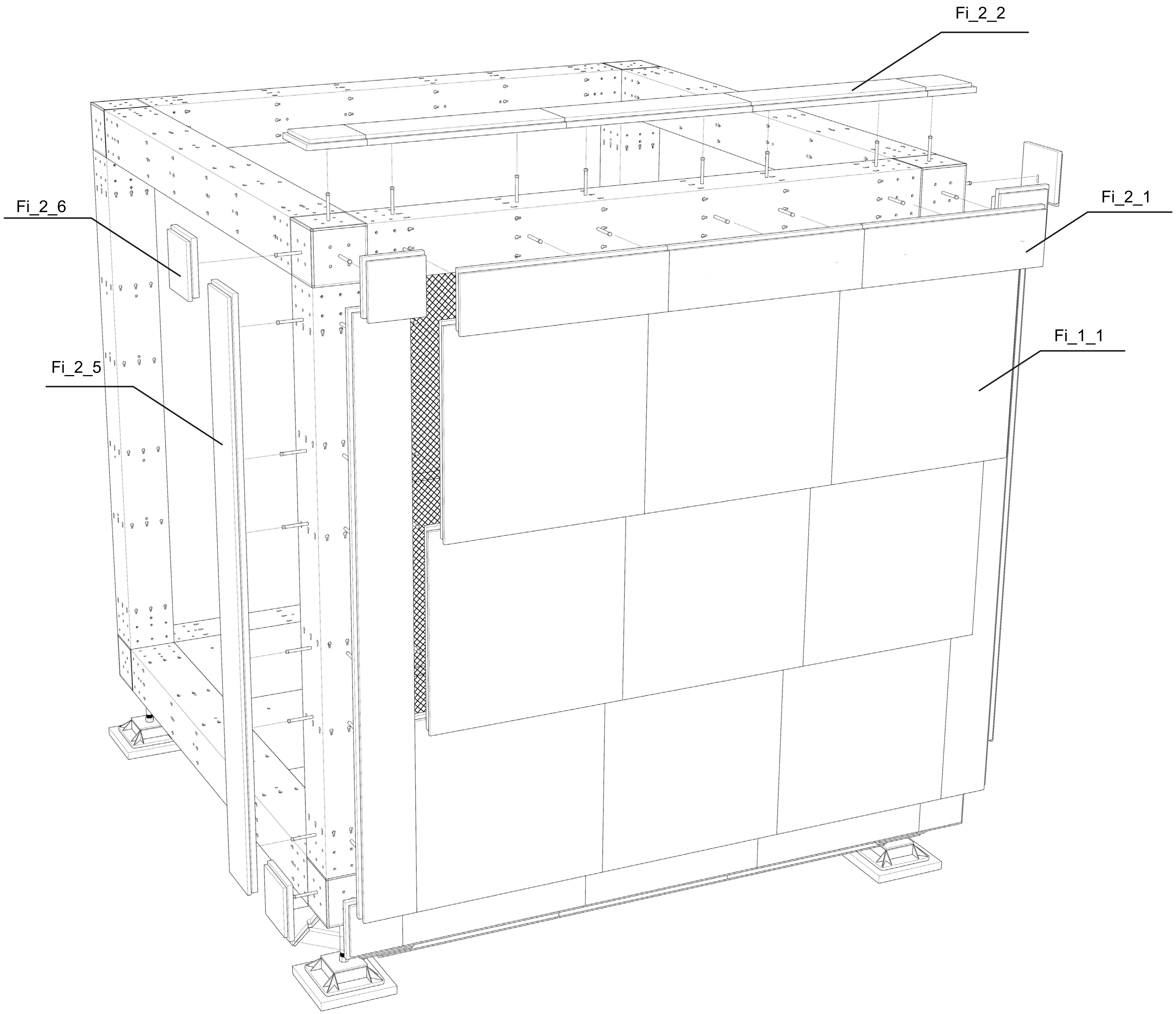


CM 19

METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fi_1_1
Fi_2_1
Fi_2_2
Fi_2_6
Fi_2_5
Finishing



