



VOLUMETRIC MASS TIMBER CONSTRUCTION FOR DORMITORIES ON US MILITARY INSTALLATIONS

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Fig 1. Hybrid timber and steel trusses at Sara Kulturhus



Fig 2: Modular unit, Hotel Revier

INTRODUCTION

In this Terminal Project, I am exploring the feasibility of employing mass timber volumetric modules as a solution for unaccompanied personnel housing (UPH), also referred to as dormitories or barracks, on U.S. military installations. Specifically, I will be answering the question: how can volumetric mass timber dormitories improve upon existing dormitories and barracks on US military installations in terms of environmental sustainability and occupant health and wellness while meeting the regulations and standards set by the government?

Recent studies have shown deficiencies in current military housing blocks which can be detrimental to resident's mental health and physical well-being, leading to operational performance decline, lack of retention and recruitment, and issues with equity within and across different branches (GAO, 2023). To better understand the external forces at play, I reviewed federal reports and federal guidelines related to dormitories and housing in the military to inform what has and has not been working, and to better understand the future needs and goals of the

Department of Defense (DoD).

I also examined and analyzed ten building case studies in which volumetric mass timber is utilized to better inform the best practices and potential issues as I continued into the design phase.

The culmination of my background research and analysis is the design of a series of three modular dormitory units based on existing unit types in the DoD catalog. Two of these modules were then designed as conceptual three-story buildings with consideration to the building programmatic requirements, lateral bracing and mechanical runs.

By standardizing unit layouts through volumetric modules, my goal is to present an adaptable, prototypical design model that could apply to a variety of building sites. The incorporation of mass timber and pre-fabrication allows for higher-quality housing along with the benefits of biophilic design, addressing some of the current concerns plaguing the existing DoD dormitories.

DILEMMAS IN THE DOD



Fig 3: Fort Riley, Kansas

The DoD currently operates 750 bases across 80 countries. Over half of those bases are in the U.S., and each state contains at least one installation (military.com). This equates to hundreds of thousands of men and women being housed in nearly 9000 dormitories and barracks (which of these terms is used for the UPHs depends on the military branch). While it varies by branch, after initial training, every unmarried service member is required to stay in this housing for a determined period correlating with their rank (GAO 2023). A report released by the Government Accountability Office (GAO) in September this year identified issues within the condition of buildings including deteriorating MEP systems, mold, insufficient thermal comfort, and durability. Overall, these issues have led to dissatisfaction with current living conditions, a decline in reenlistment numbers, and poor mental and physical health.

Over half of the officials interviewed during the study claimed barracks living conditions are an important factor when considering reenlistment. Other surveys have indicated subpar experiences living in the barracks contributed to decisions

not to reenlist, citing lack of confidence in management and lack of control over living conditions. Some senior-enlisted members reported needing lower standards for training due to dorm-dwellers being unfocused due to a combination of factors including lack of sleep and hot showers. Other senior officers noted reduced productivity and work performance, lower morale, and higher instances of mental health episodes (GAO, 2023). A 2020 study conducted by a recent UO PhD, Sean-Michael Kelley, further illustrates the detrimental mental and physical effects of poorly designed barracks. His research focuses on the lack of social connections between residents exacerbated by antiterrorism design and a focus on individual rooms (Kelley, 2020). While Kelley does not conclude with a best design floor plan, he does conclude with some general recommendations for future barrack design to increase social interaction and resident health including single-loaded corridors to create an entry threshold, inclusion of exterior balconies, and apartment-style units with common areas. Part of Kelley’s work was to interview residents residing in different types of dormitories from different eras of military history. While this is

beneficial for comparative research, the lack of standardization in building standards and unit design across installations has been found to diminish morale, leading service members to feel as though they’re being treated unfairly, a sentiment in direct contrast of the goals outlined in the Military Compensation Background Papers (GAO, 2023). Mass timber panels are by their nature a customized product, but standardized pre-fabricated modules are a system that comes the closest to a commoditized product (Muszynski, 2021; Atkins et al, 2023). More standardization in the manufacturing process has economic in addition to the social benefits including ability for rapid deployment and cost reduction (Bertram et al, 2019).