CM 20

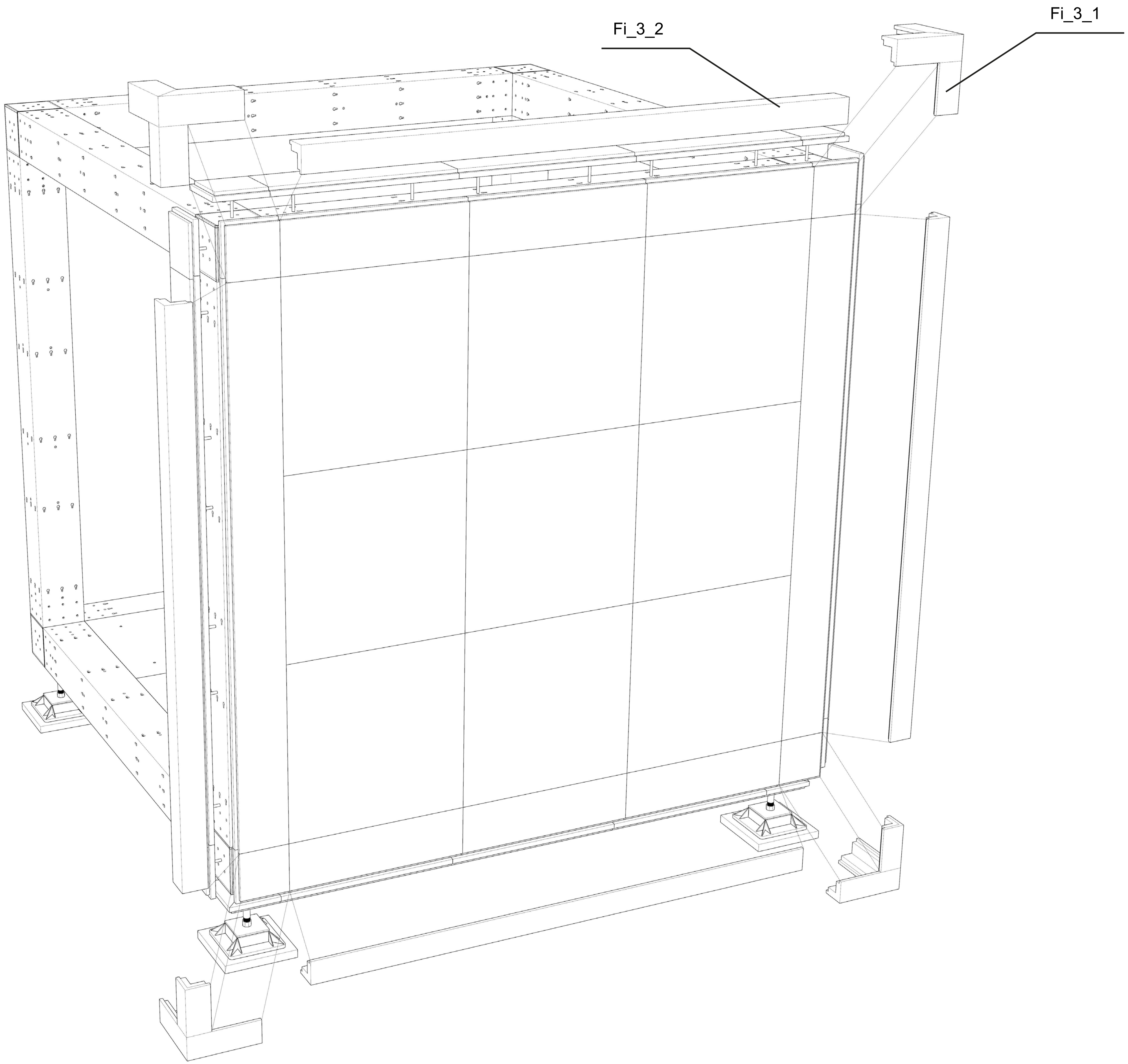
METAL SYSTEM

ASSEMBLY INSTRUCTIONS

Fi_3_1

Fi_3_2

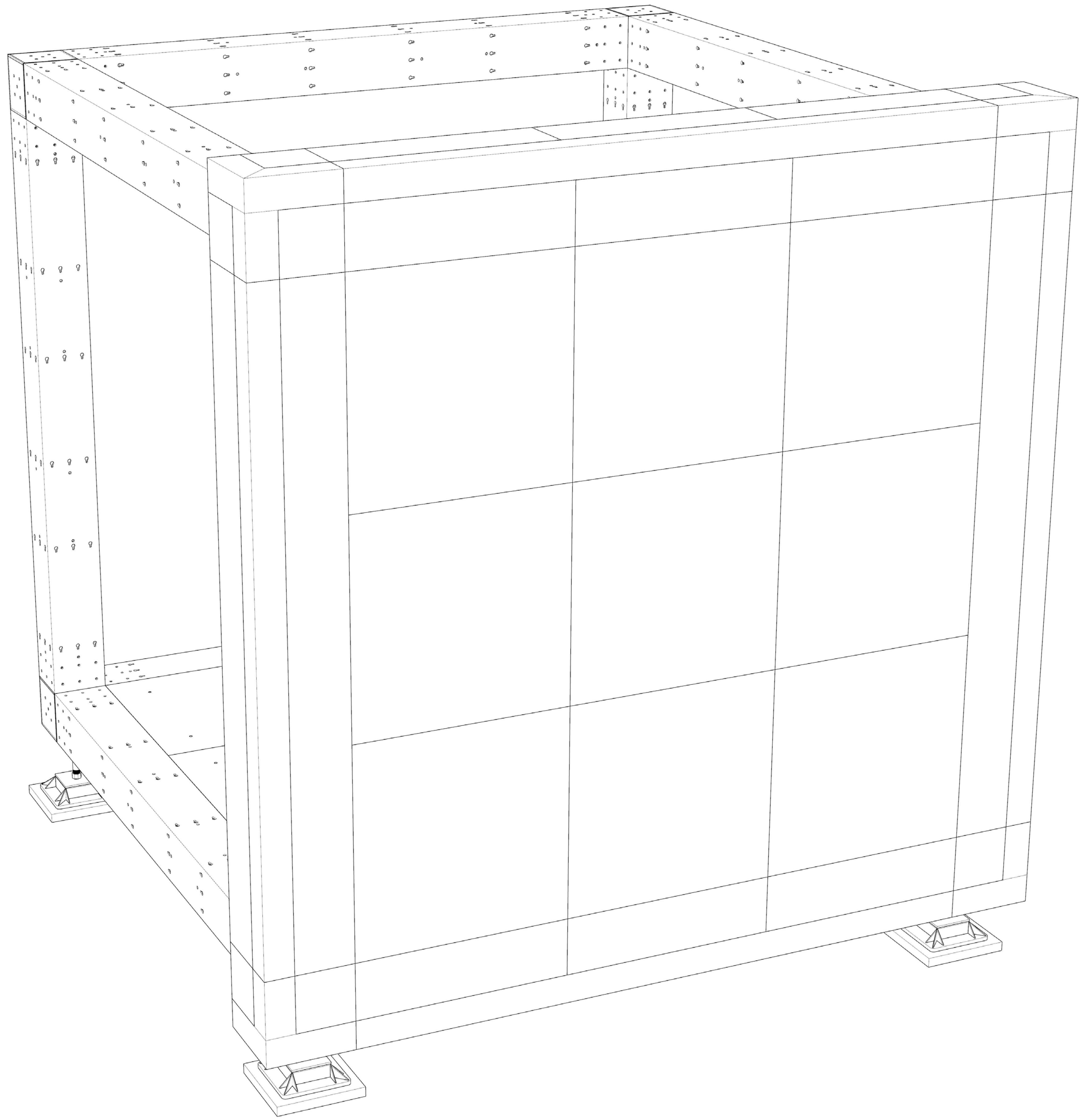
Finishing edges



CM 21

METAL SYSTEM

ASSEMBLY INSTRUCTIONS



7.2.3.**Wood Technical Drawing**

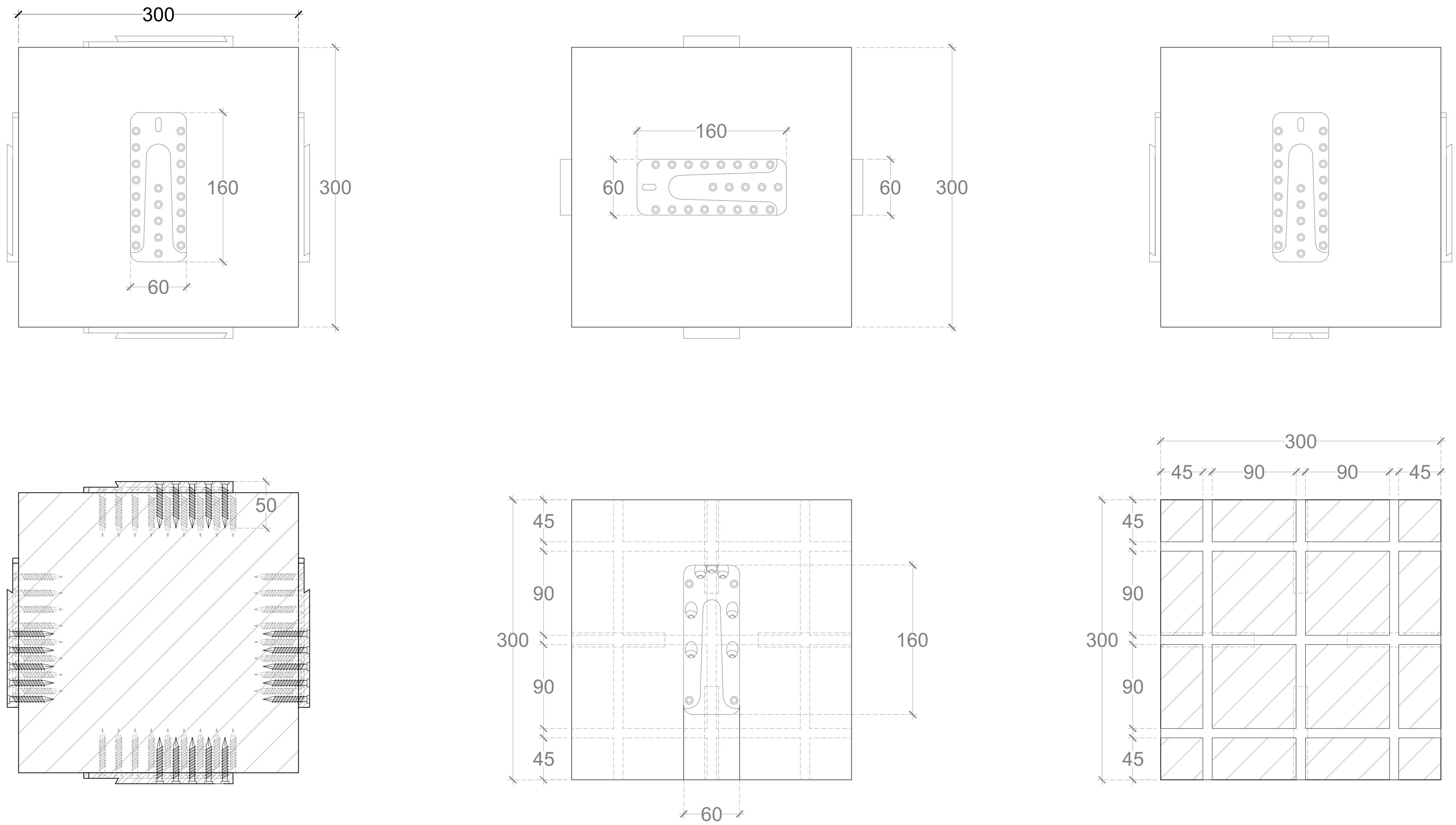
AW 01

WOOD SYSTEM

COMPONENTS

SCALE 1:5

Jn_1_1
Frame structural Joint



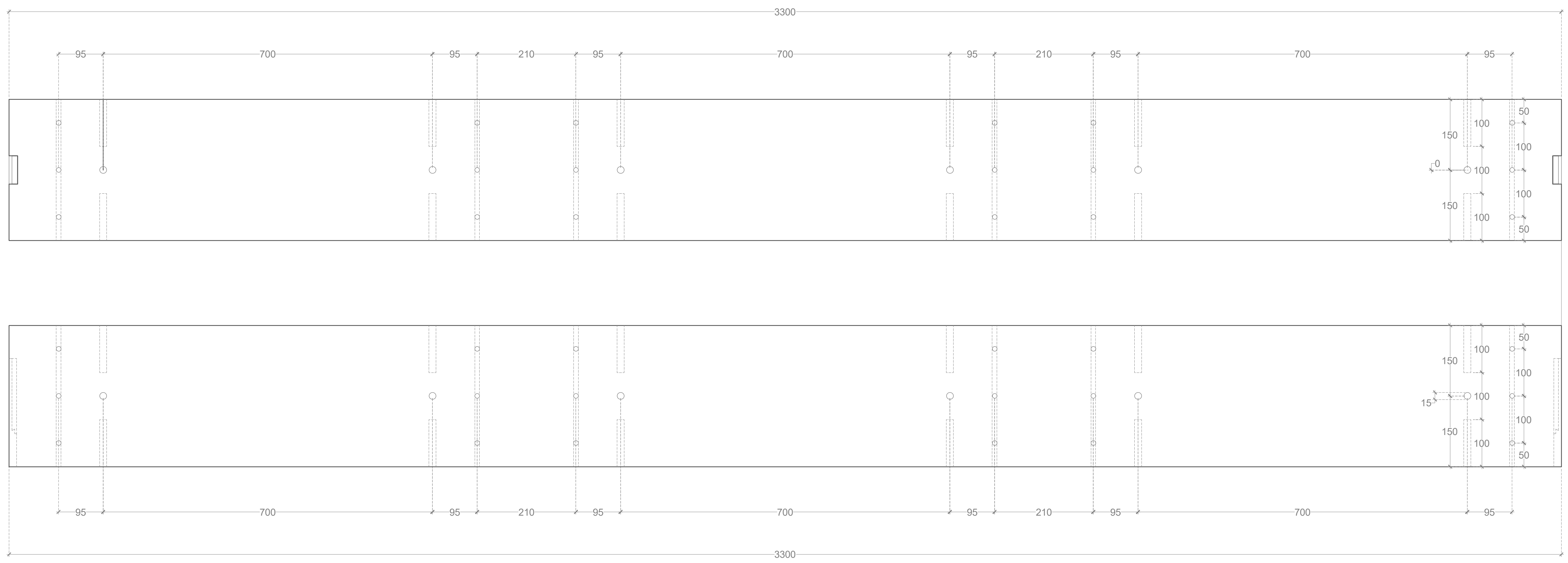
AW 02

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fr_1_1
Beam/Column



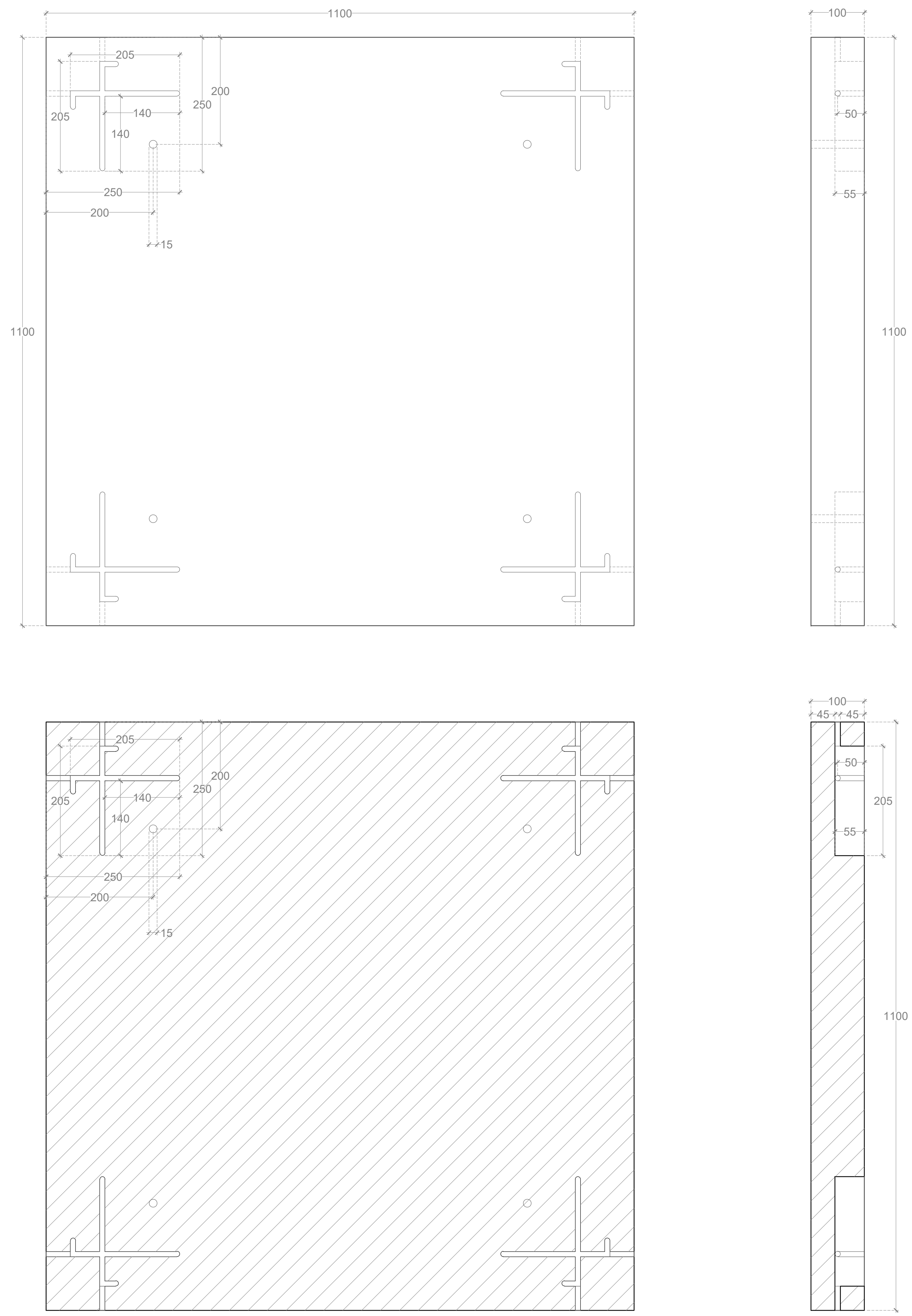
AW 03

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Pa_1_1
Panel cladding



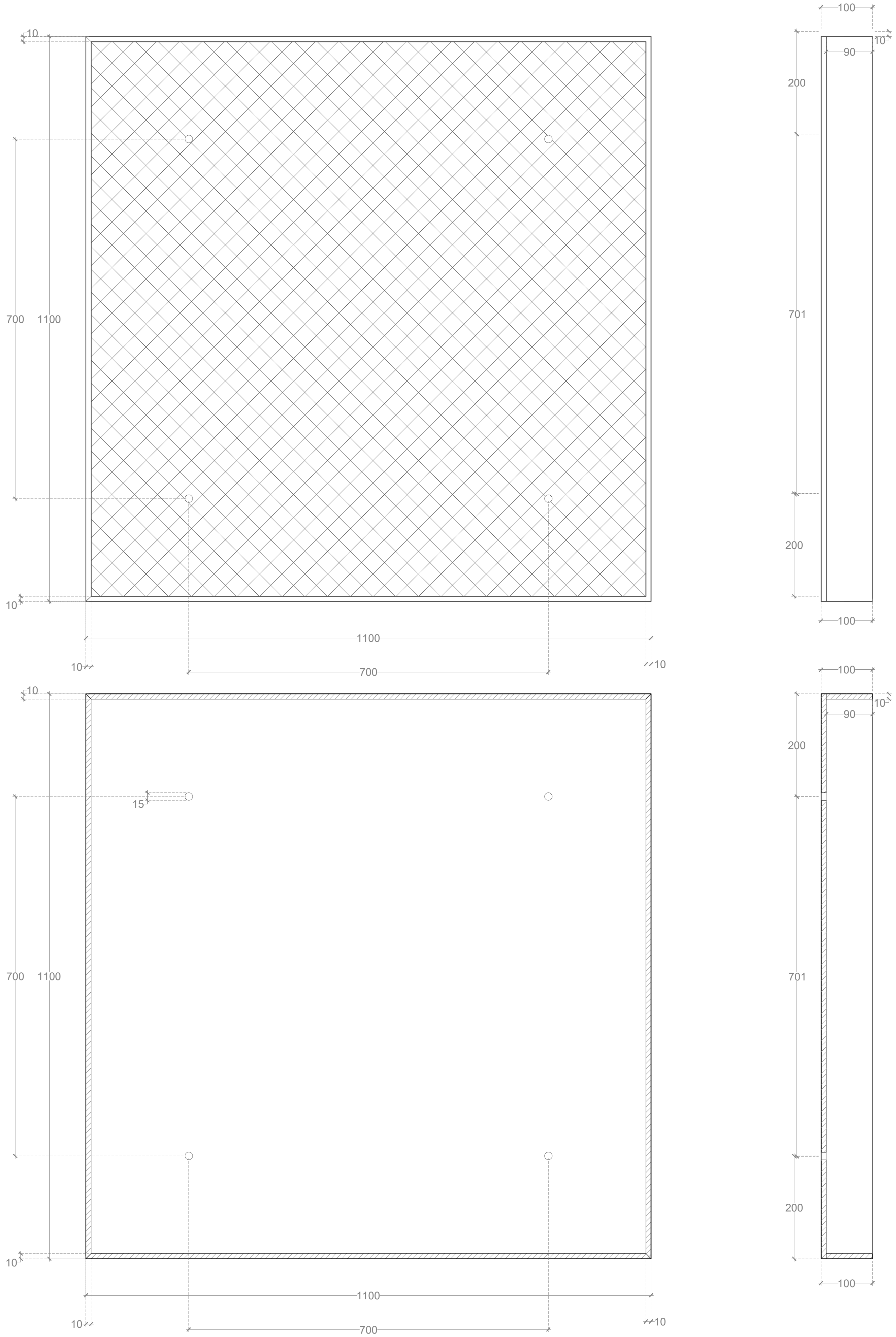
AW 04

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Pa_2_1
Panel cladding - Insulation wall



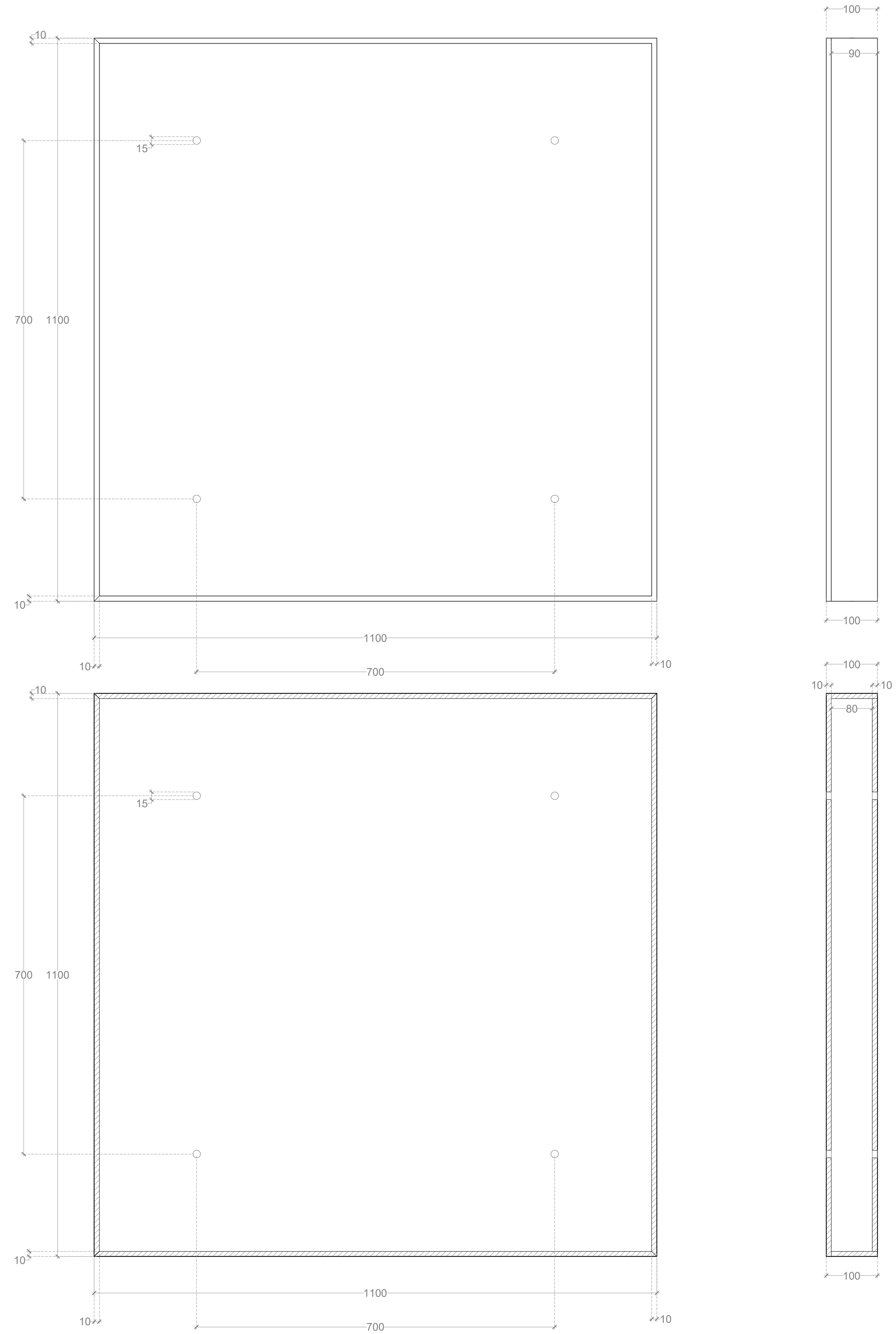
AW 05

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Pa_2_2
Panel cladding - Insulation/
Thermal Mass floor



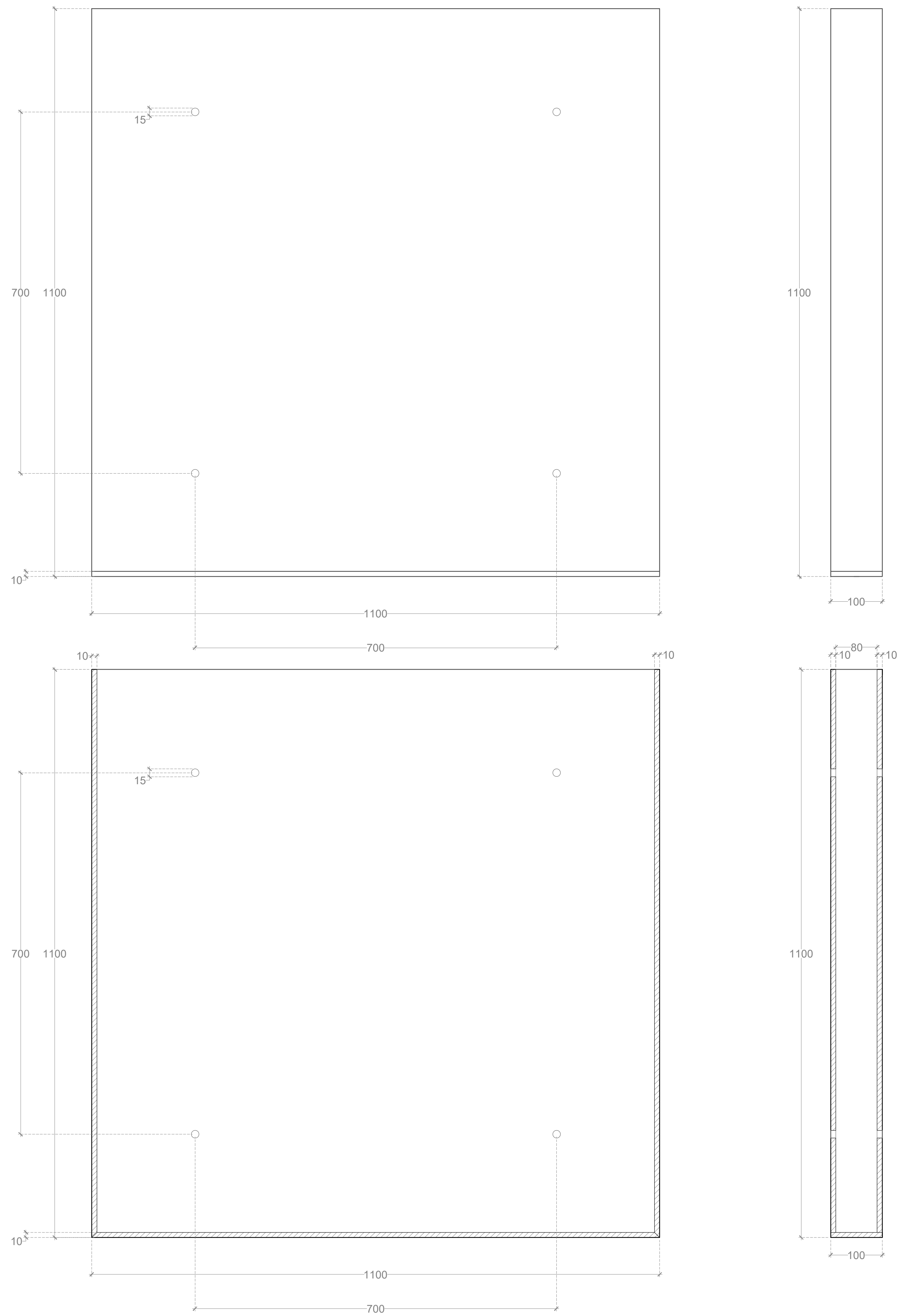
AW 06

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Pa_2_3
Panel cladding - Thermal Mass wall



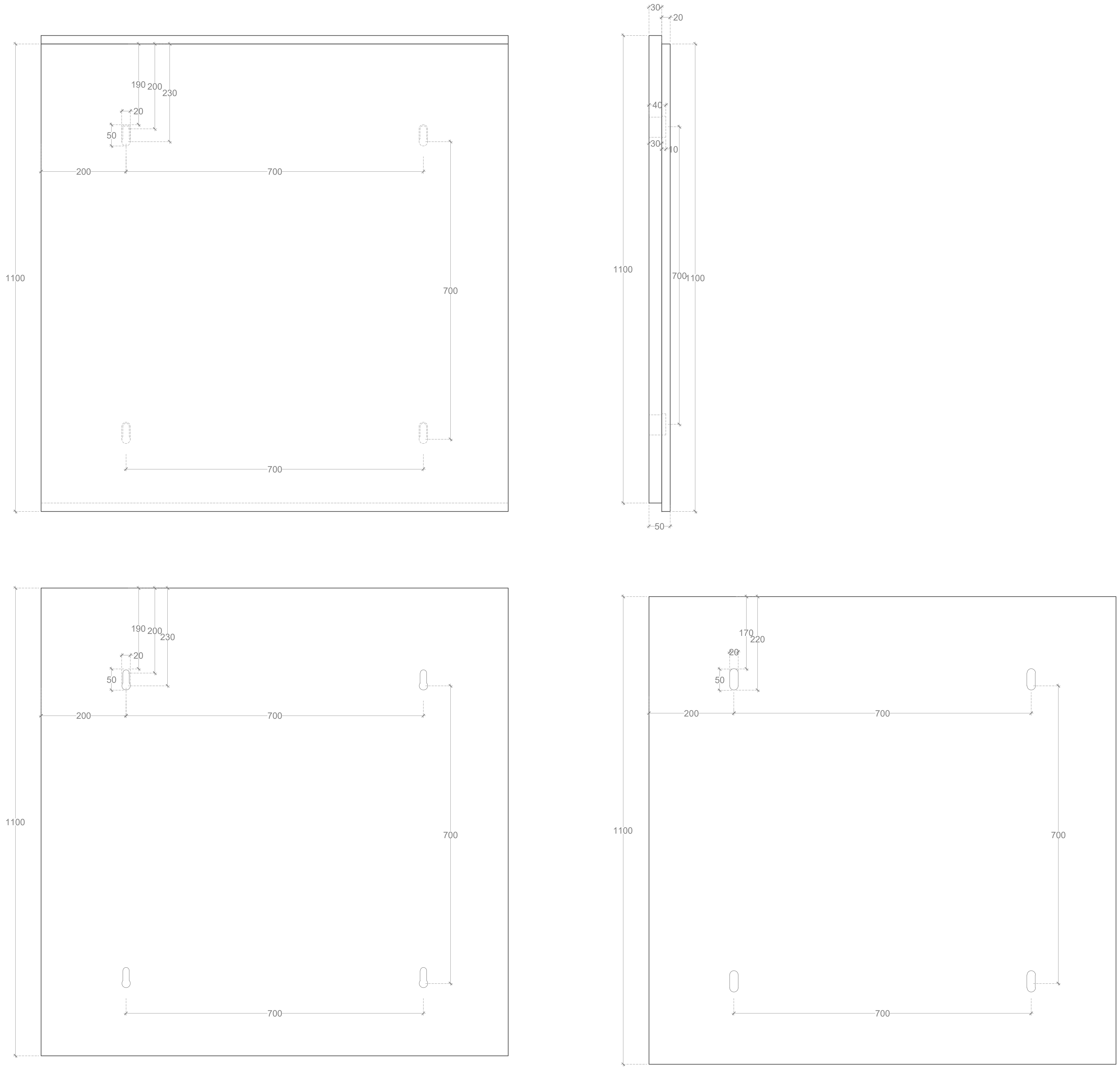
AW 07

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fi_1_1
Finishing Panel



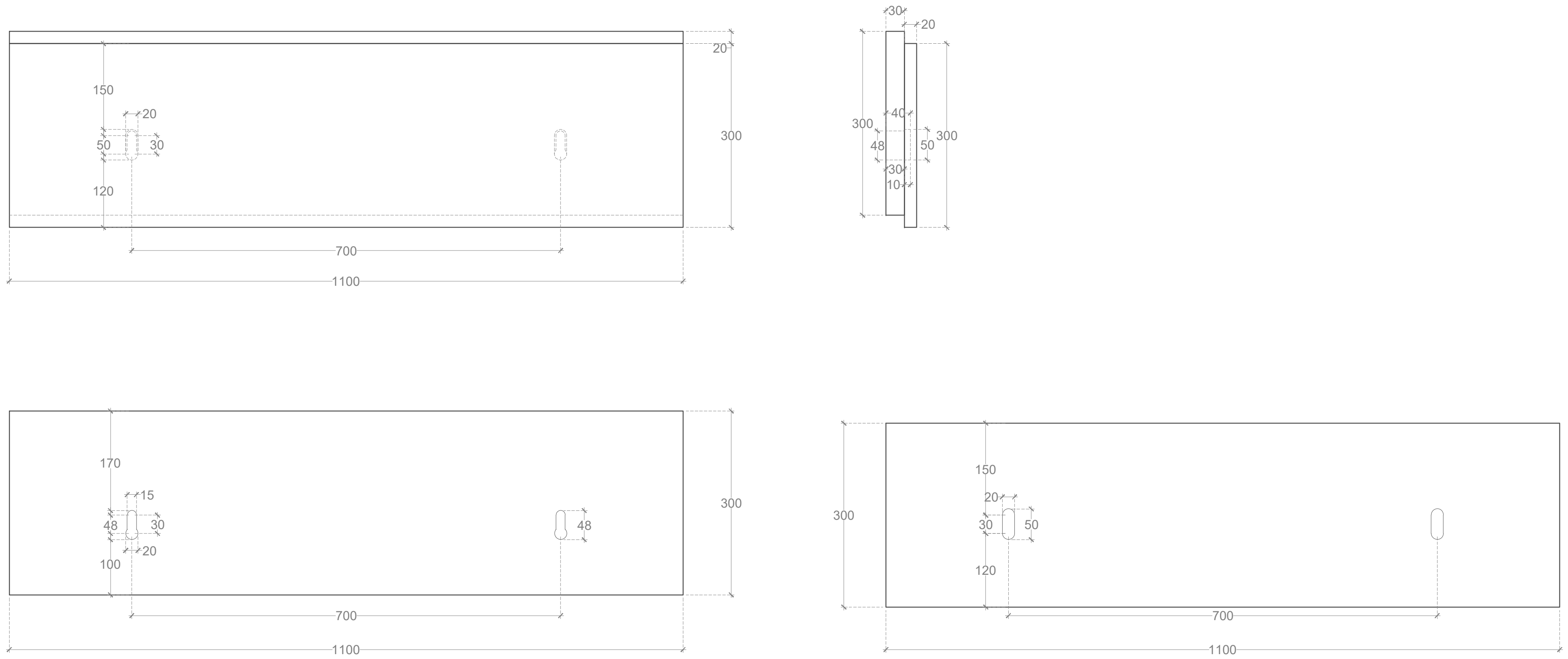
AW 08

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_1
Finishing Panel - frame border 01



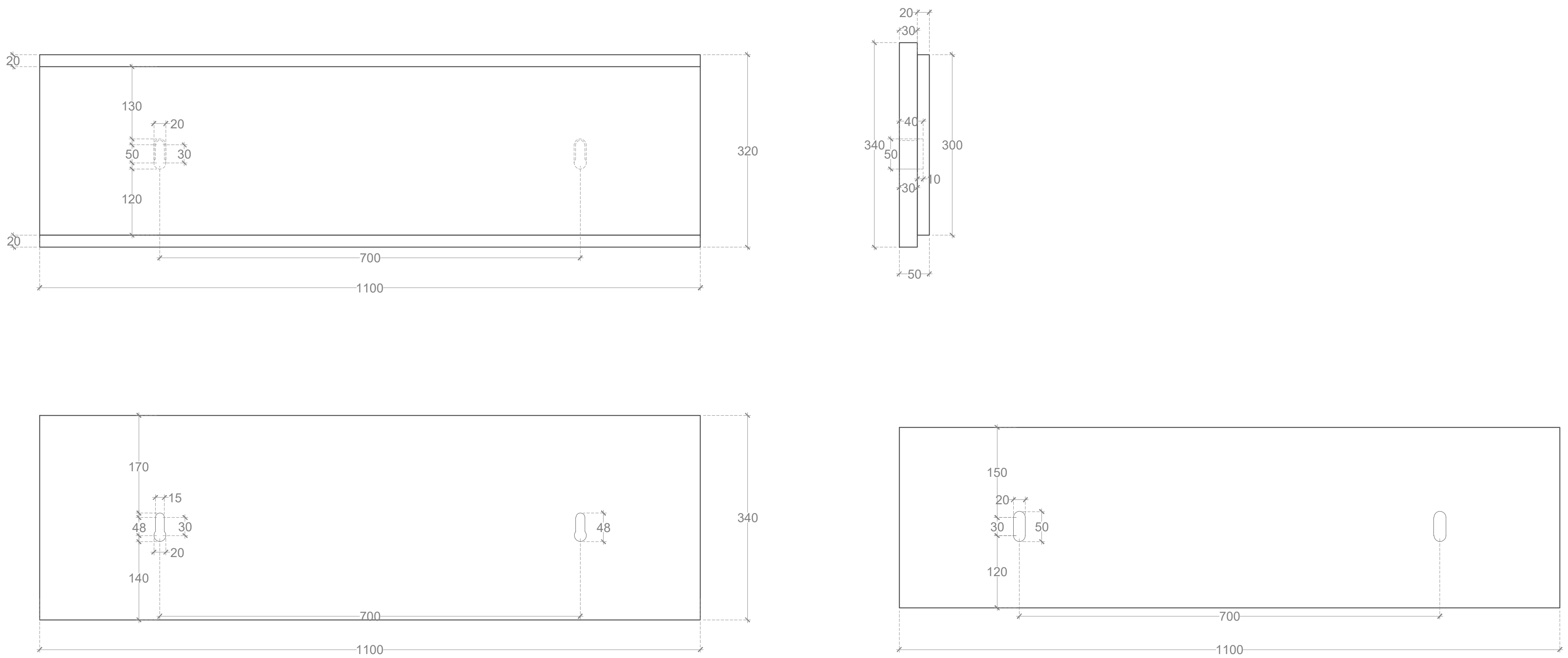
AW 09

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_2
Finishing Panel - frame border 02



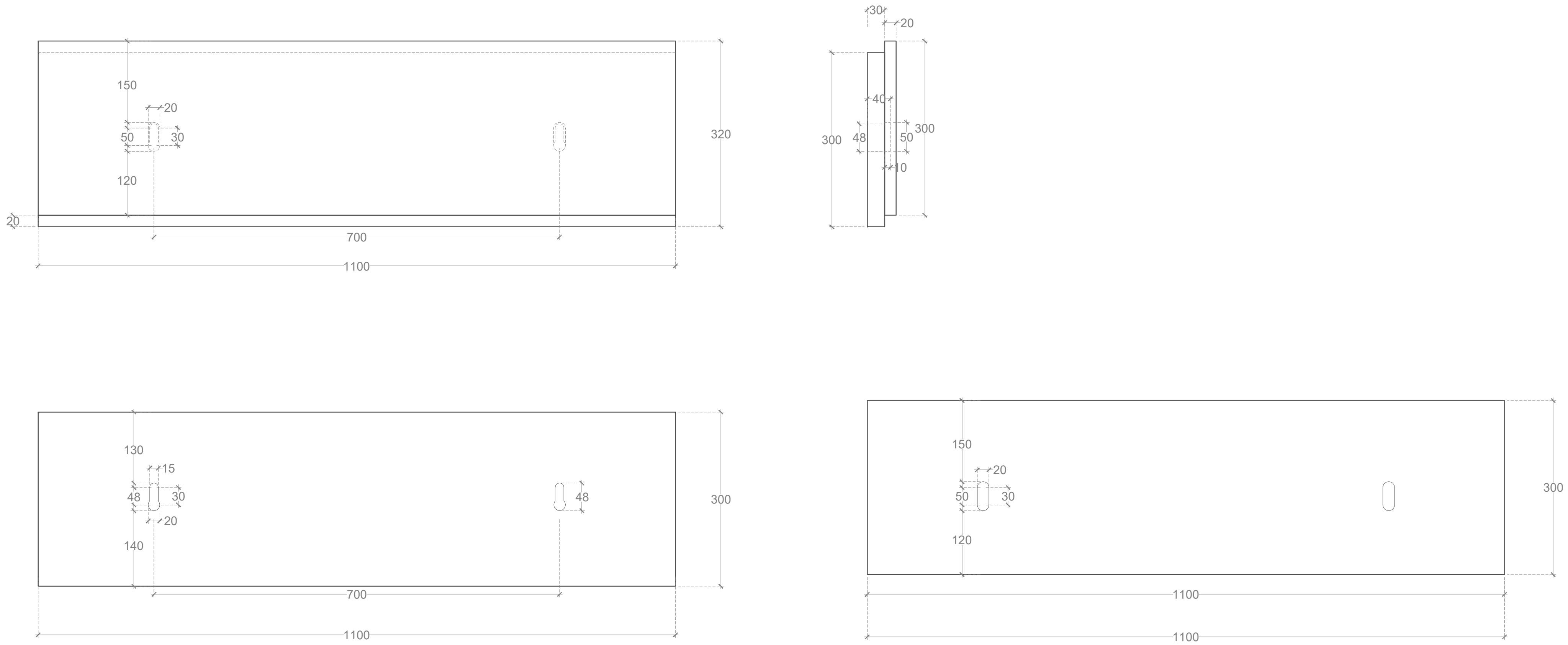
AW 10

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_3
Finishing Panel - frame border 03



AW 11

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_4
Finishing Panel - long frame border horizontal

AW 12

WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_5
Finishing Panel - long frame border vertical

AW 13

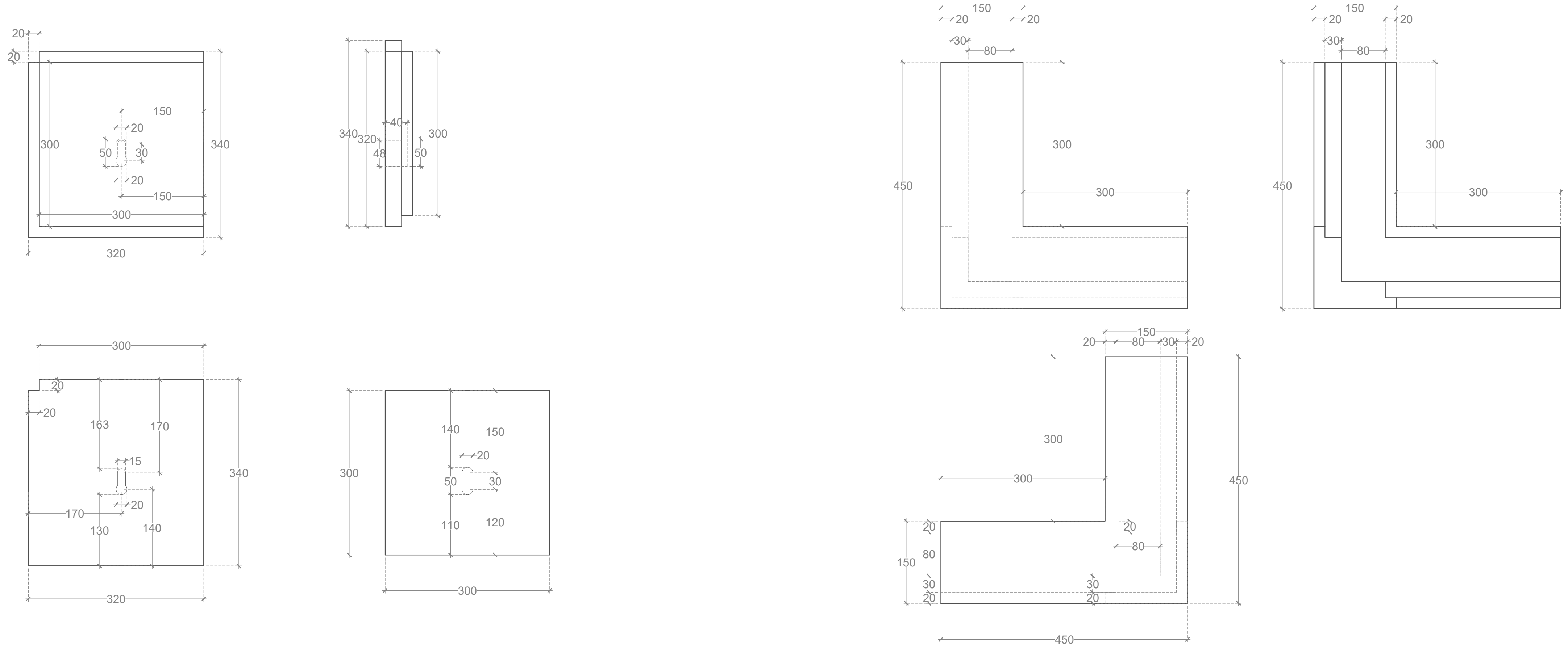
WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fi_2_6
Finishing Panel - joint border

Fi_3_1
Finishing Panel - angolar border



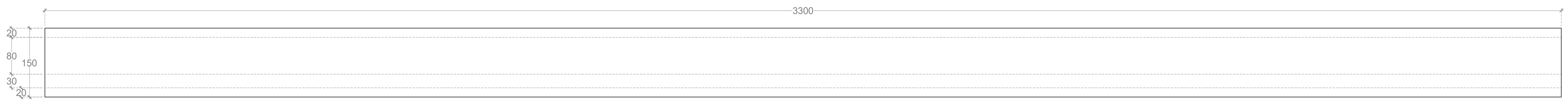
AW 14

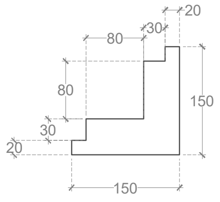
WOOD SYSTEM

COMPONENTS

SCALE 1:10

Fi_3_2
Finishing Edge - edge border





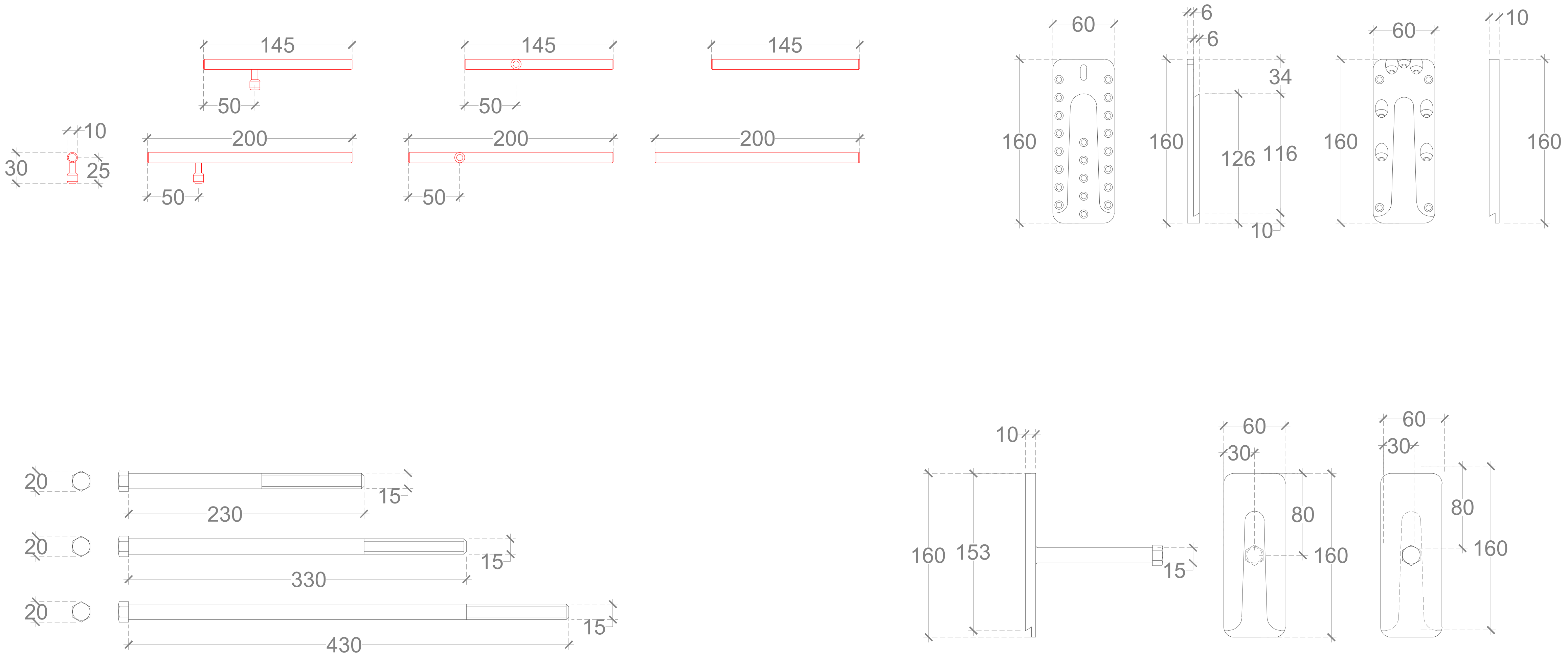
AW 15

WOOD SYSTEM

COMPONENTS

SCALE 1:5

Metalware



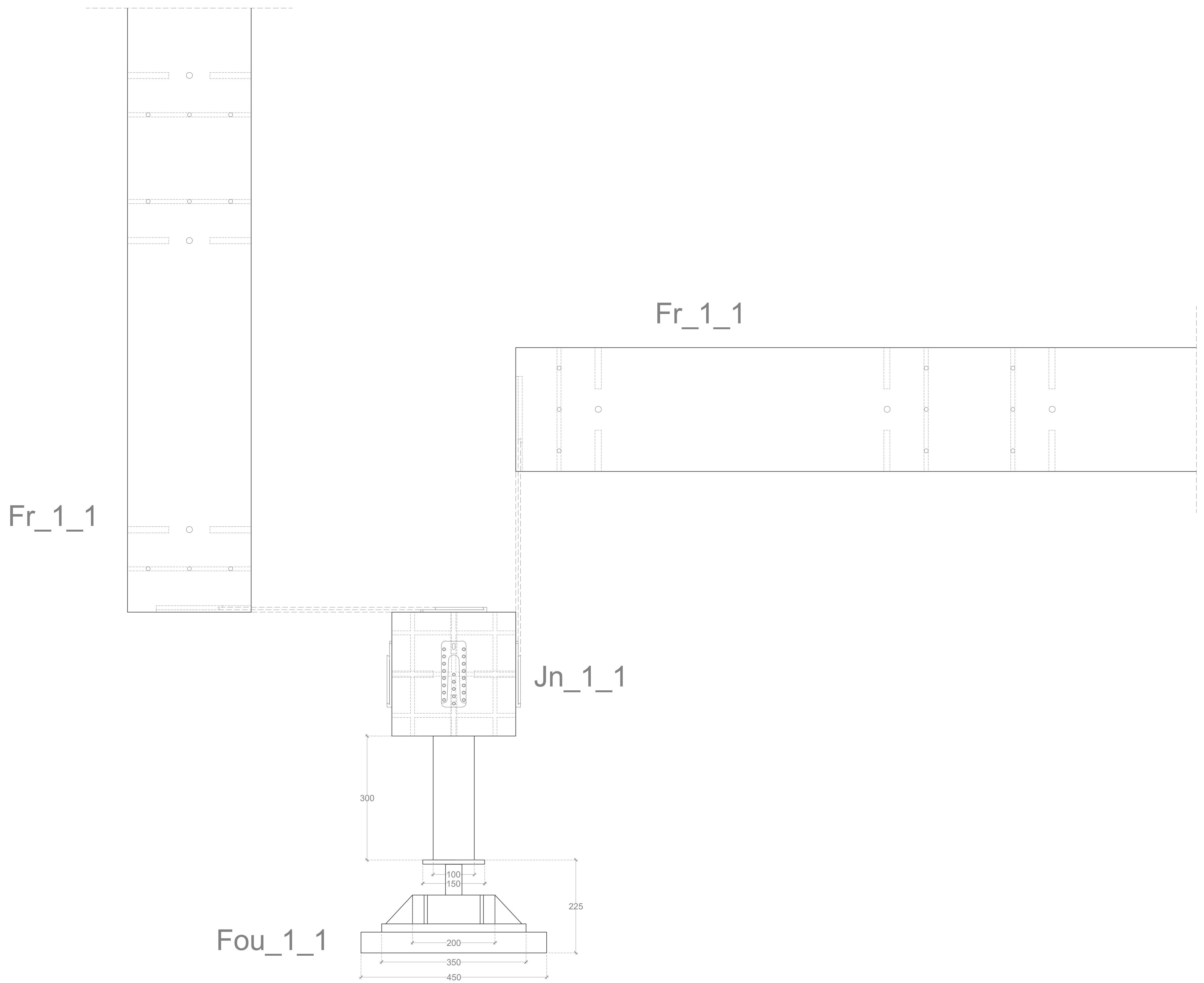
BW 01

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Detail connection:
Joint (Jn_1_1)
Beam (Fr_1_1)
Column (Fr_1_1)
Foundation (Fou_1_1)



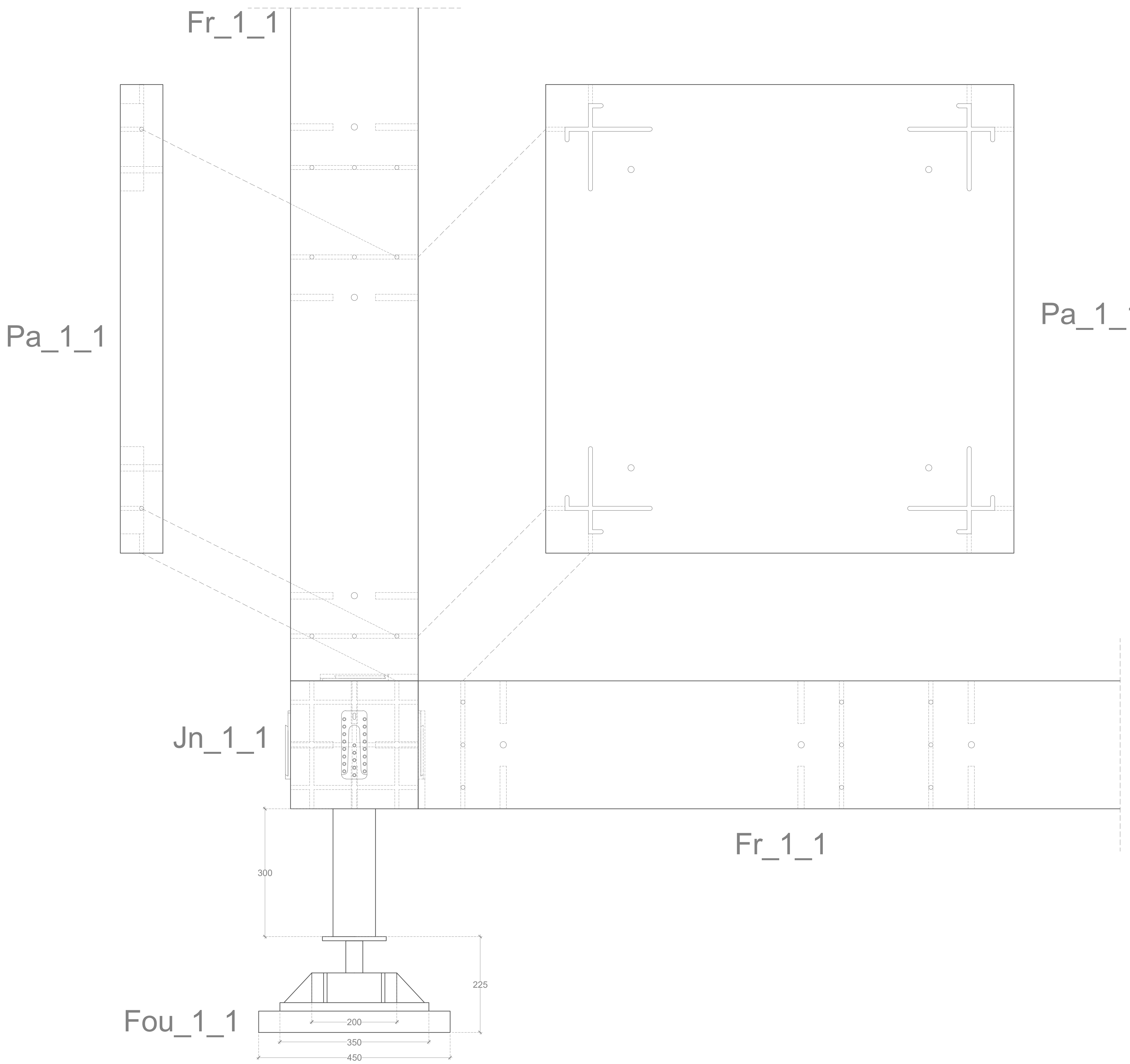
BW 02

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Detail connection:
Joint (Jn_1_1)
Beam (Fr_1_1)
Column (Fr_1_1)
Foundation (Fou_1_1)
Panel (Pa_1_1)