Due to deteriorating conditions, dormitories and barracks are ripe for redesign (GAO, 2023); the DoD is interested in a sustainable future and mass timber construction (Office, 2021). CLT has been deemed a viable option for projects if economic considerations are met. In the 2023 Mass Timber report, authors report that while associated raw materials can be 15-20% higher with mass timber, there are overall cost benefits with reduced construction times, less variability, and reduced foundational needs which are starting to even the playing field (Atkins et al, 2023). The changing economic landscape combined with the social and health benefits found through the biophilia of exposed timber construction, makes mass timber a viable choice for future construction on military installations.

Unsatisfactory Conditions
Lack of Equity
Poor Mental + Social Health
Retention + Recruitment
Labor + Construction Issues
Meeting Sustainability Goals

OPPORTUNITIES IN MASS TIMBER



Fig 4: Hotel Revier, Switzerland

While mass timber is gaining in popularity, there are still some barriers to adoption including concerns about mold and pests, acoustic and vibration issues, and apprehensions about natural disasters including earthquakes and fire. When utilizing a bio-based material, decay from fungus and pests is always going to be a concern (Cappellazzi et al, 2020). However, there is currently common use of untreated lumber inside wall cavities and as sheathing both on the interior and exterior without causing too much concern. As with all buildings, proper enclosure detailing is required to mitigate water penetration and to allow the material to dry out in the case of wetting. There are additional concerns with saturating mass timber given it's dense, solid nature, leading to long time periods for drying (Cappellazzi et al, 2020) but this argues for the benefits of pre-fabricating full modules off-site, ensuring the exteriors are fully weather-protected before being exposed to the natural elements. The nature of solid wood does pose problems for acoustics and vibrations, but studies show mitigating strategies can be effective (McLain, 2020). One often used strategy to improve sound isolation is pouring a thin layer of concrete on

top of mass timber decking creating a composite slab; in the proposed volumetric model, this wouldn't be an effective strategy as the goal is to minimize on-site work. A 2018 report released by WoodWorks lists three primary ways to improve acoustical performance in mass timber assemblies: add mass, add noise barriers, and add decouplers. The pre-fabricated module proposed in this project can utilize all three methods – when assembled together, the finished construction will likely have double panels in walls and ceilings (Carvalho et al, 2020), leaving an air gap or space for the addition of an acoustic mat to alleviate sound and vibration transmission between units.

Addressing mass timber performance in response to seismic events and fire, multiple studies have been conducted testing cross-laminated timber (CLT) (Bhandari et al, 2023; Chen et al, 2020; Zelinka et al, 2018). Following a two-story shake-table test in 2017 and a three-story test 2022-23 in OSU's Emmerson Lab, in Spring 2023, a 10-story test was conducted on a shake table at University of California San Diego, simulating the 1994 Northridge earthquake followed by the 1999

Chichi earthquake. Post testing, researchers found no structural damage (Rubacava, 2023). Research in this field is ongoing and extends beyond mass timber into composites and other lateral force resisting systems, including combining mass timber modules with a steel braced frame (Mithun, Aspect, 2021-22). Some of the most extensive fire testing on mass timber structures was conducted as a pre-cursor to the Type IV building code updates (Zelinka et al, 2018). In order to prove the safety for tall timber structures, five full-scale, two-story apartment mock-ups were constructed in the burn room of the Bureau of Alcohol, Tobacco, Firearms and Explosives Fire Research Laboratory. These experiments were conducted both with and without sprinkler systems. Results from this testing found that the CLT structure formed a protective layer of char and essentially self-extinguished. General industry guidance is to design a 1" sacrificial char layer to achieve a one-hour fire rating, although new experiments are being done to better understand charring rates by species and provide more specific guidelines (Liu and Fischer, 2023). Interest and research in fire

performance continues to gain traction as mass timber grows in popularity. In June 2023, Oregon State University received a \$1 million federal grant to study the effects of fire on mass timber (James, 2023).

Other than the well-documented environmental and carbon sequestration benefits of wood, the biggest benefit to occupants is the effects of biophilia. Research has shown multiple positive effects including improved concentration, reduced anger and fear, reduced anxiety, better sleep, and even thermal benefits (Ikei et al, 2017; Morita et al, 2020). While wood is used in the form of dimensional lumber to construct multi-family housing, very little of it is exposed on the interior to take advantage of the proven health benefits. Mass timber panels offer the opportunity to expose wood on multiple surfaces in a dwelling unit bolstering intangible health benefits for residents. In addition, solid wood is denser and more durable than hollow walls covered in gypsum board and can provide a tighter thermal envelope.