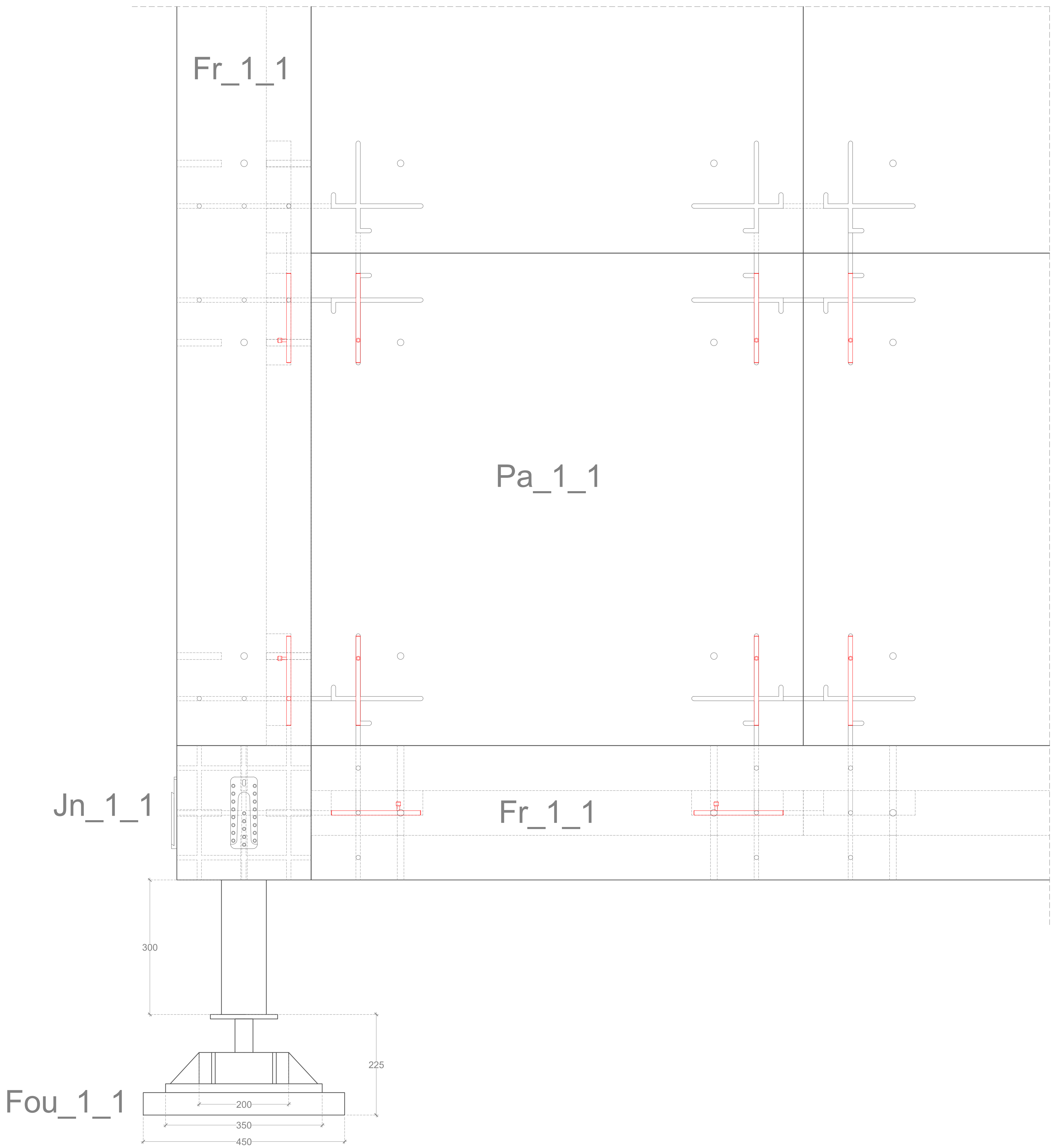
BW 03

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 01



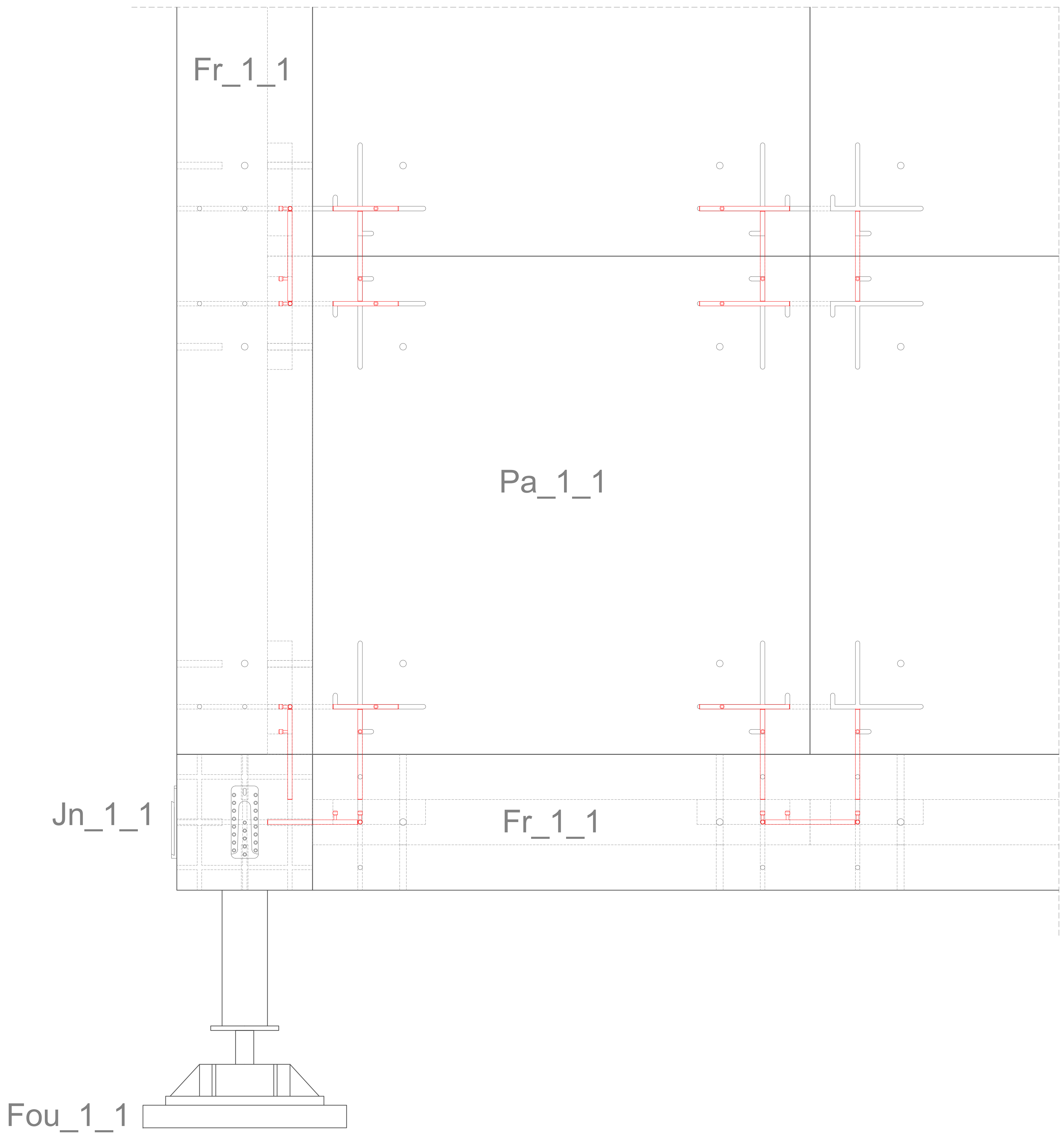
BW 04

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 02



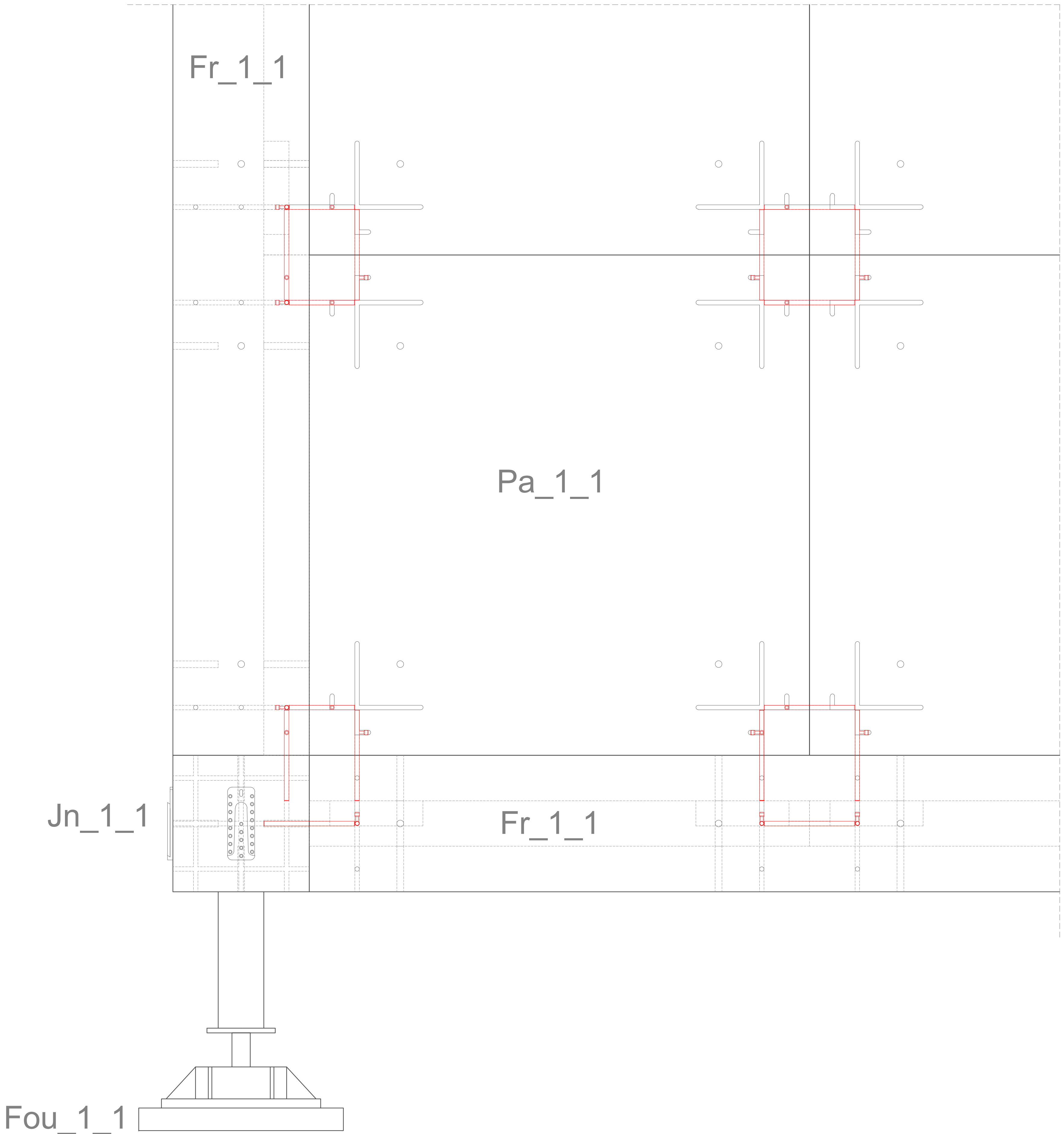
BW 05

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 03



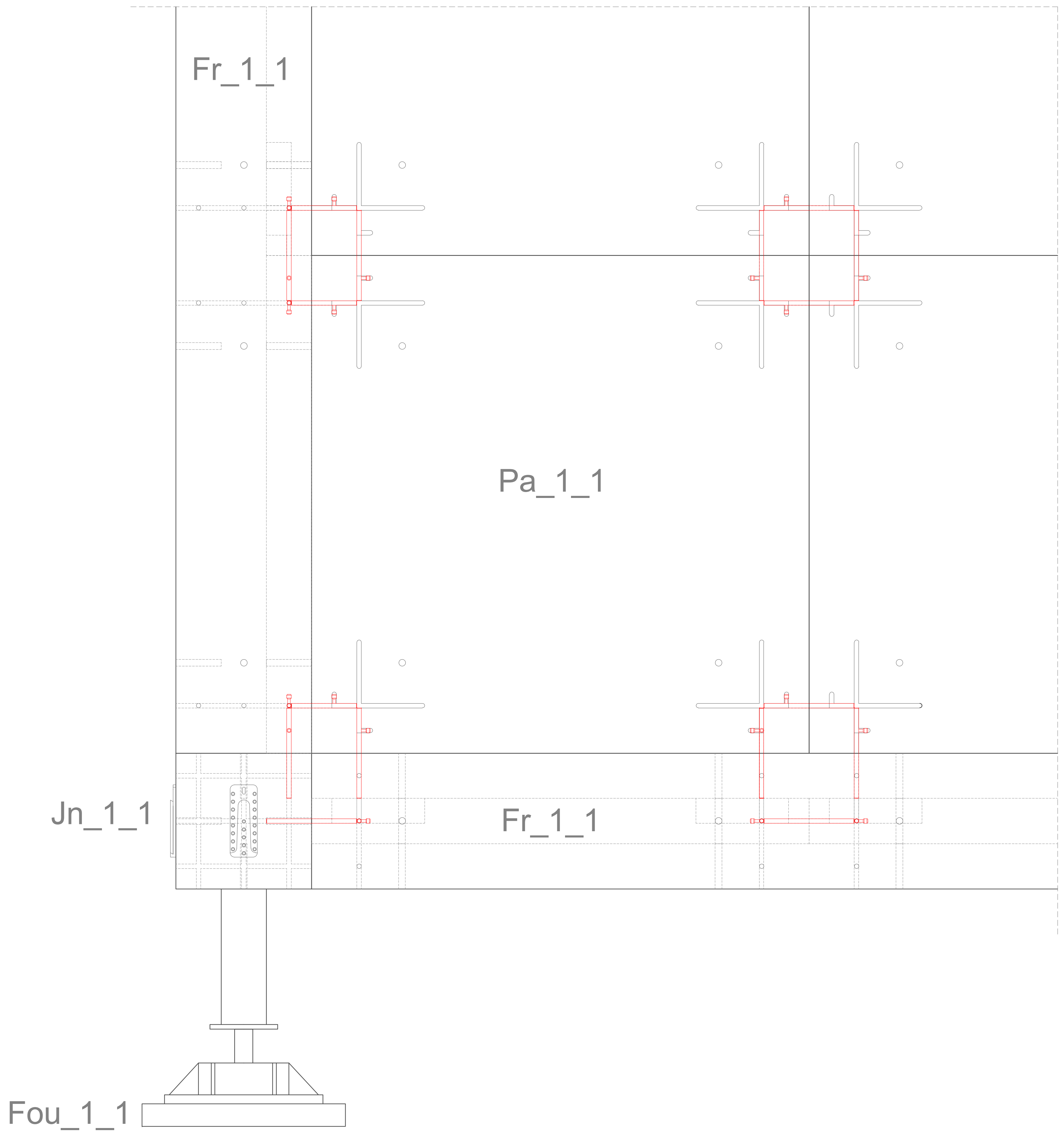
BW 06

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 04



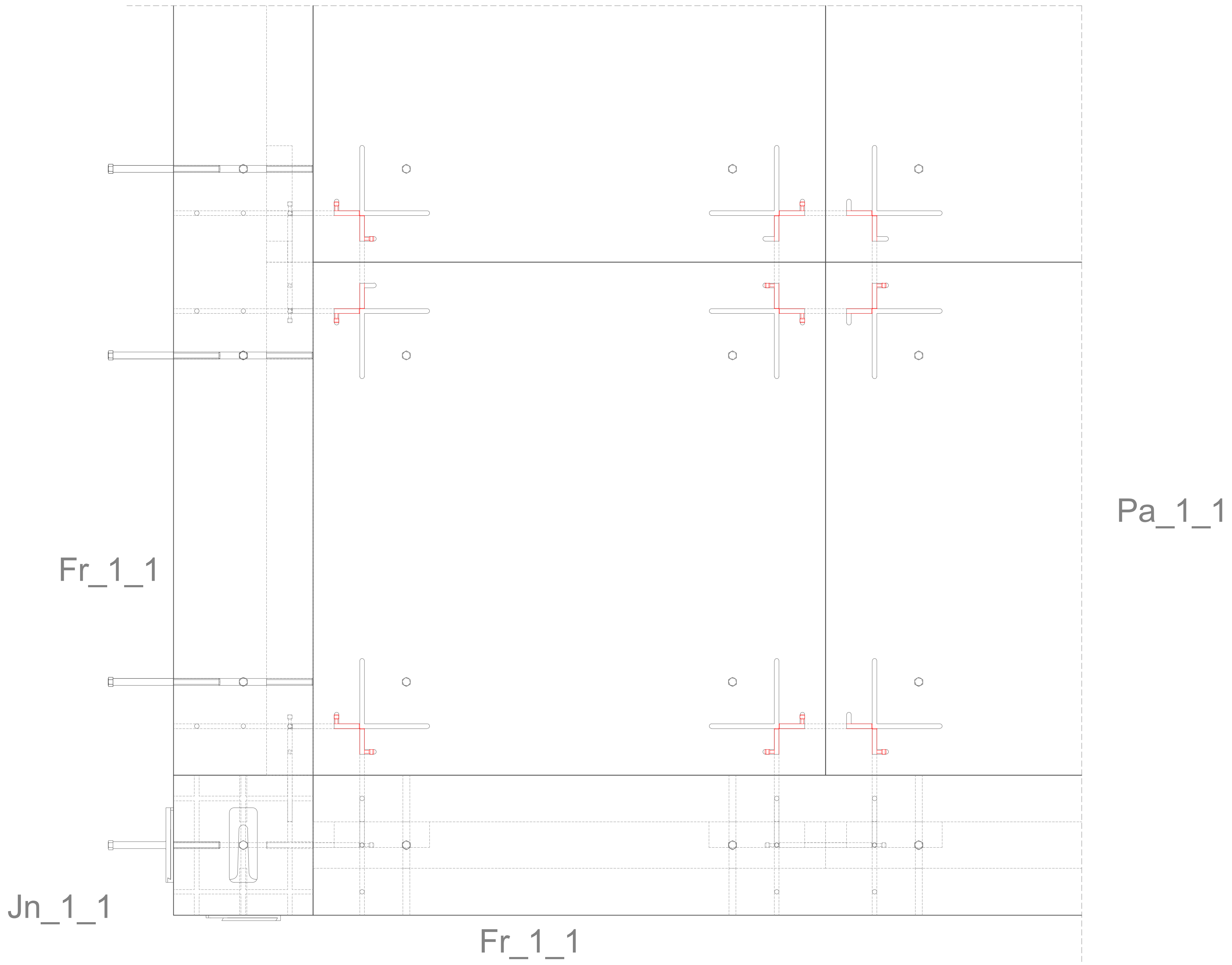
BW 07

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 05



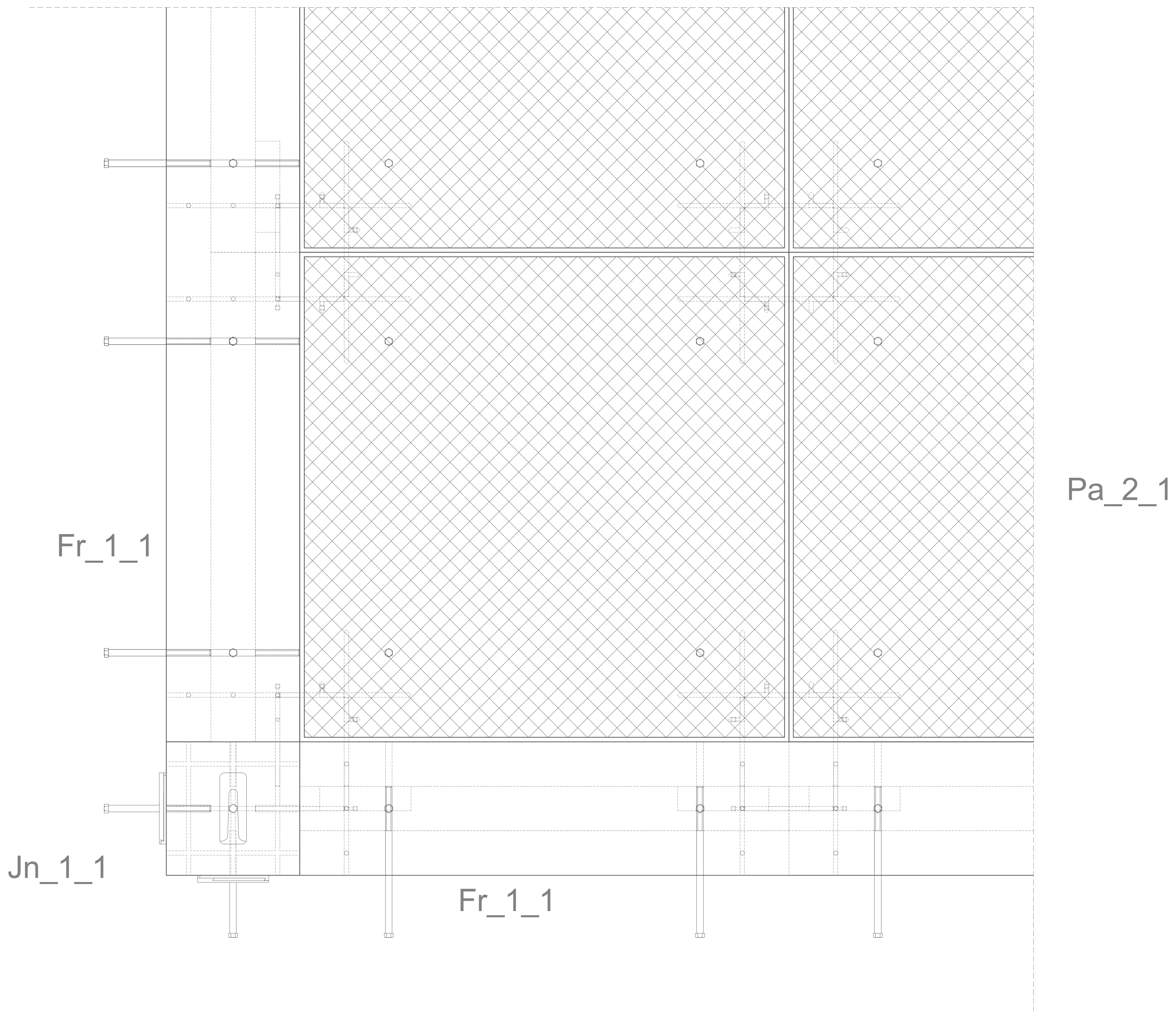
BW 08

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Panels assembly sequence 06



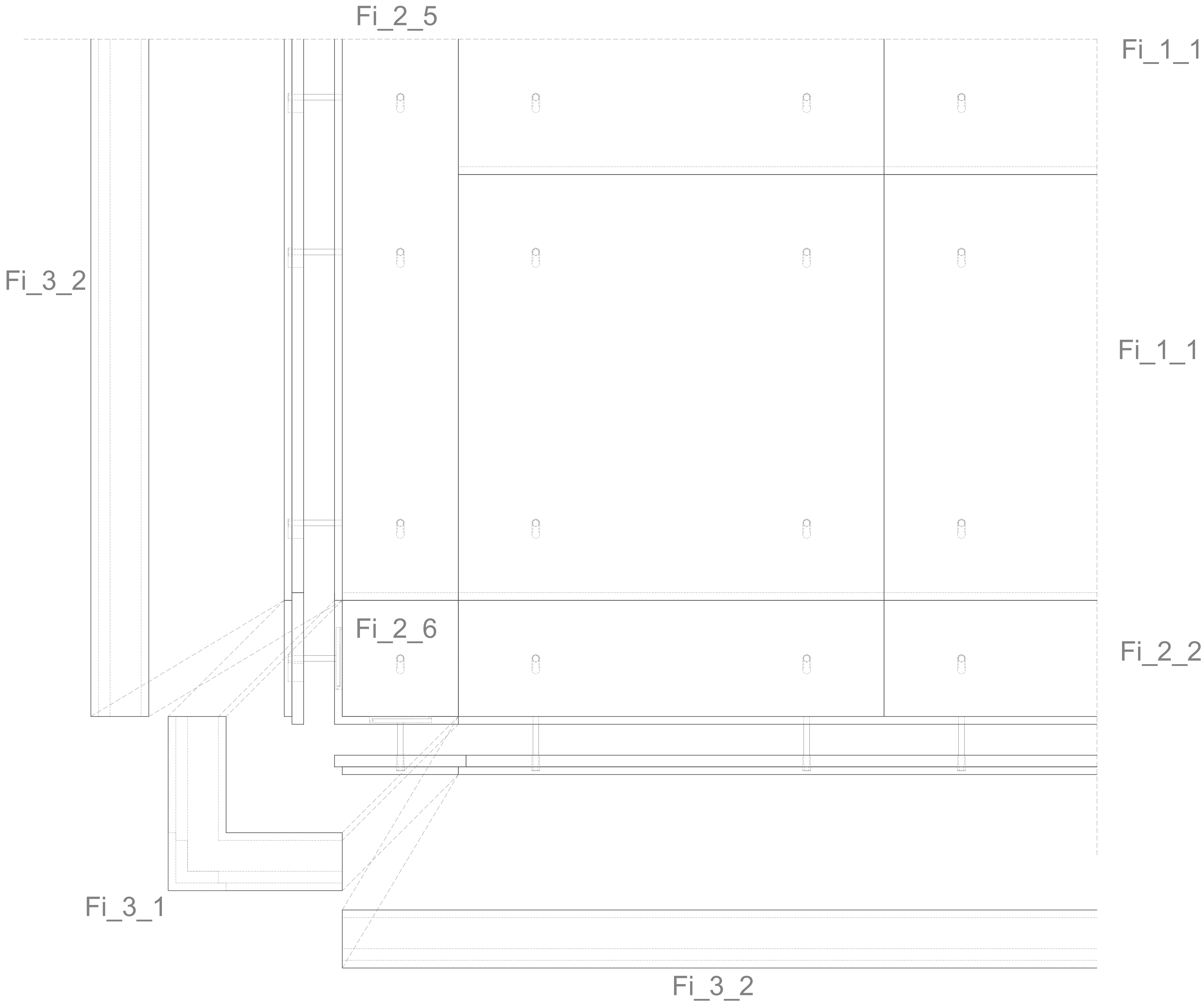
BW 09

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Finishing assembly sequence



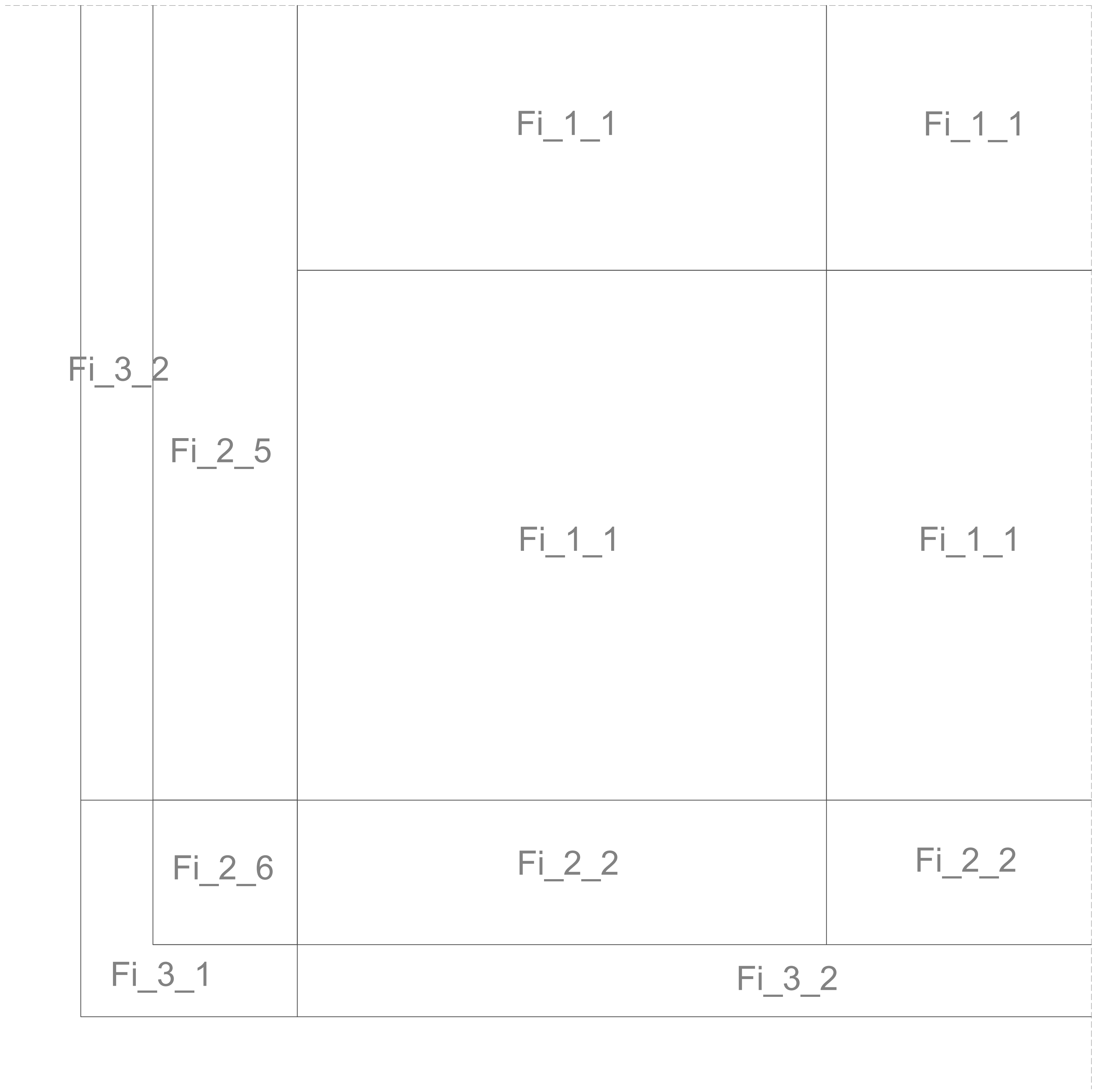
BW 10

WOOD SYSTEM

CONSTRUCTION DETAIL

SCALE 1:10

Finishing complete



7.2.4. **Assembly Instructions – Wood**

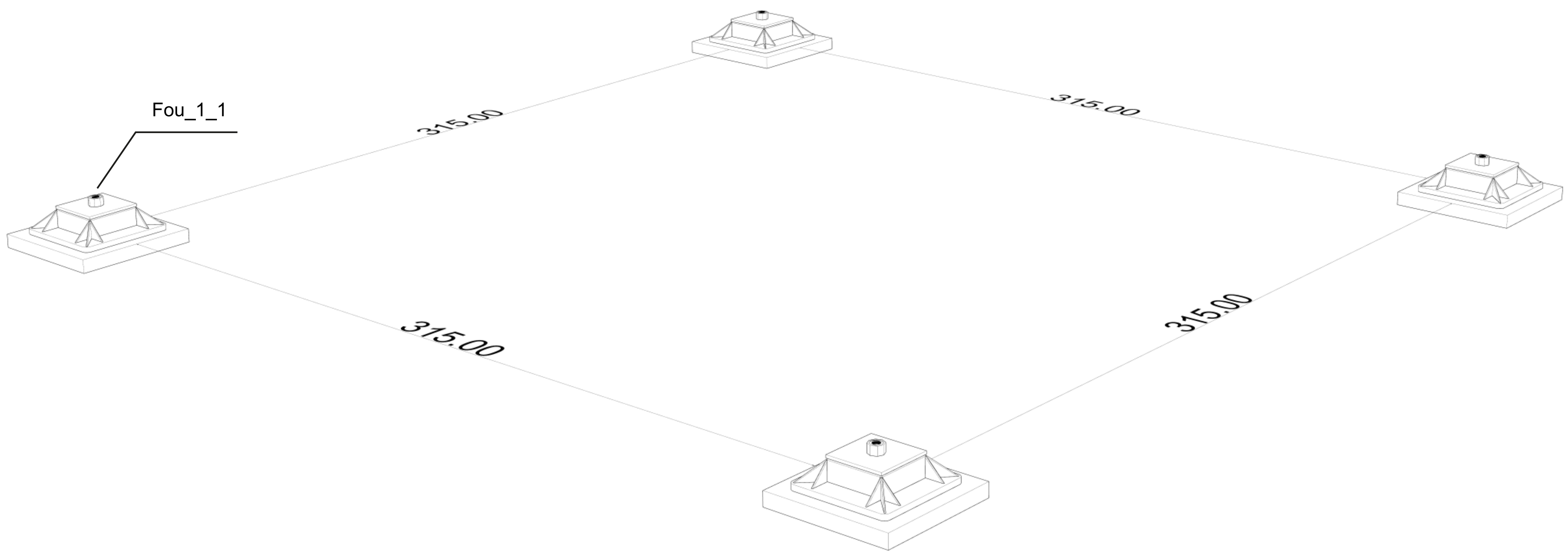
CW 01

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_1

Foundations placement



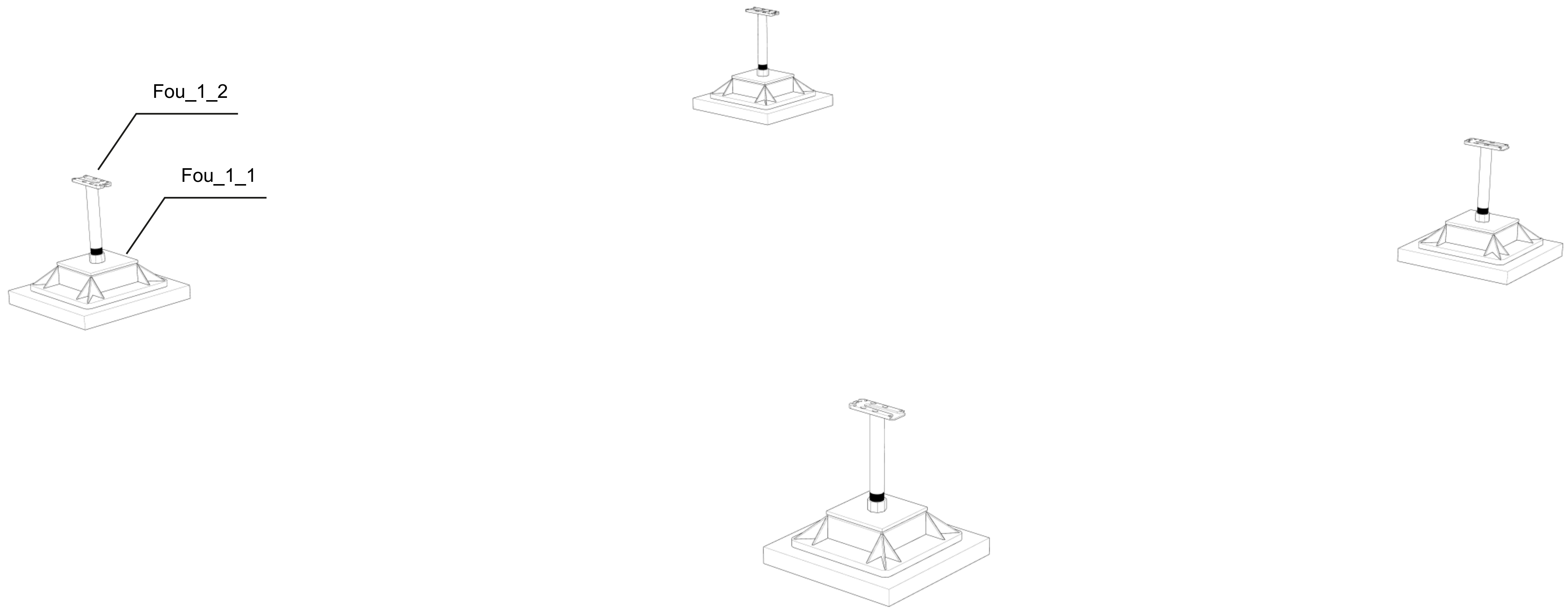
CW 02

WOOD SYSTEM

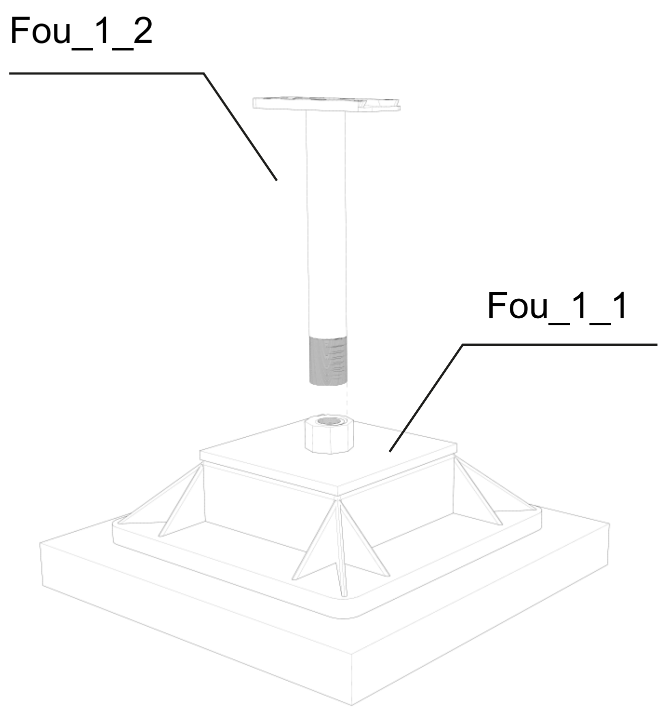
ASSEMBLY INSTRUCTIONS

Fou_1_1
Fou_1_2

Framework-Foundations junctions



DETAILS



CW 03

WOOD SYSTEM

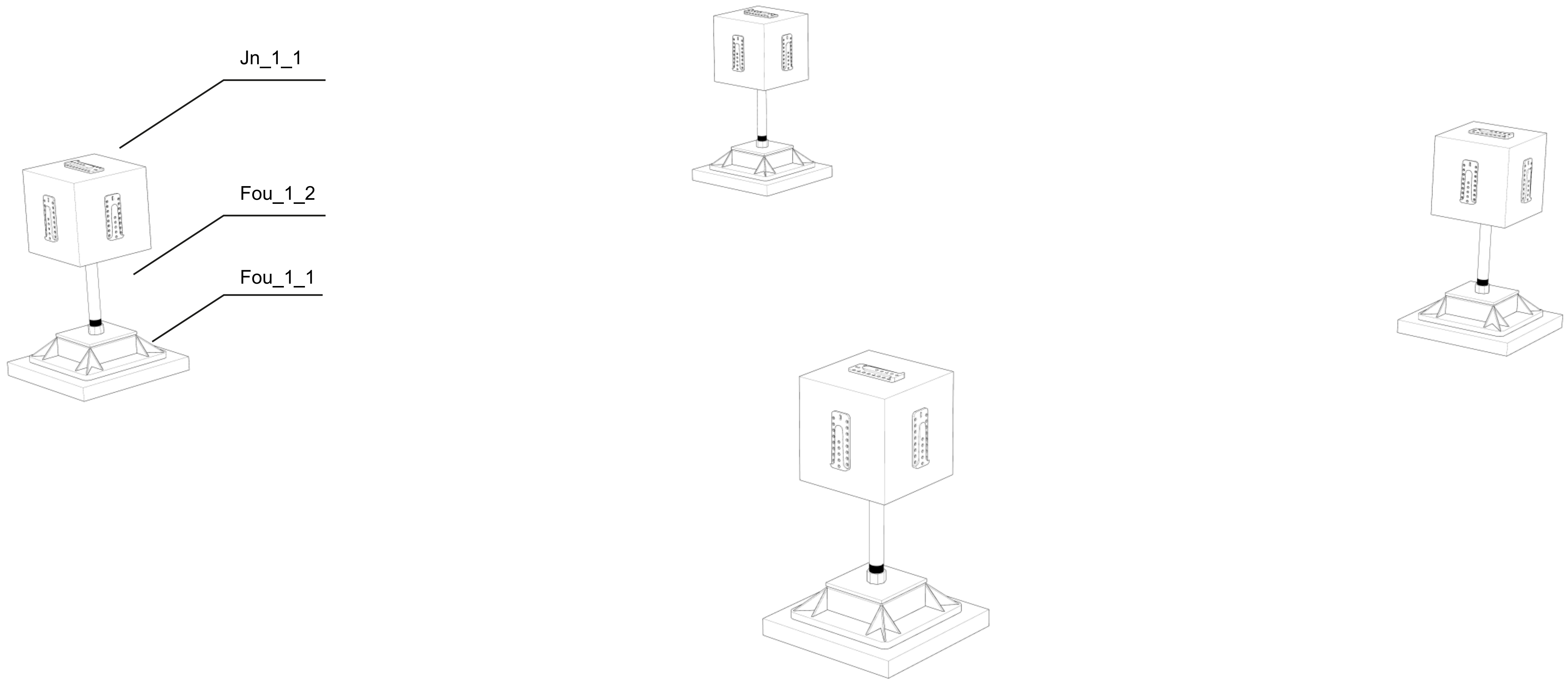
ASSEMBLY INSTRUCTIONS

Fou_1_2

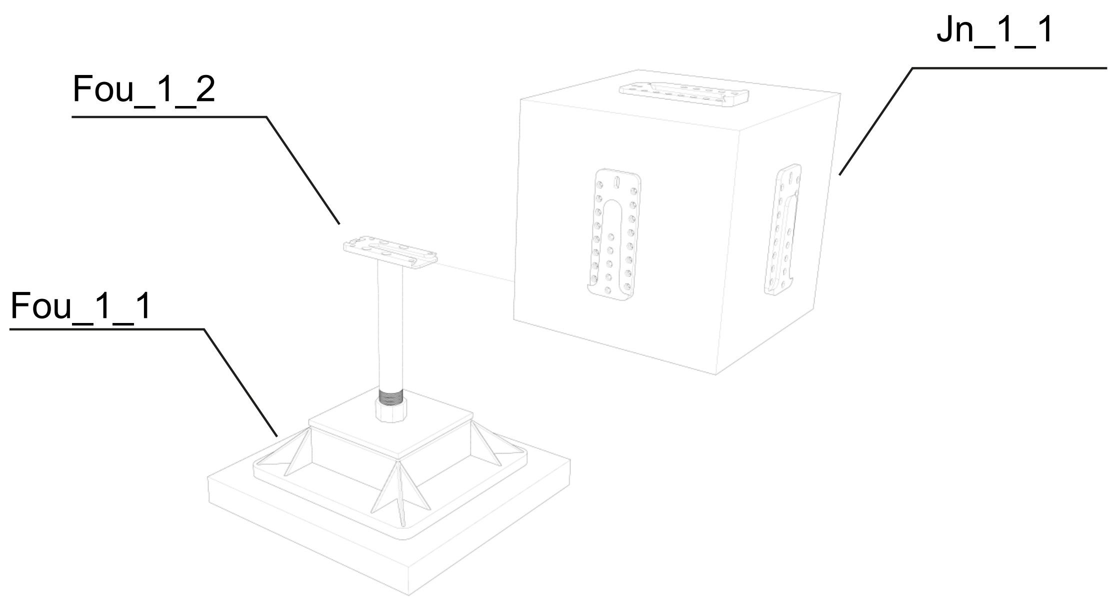
Fou_1_1

Jn_1_1

Structural junctions



DETAILS



CW 04

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

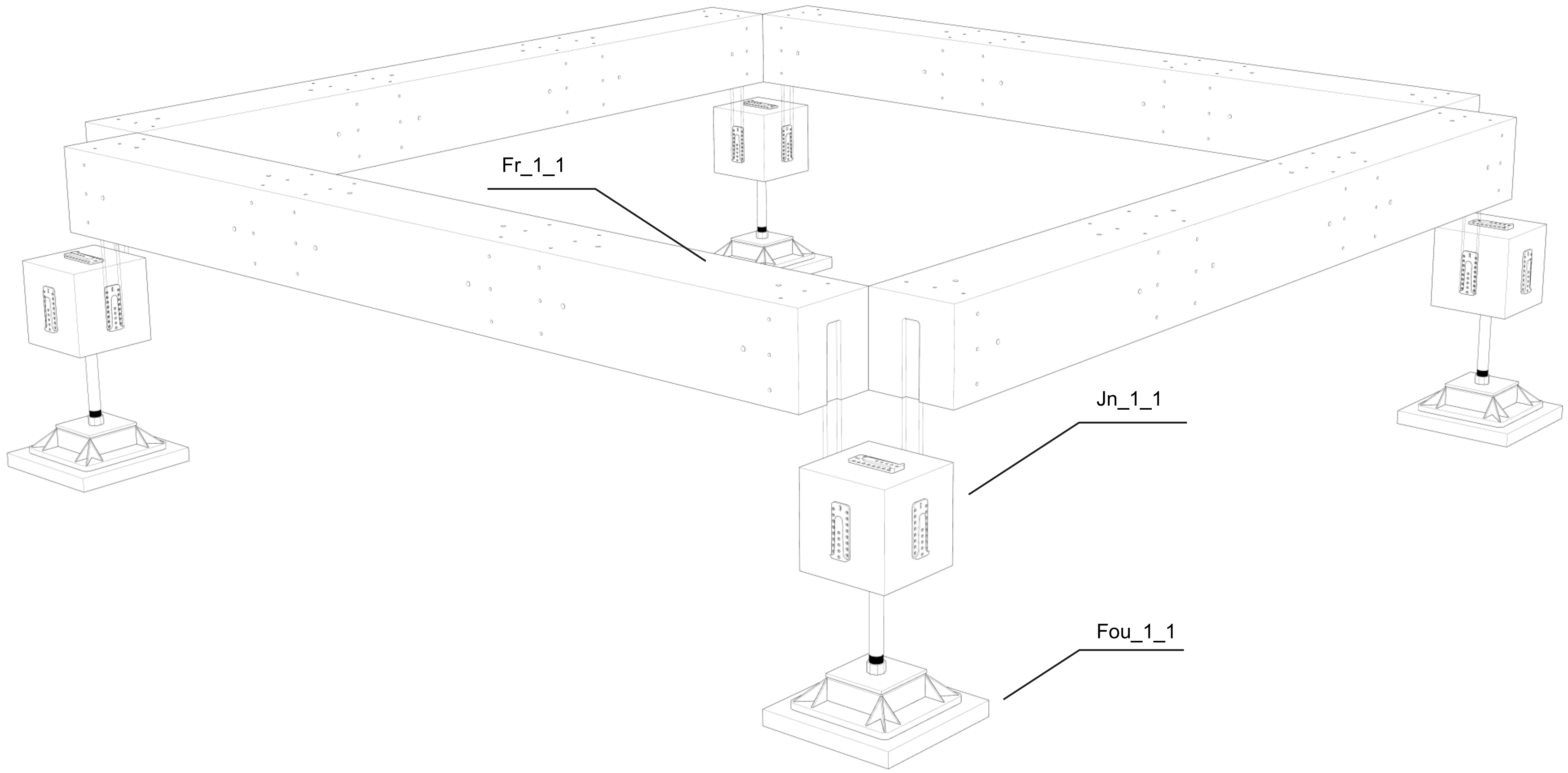
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Beeams framework