Increased Usable Square Footage
Fire Protection
Faster Construction
Solid Wall Durability
Longevity
Biophilia
Co-Benefits Along Supply Chain
Carbon Sequestration

A CASE FOR MODULAR



Fig 5: Unit modules in factory for student housing at Gottingen

The first CLT panels were produced in Austria and Germany in the 1990s and their industry has continued to grow. The Alpine region currently accounts for 70% of global CLT production (Muszynski, 2021). The American industry is much newer, just getting its start in 2015 with DR Johnson manufacturing the first structurally certified CLT panels in the USA (drjlumber.com). While the industry is still somewhat new, the Woodworks Innovation Network, an interactive map tracking mass timber projects in the U.S., shows exponential growth in the last five years, particularly in the Pacific Northwest and East Coast. However, despite the increase in overall projects, there is a notable absence of mass timber volumetric, modular multi-family construction. Despite numerous examples being built as far back as 2008 in Europe, the Ammerwald BMW hotel in Germany being the earliest example, there are yet to be any completed projects in North America. The Wadajir Market and Residence by Mithun made it through construction documentation, and a two-story micro-unit pilot project, but due to internal organizational issues of the developer has been paused indefinitely (Curtis and Noll,

2021). One recent development in the field that did reach completion is Mass Casitas, spearheaded by Hacienda CDC, a pilot housing project in response to the growing need for quick, affordable housing. In September 2023, six single-family volumetric modules were constructed in a warehouse at the Port of Portland's Terminal 2 site and installed in several locations in Oregon (Mass Casitas). Each unit is constructed with mass plywood panels creating the structure on six sides. Units were weather-proofed and shipped to the site where some additional work was performed including foundations and cladding. If the prototypes are successful, the intention is to mass-produce modules in a new factory at the Port of Portland.

A 2019 study by McKinsey and Company found the value for modular construction in Europe and the U.S. could reach \$130 billion by 2030 (Bertram et al, 2019). They defined the benefits of modular construction to include reduced construction costs and overall building lifetime cost, reduced construction timelines, less variability in construction costs, and improved overall building quality including energy and

seismic performance. In addition, the increasing need for affordable housing and a declining availability of skilled laborers sets the stage for long-term modular success. McKinsey noted one of the biggest challenges to overcome, particularly in the U.S. market, is the perception of manufactured housing as being poor quality. Unfortunately, despite being a separate type of building with different design standards, pre-fabricated construction is often lumped in with manufactured housing and suffers from the same negative perceptions. There are companies working to change that view such as Opal Shelter based in Vermont; they have designed a system of energy-efficient, zero-waste, panelized CLT modules that can be combined to create dwelling units from 500sf to 1500sf (opalshelter.us). In the U.S., most mass timber projects are pre-fabricated and panelized, not volumetric. While

the volumetric modular multi-family model has yet to be proven in mass timber products in the U.S., the potential building benefits remain the same, plus additional co-benefits including carbon sequestration, biophilia for occupants, and economic revitalization in depressed timber regions both in the PNW and East Coast through an increased market for timber products.

Standardization
Reduced Supply-Chain Variability
Addresses Labor Shortages
Less On-Site Construction
Reduced Construction Delays
Quality Control
Economies of Scale



WOHNEN 550
MULTIPLE LOCATIONS



ADOMA APARTMENTS
2015
TOULOUSE, FRANCE



WOODIE
2019
HAMBURG, GERMANY



BMW HOTEL
2008
AMMERWALD, GERMANY



PLATENSIEDLUNG
2020
FRANKFURT, GERMANY



HOTEL REVIER
2017
LEZERHEIDE, SWITZ.



STUDENT UNION
2013
HEIDELBERG, GERMANY



SARA KULTURHUS
2021
SKELLEFTEÅ, SWEDEN



STUDENT RESIDENCE
2020
GOTTINGEN GERMANY



SCHOOL EXPANSION
2018
FRANKFURT, GERMANY

CASE STUDIES

In the course of conducting background research, ten volumetric modular mass timber case studies were selected for further analysis. All of these projects are situated within Europe, with a predominant concentration in Germany. Notably, two companies emerge as key players responsible for the majority of timber manufacturing seen in these projects: Kaufmann Bausysteme, headquartered in Reutte, Austria, and LiWood, based in Munich, Germany. Both entities specialize exclusively in timber modular construction, offering their knowledge and services to projects across various sectors and scales.

The selection of the ten case studies was governed by two primary criteria. Firstly, emphasis was placed on the construction methodology employed, with a secondary focus on projects within the housing, dormitory, and hospitality sectors. An exception to this criterion is the modular system employed for school expansion endeavors in Frankfurt, Germany.