CW 05

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

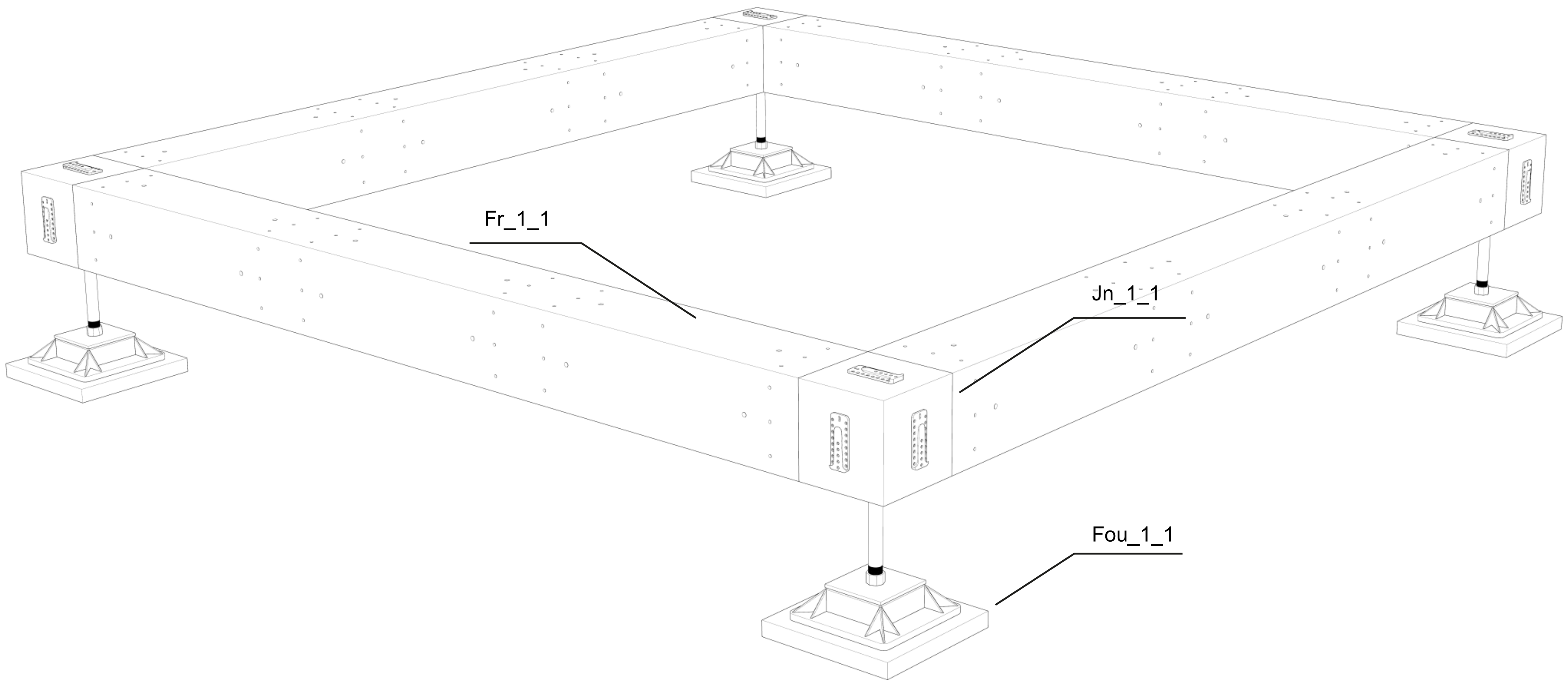
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Base framework



CW 06

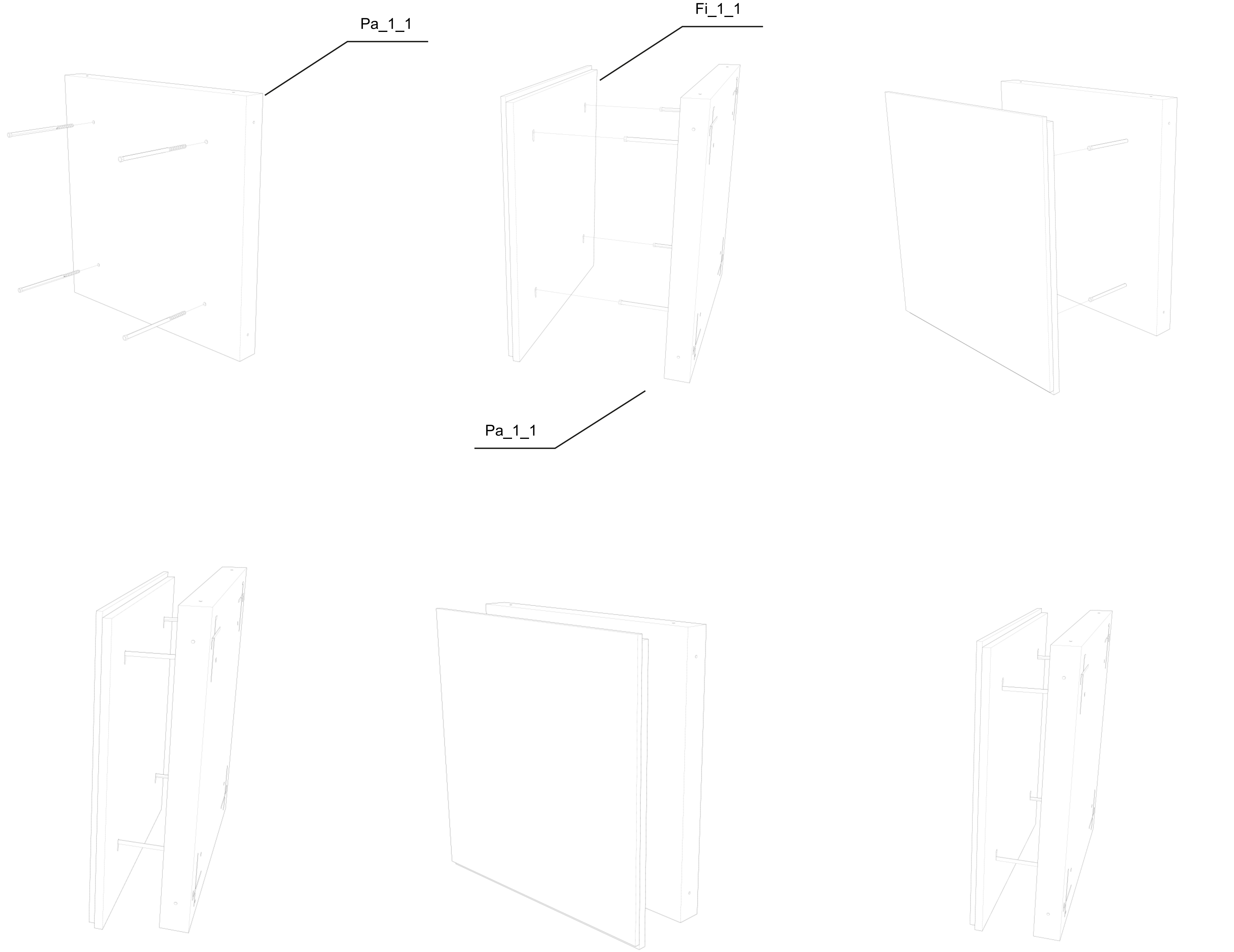
WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Pa_1_1