This particular case garnered attention due to its innovative approach, which involves the integration of LVL beam to connect semi-open modules, creating large, open classrooms. The adaptability of this concept to the housing realm warranted its inclusion for comparative analysis.

WOHNEN 550



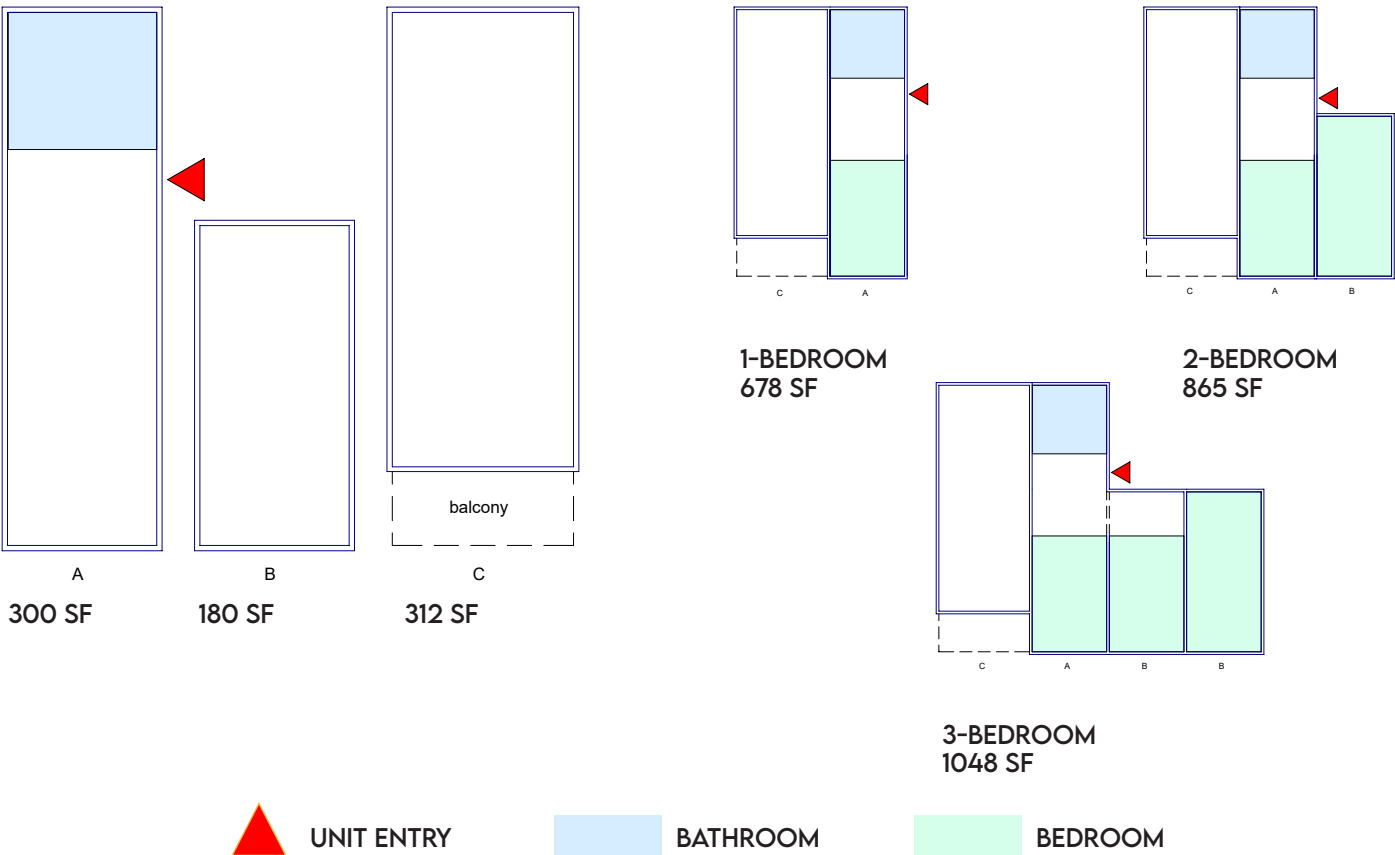
YEAR COMPLETED 2016+
LOCATION AUSTRIA
ARCHITECT JOHANNES KAUFMANN ARCHITEKTUR
ENGINEER MERZ KLEY PARTNER
MANUFACTURER KAUFMANN BAUSYSTEME

NUMBER OF MODULES VARIES
CONSTRUCTION TIME 6-9 MONTHS

The Wohnen 550 program is an initiative for affordable housing administered by the non-profit housing developer Vogewosi in Austria. Their primary focus is on constructing high-quality, affordable housing units that are both efficient and environmentally sensitive. Through a partnership with Kaufmann Bausysteme, an experienced manufacturer of mass timber modular structures, they are able to swiftly address housing demands across various cities in the country.