Fi_1_1

Panel + finishing assembly



CW 07

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

Fou_1_1

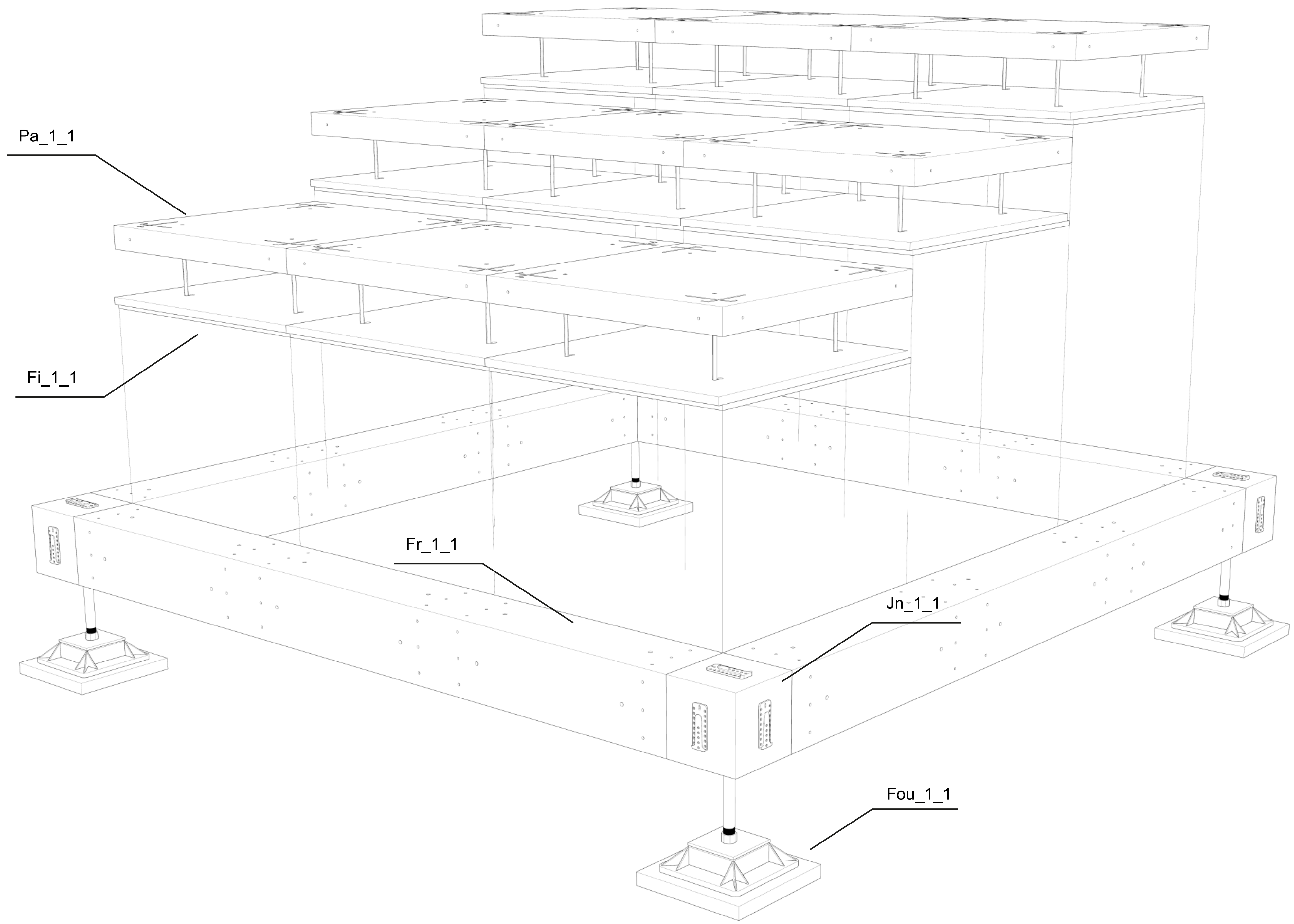
Jn_1_1

Fr_1_1

Pa_1_1

Fi_1_1

Floor structural panel + external finishing



CW 08

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

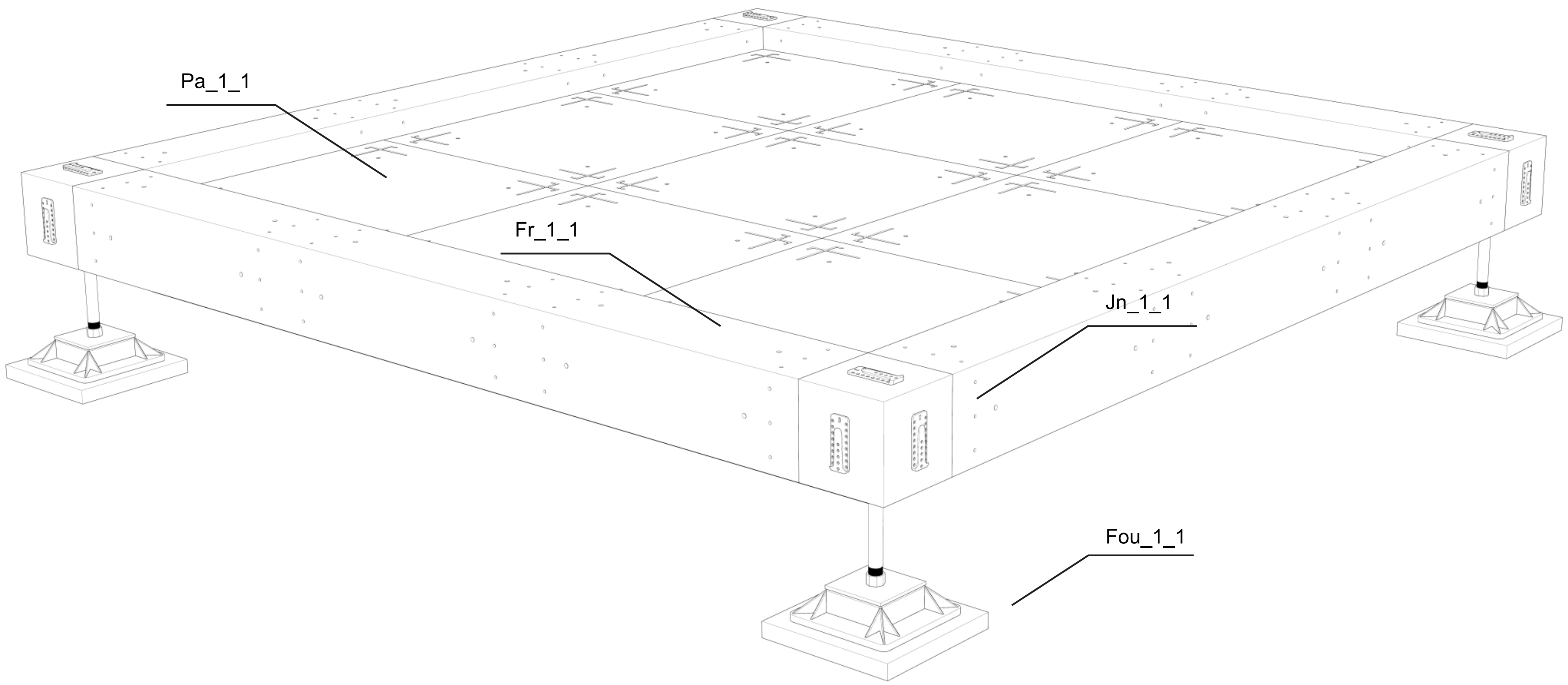
Fou_1_1

Jn_1_1

Fr_1_1

Pa_1_1

Base floor structure



CW 09

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

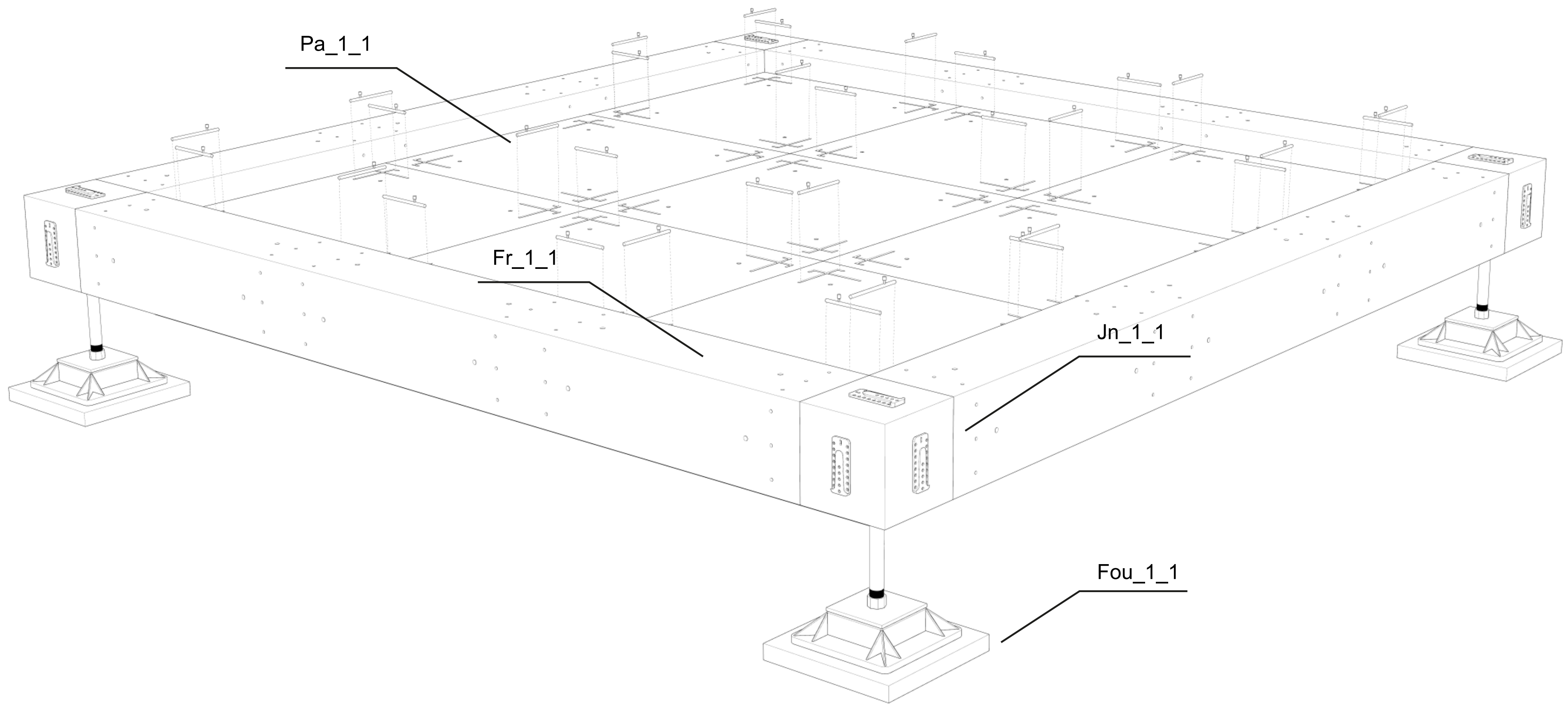
Fou_1_1

Jn_1_1

Fr_1_1

Pa_1_1

Metalware junction of the floor panel



CW 10

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

Fou_1_1

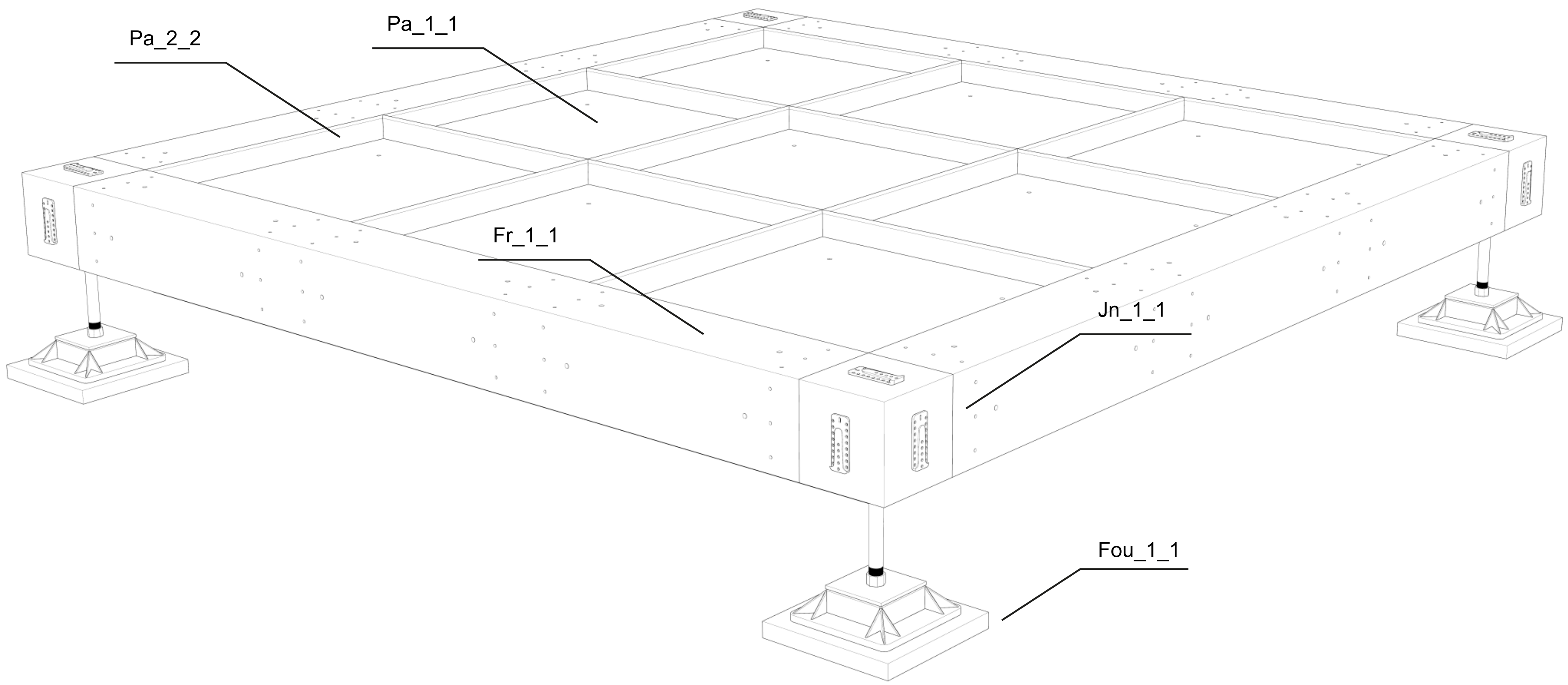
Jn_1_1

Fr_1_1

Pa_1_1

Pa_2_2

Panel cladding - Insulation/
Thermal Mass floor



CW 11

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

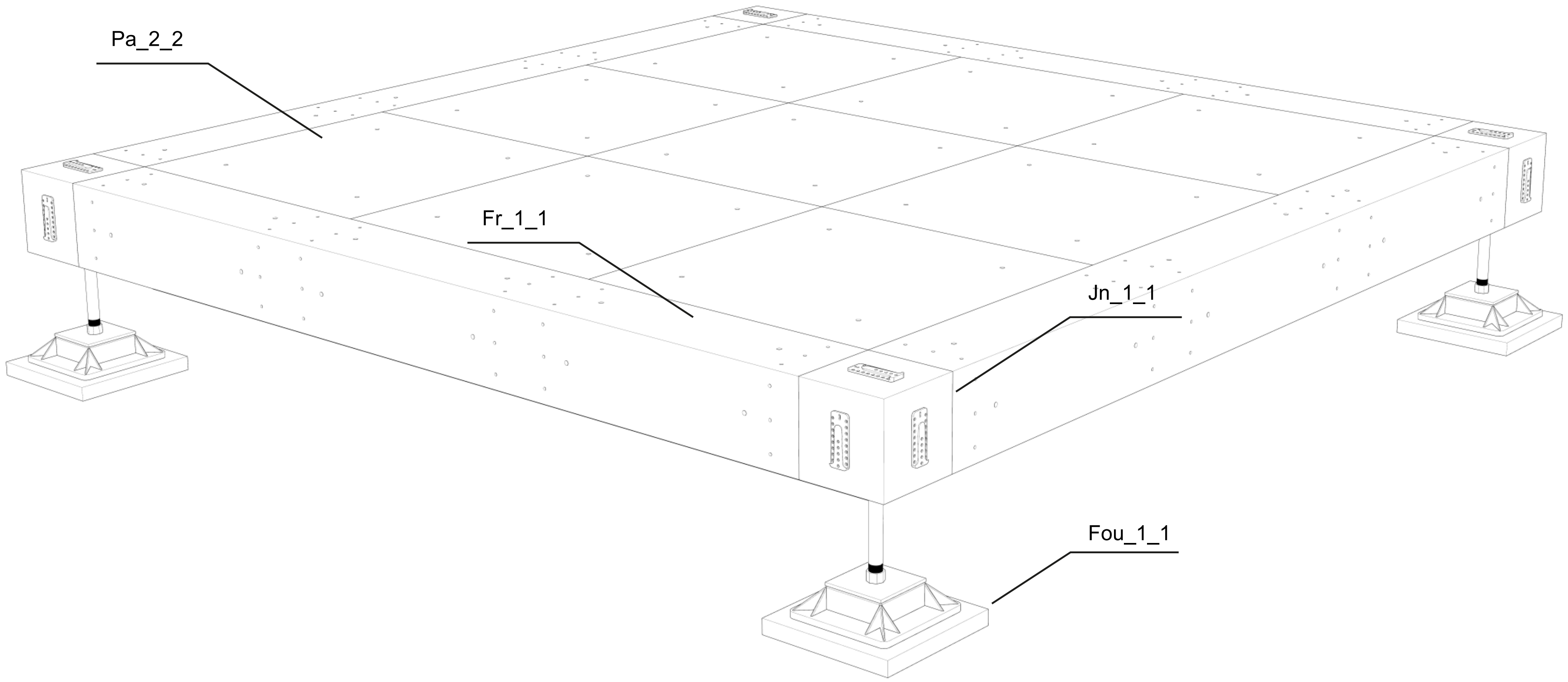
Fou_1_1

Jn_1_1

Fr_1_1

Pa_2_2

Internal finishing of the floor



CW 12

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

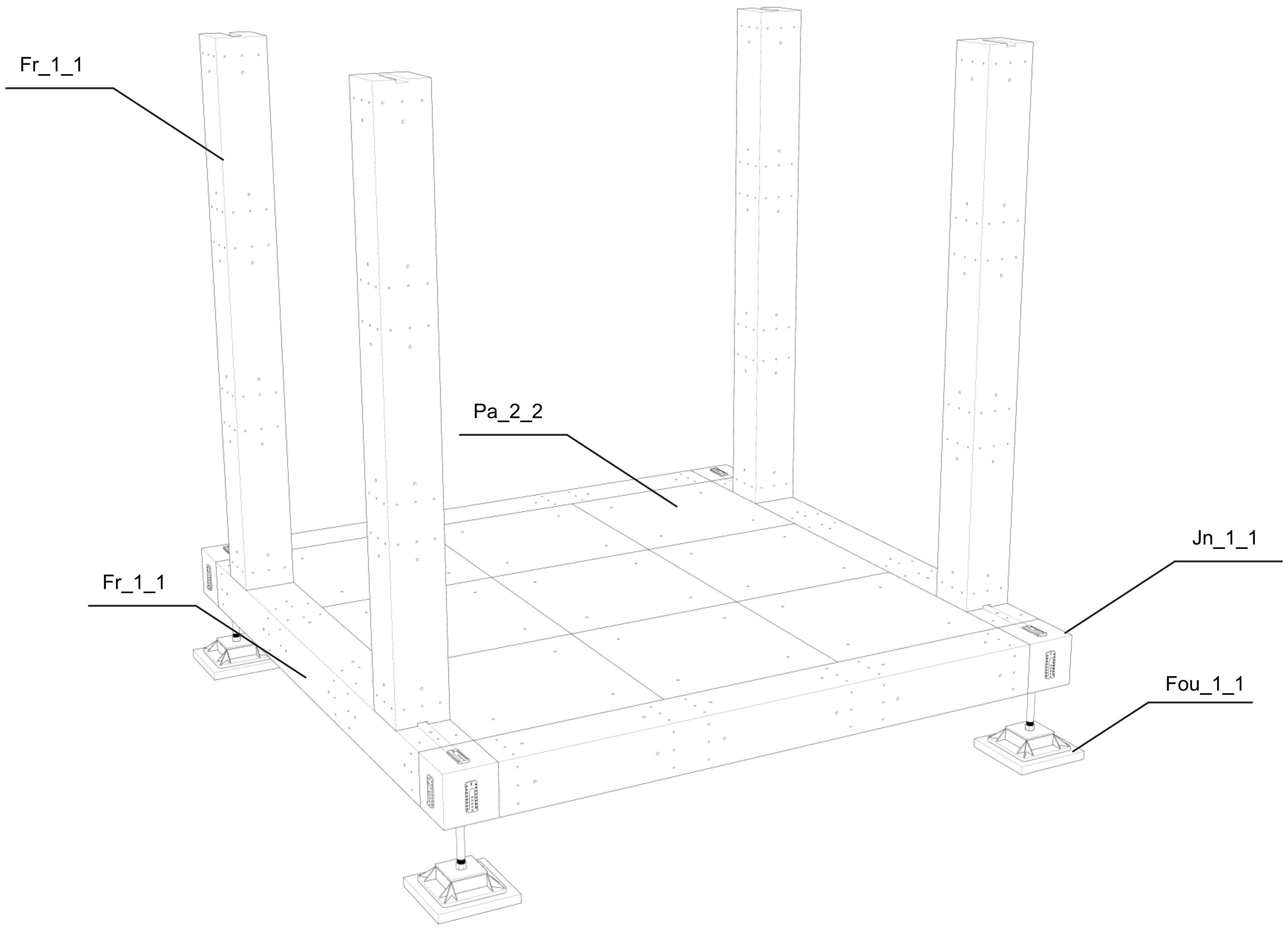
Fou_1_1

Jn_1_1

Fr_1_1

Pa_2_2

Columns



CW 13

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

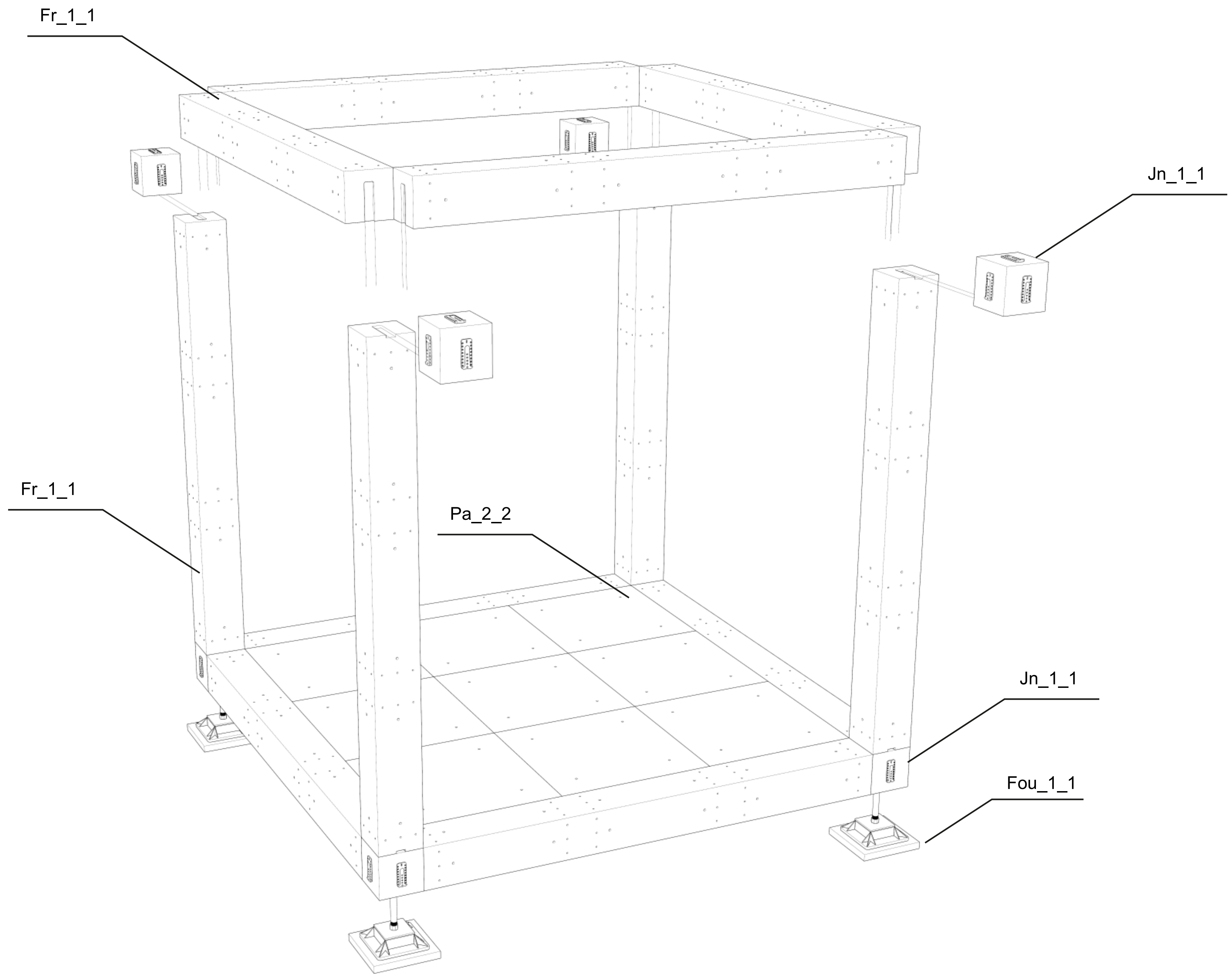
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Upper framework



CW 14

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

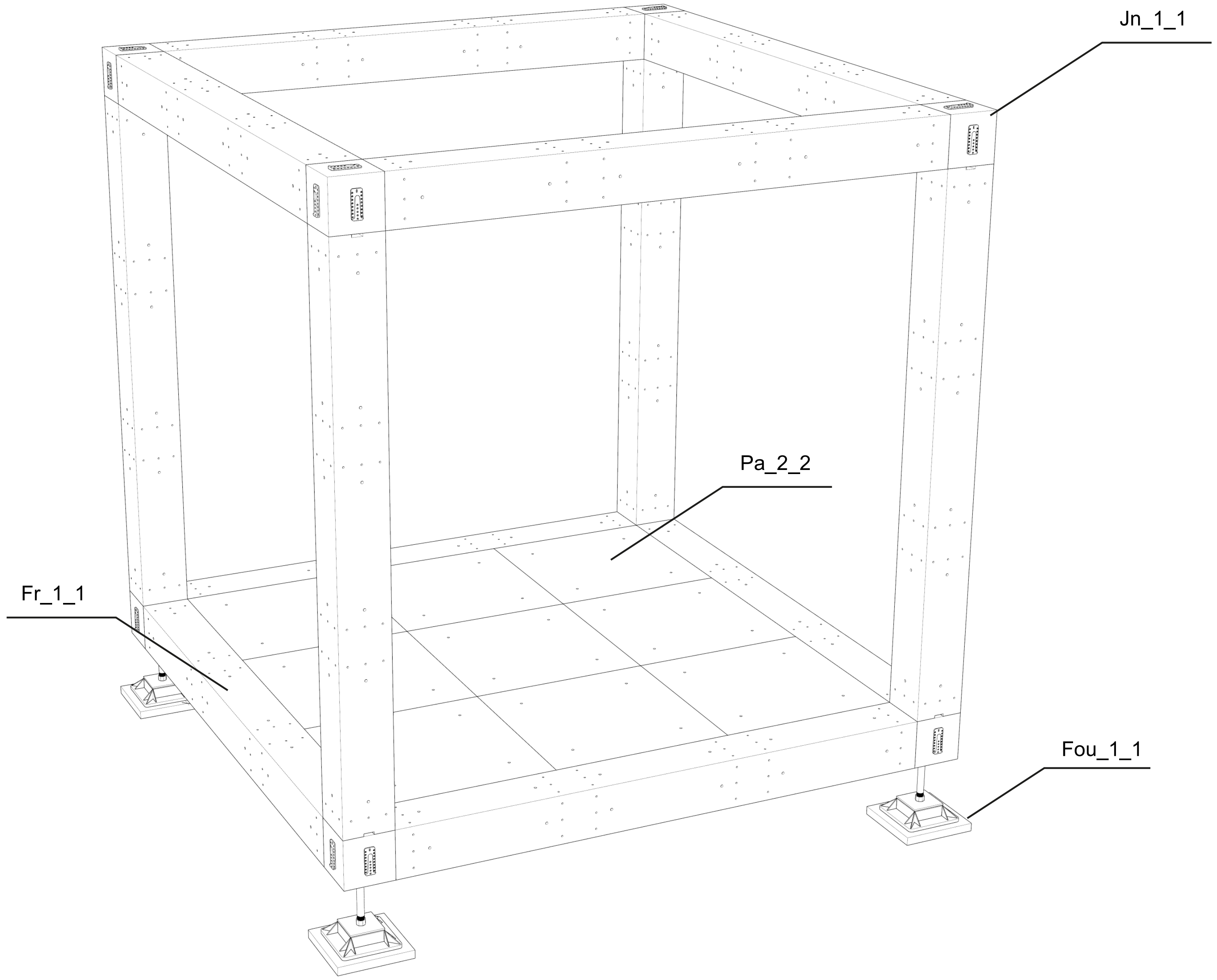
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Upper framework



CW 15

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

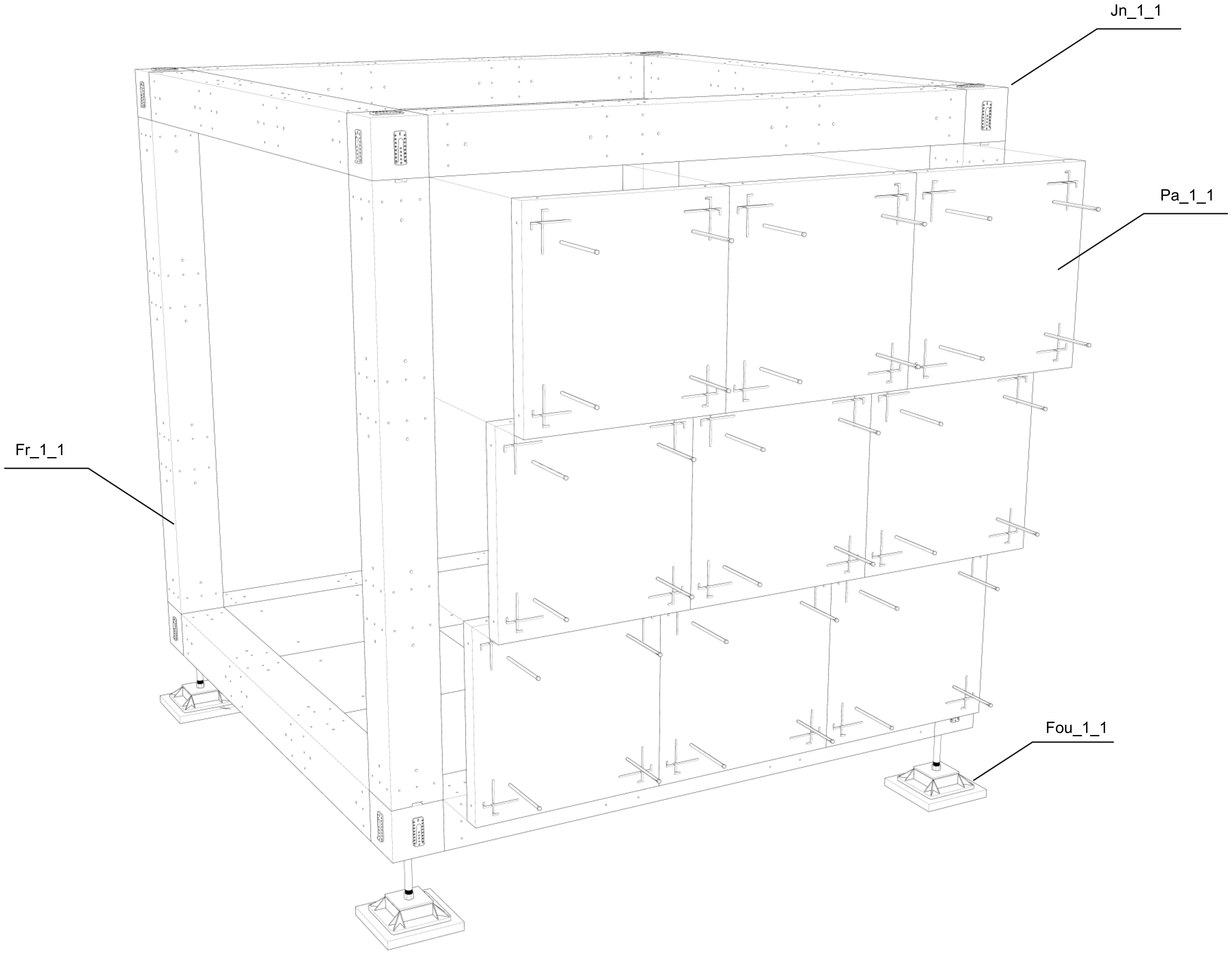
Fou_1_1

Jn_1_1

Fr_1_1

Pa_1_1

Wall panel



CW 16

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

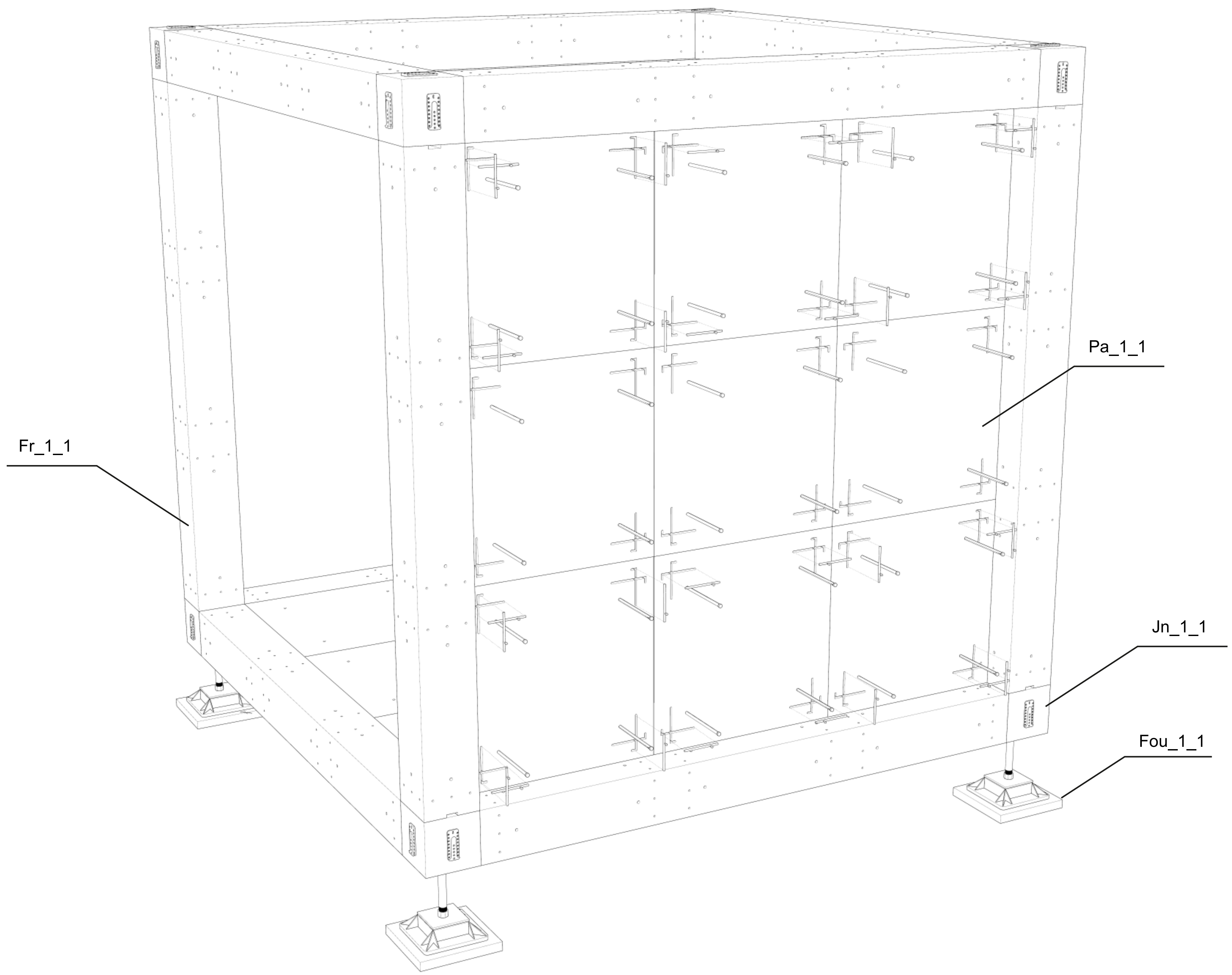
Fou_1_2

Fou_1_1

Jn_1_1

Fr_1_1

Metalware junction of the wall panel



CW 17

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

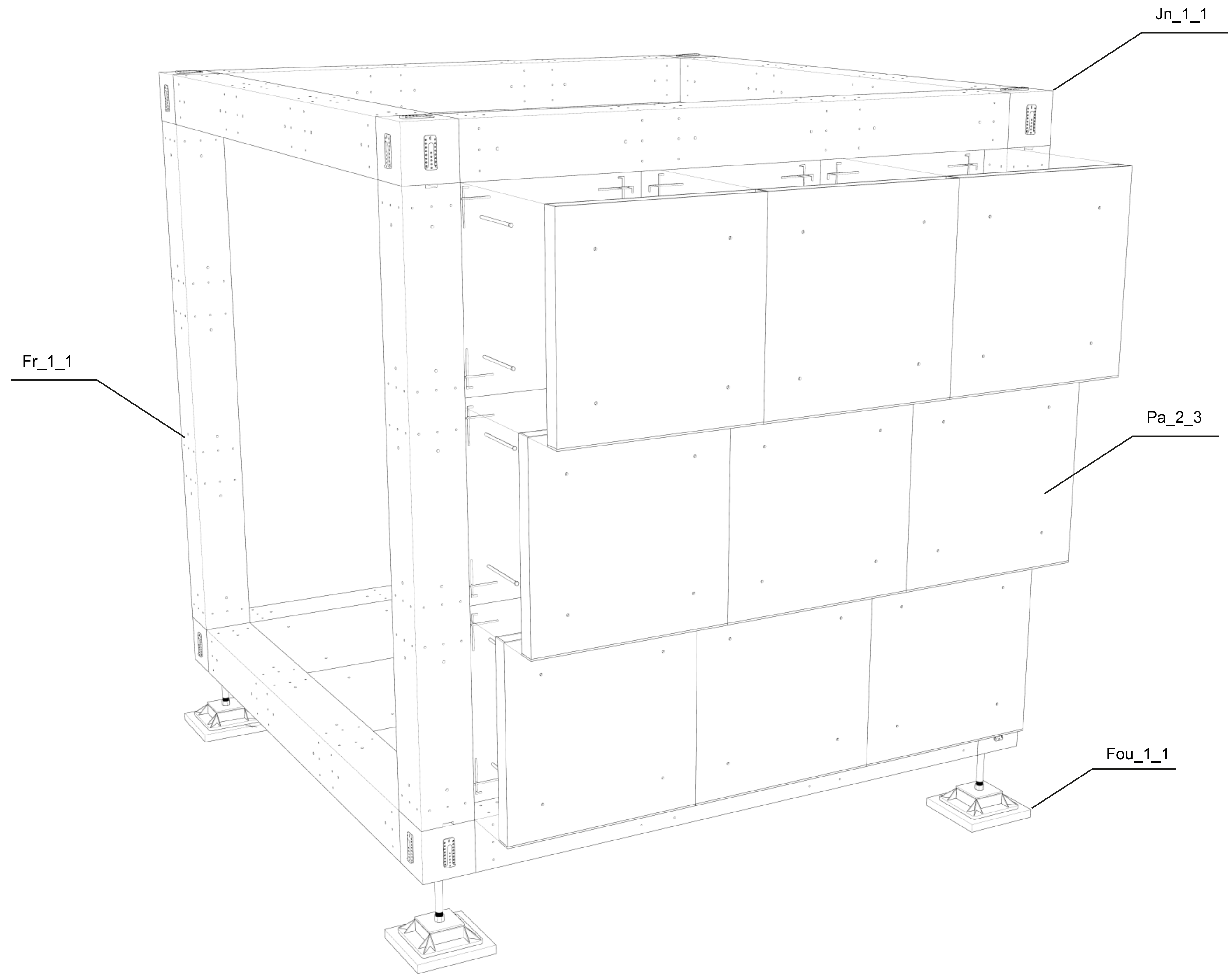
Fou_1_1

Jn_1_1

Fr_1_1

Pa_2_3

Panel cladding Thermal Mass wall



CW 18

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

Fou_1_1

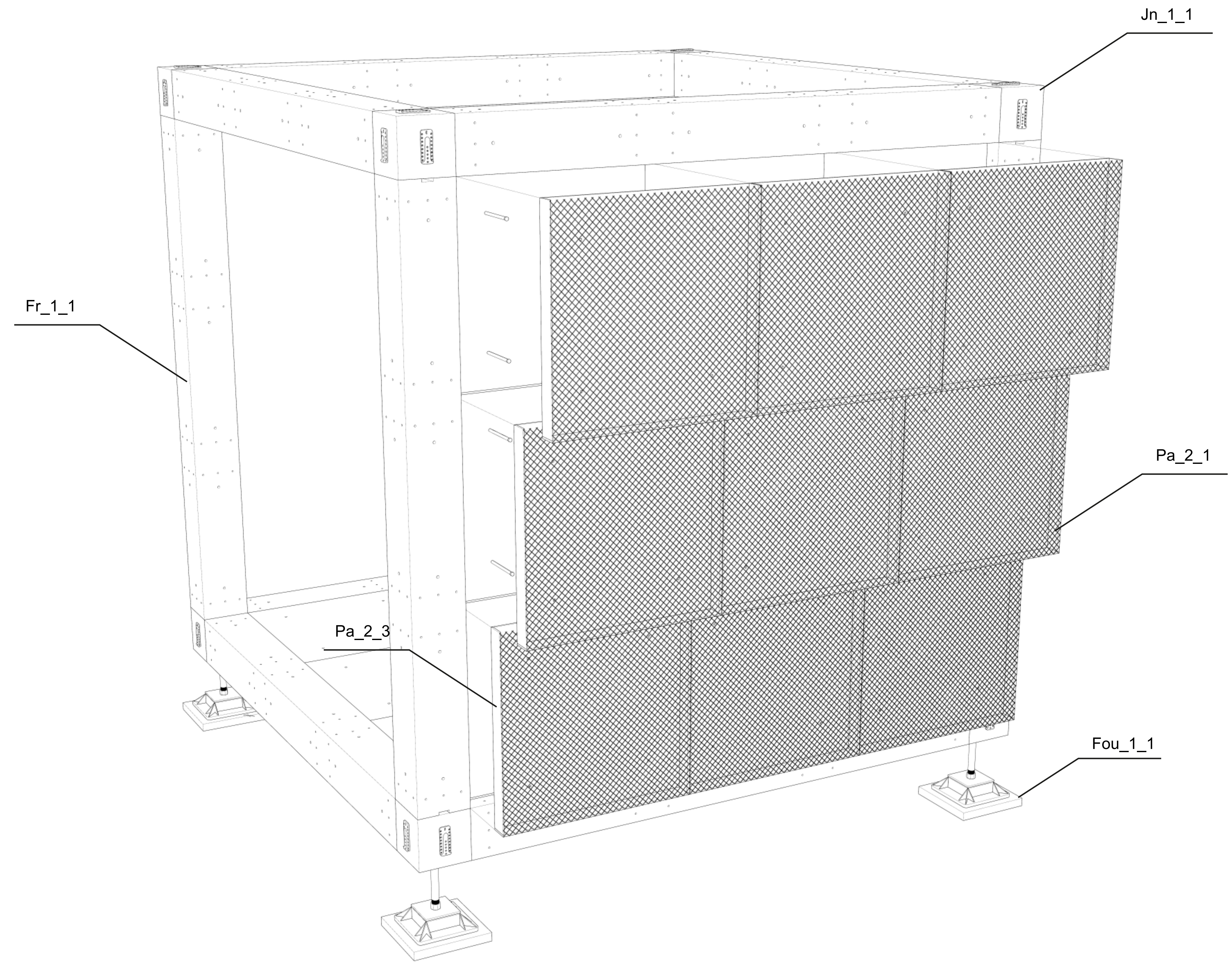
Jn_1_1

Fr_1_1

Pa_2_3

Pa_2_1

Panel cladding Insulation wall



CW 19

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fou_1_2

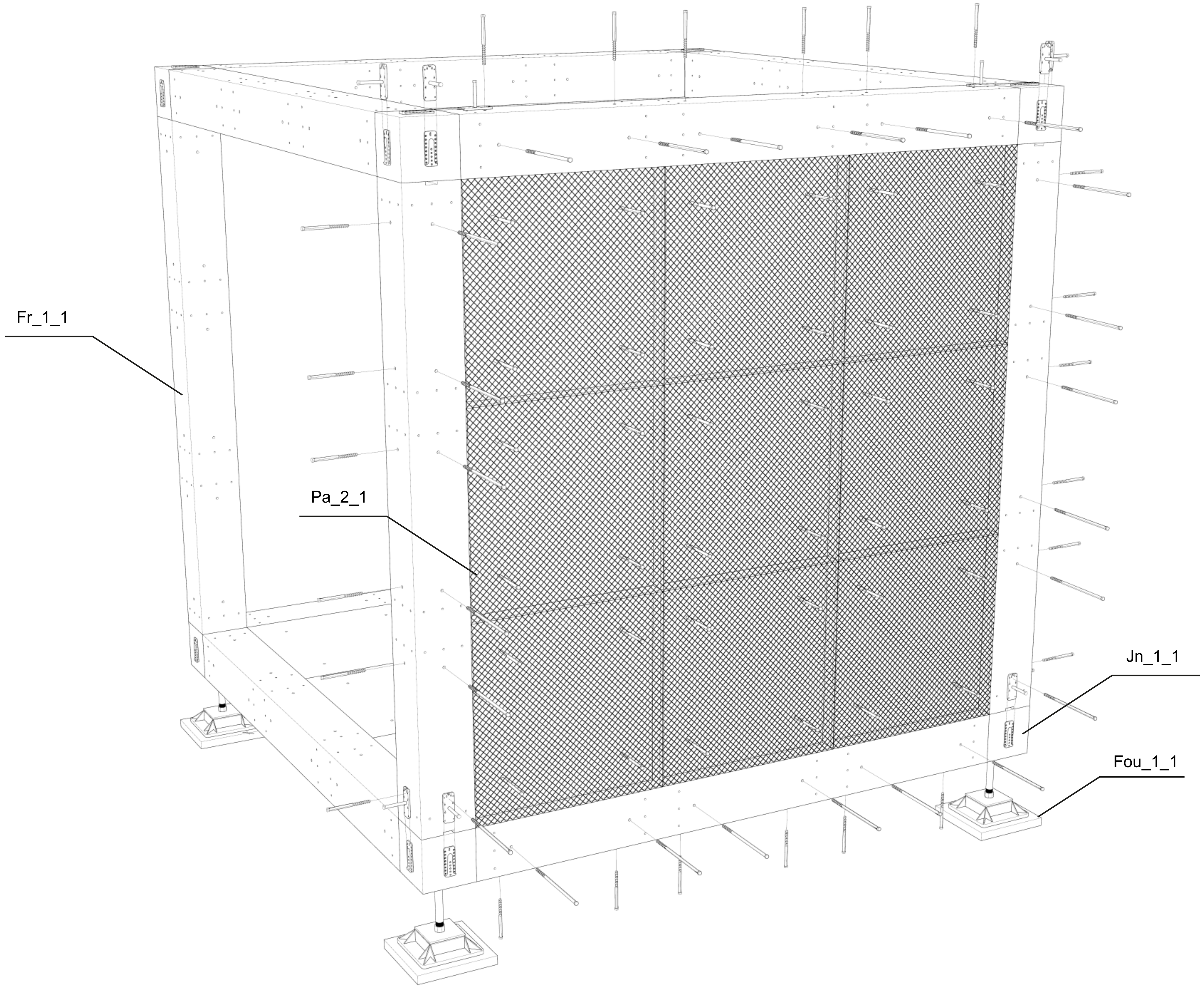
Fou_1_1

Jn_1_1

Fr_1_1

Pa_2_1

Metalware finishing structure



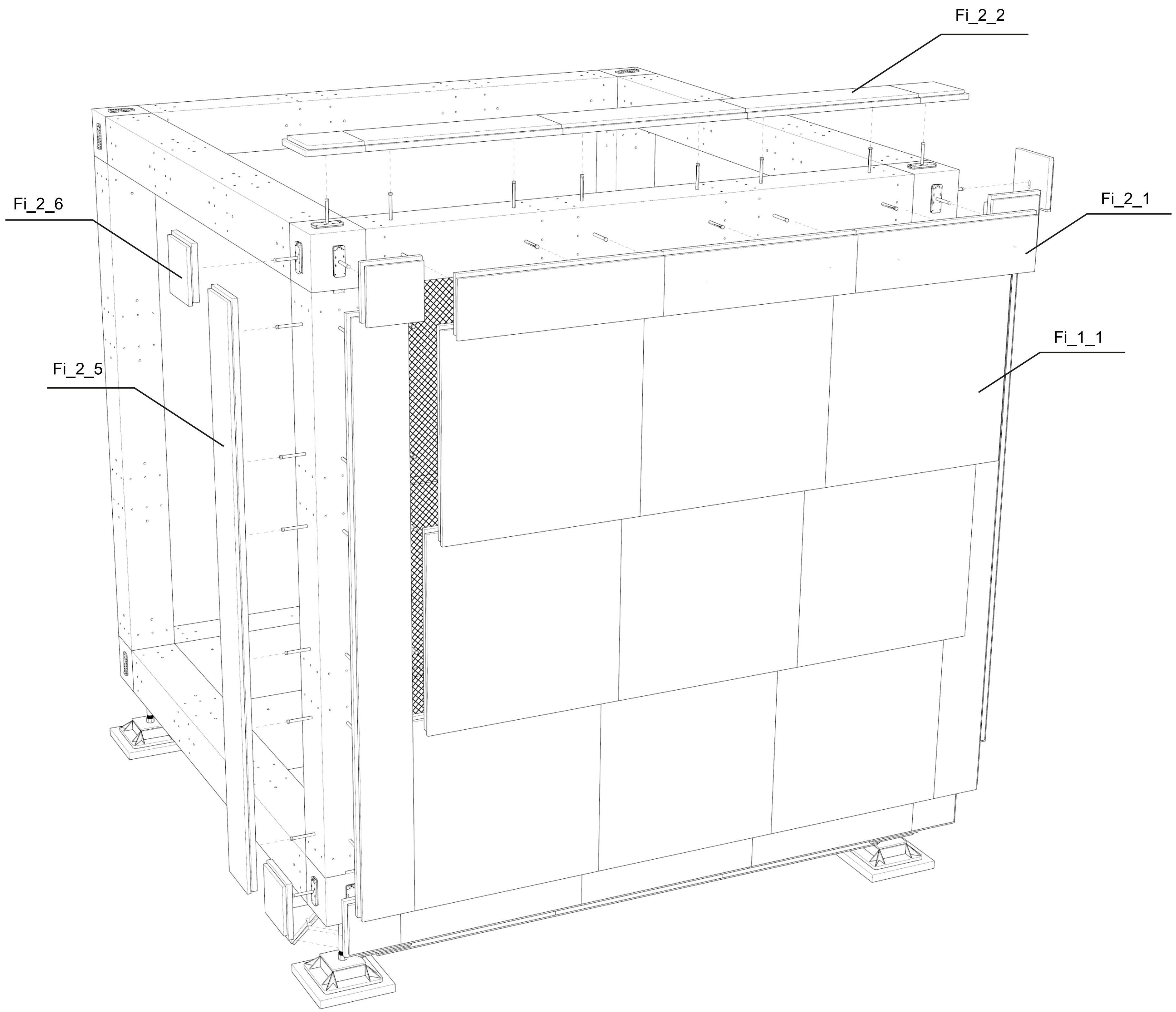
CW 20

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fi_1_1
Fi_2_1
Fi_2_2
Fi_2_6
Fi_2_5

Finishing



CW 21

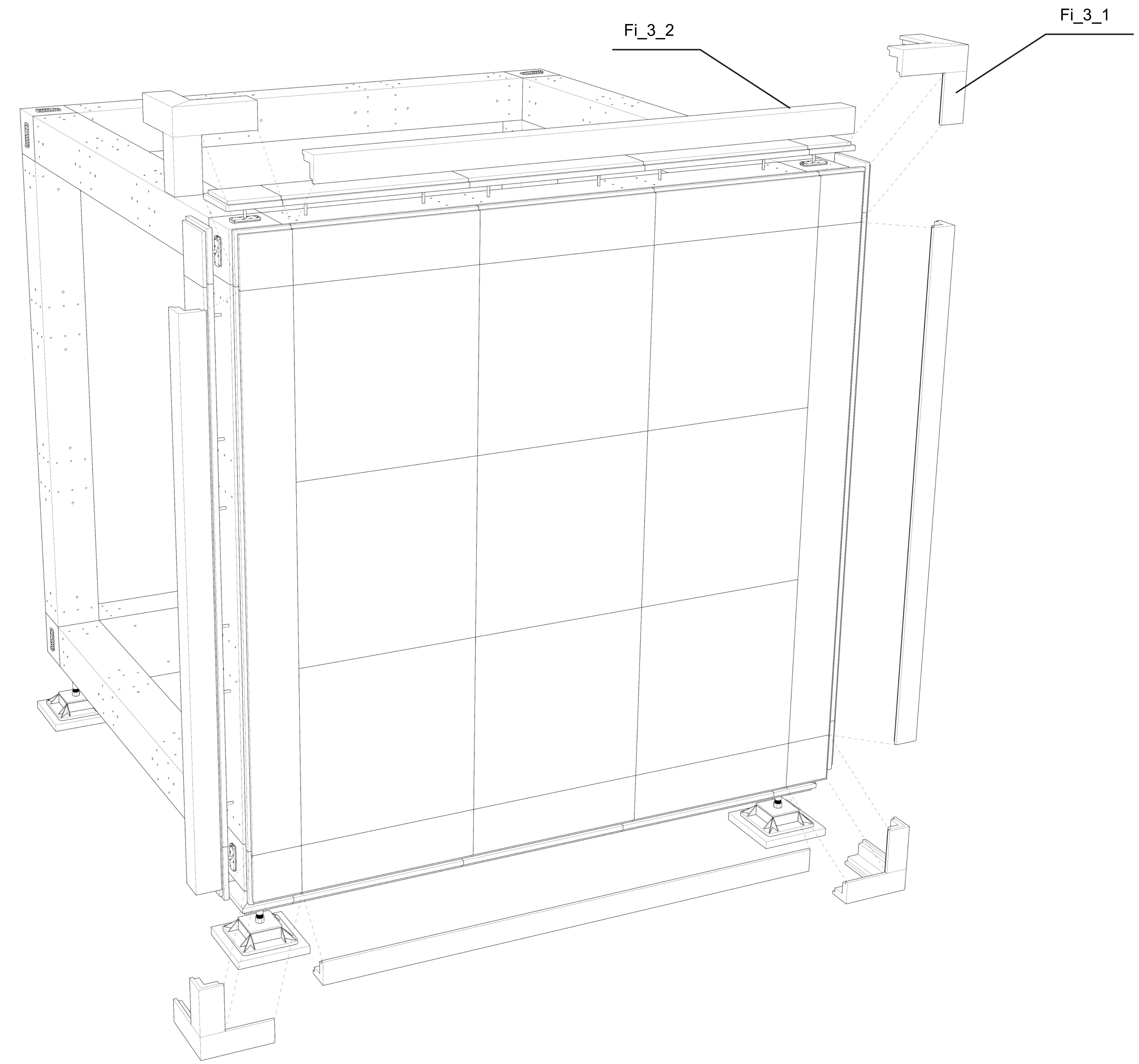
WOOD SYSTEM

ASSEMBLY INSTRUCTIONS

Fi_3_1

Fi_3_2

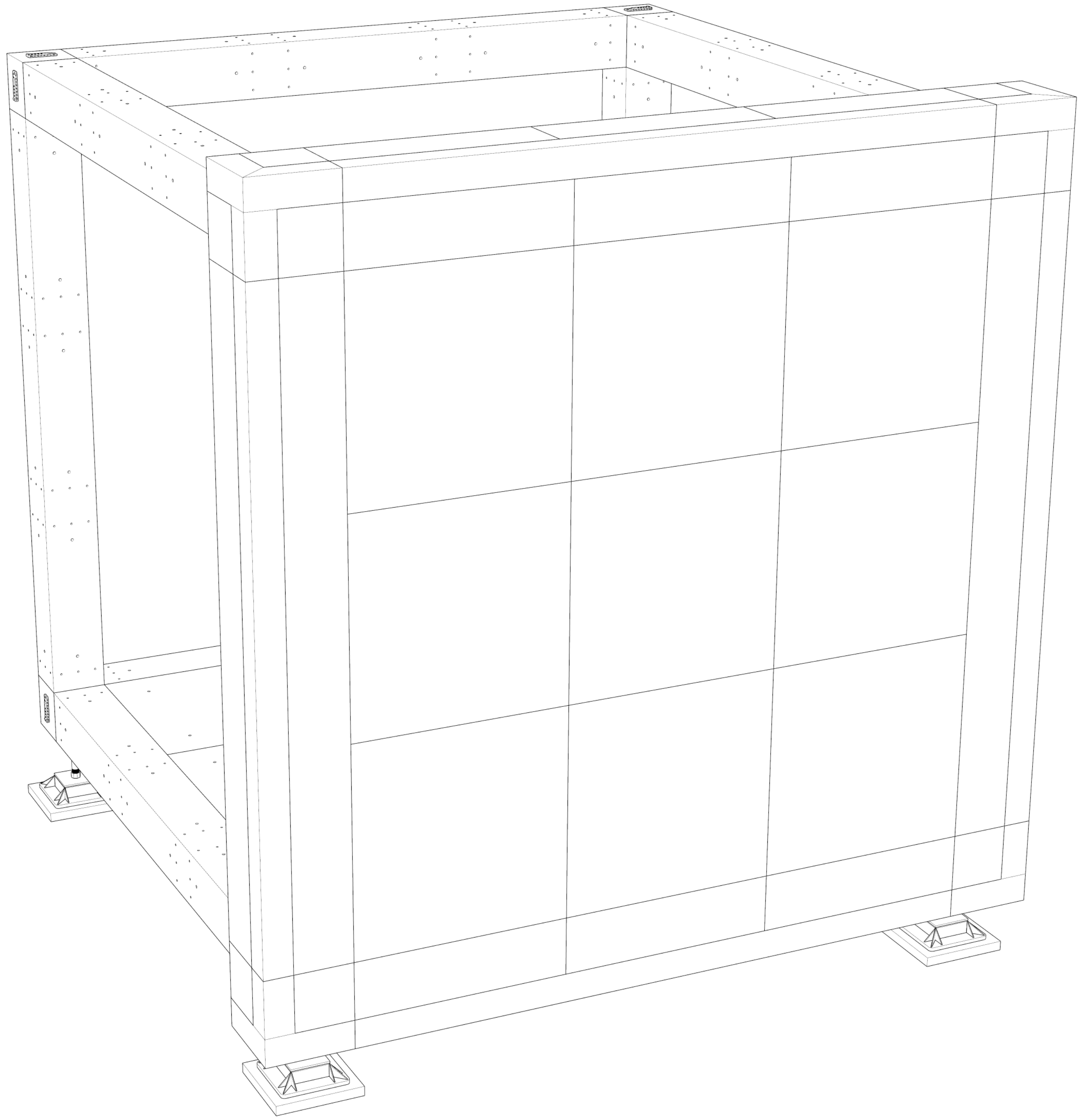
Finishing edges



CW 22

WOOD SYSTEM

ASSEMBLY INSTRUCTIONS



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