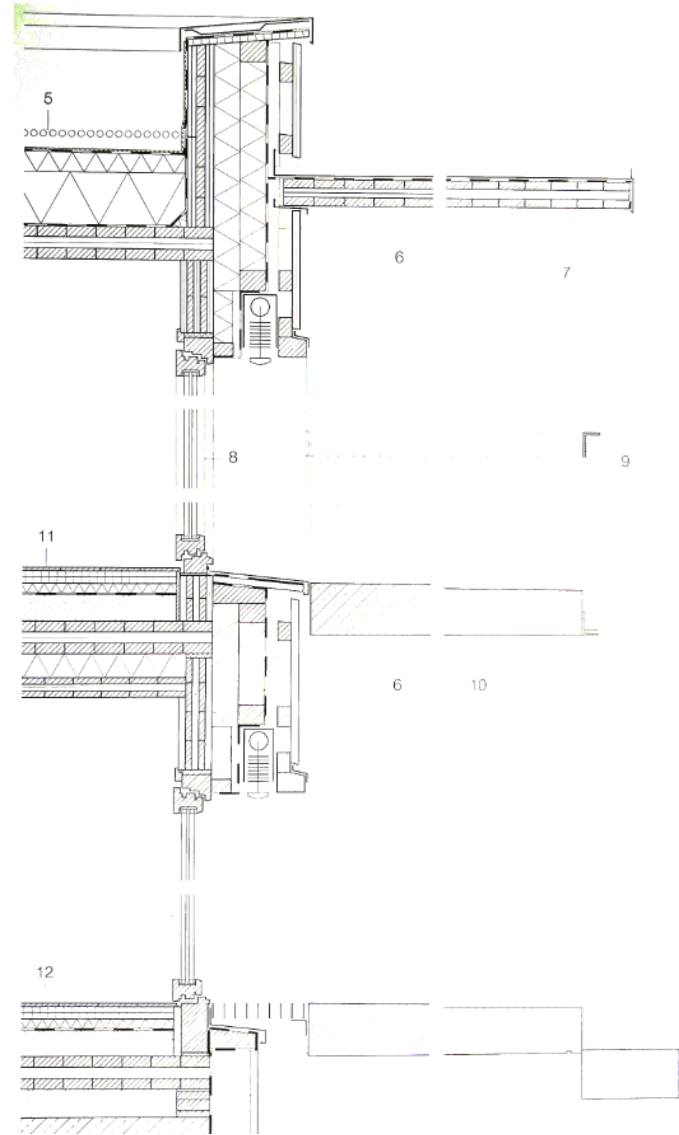
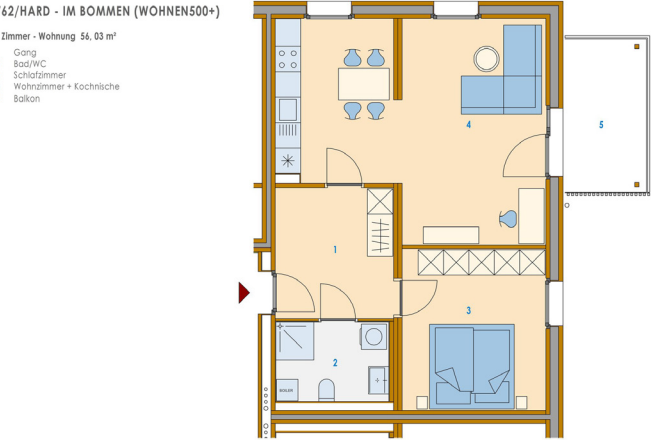
These starter apartments are specifically targeted towards young renters and are offered in three different unit types: small, medium, and large. Each unit is priced at 550 euros per month, inclusive of utilities. Currently, there are three completed projects, with two more under construction. Typically, the modules are arranged in a centralized layout around a precast concrete stair core. The unit types are stacked from floor to floor, contributing to the structural integrity of the building.

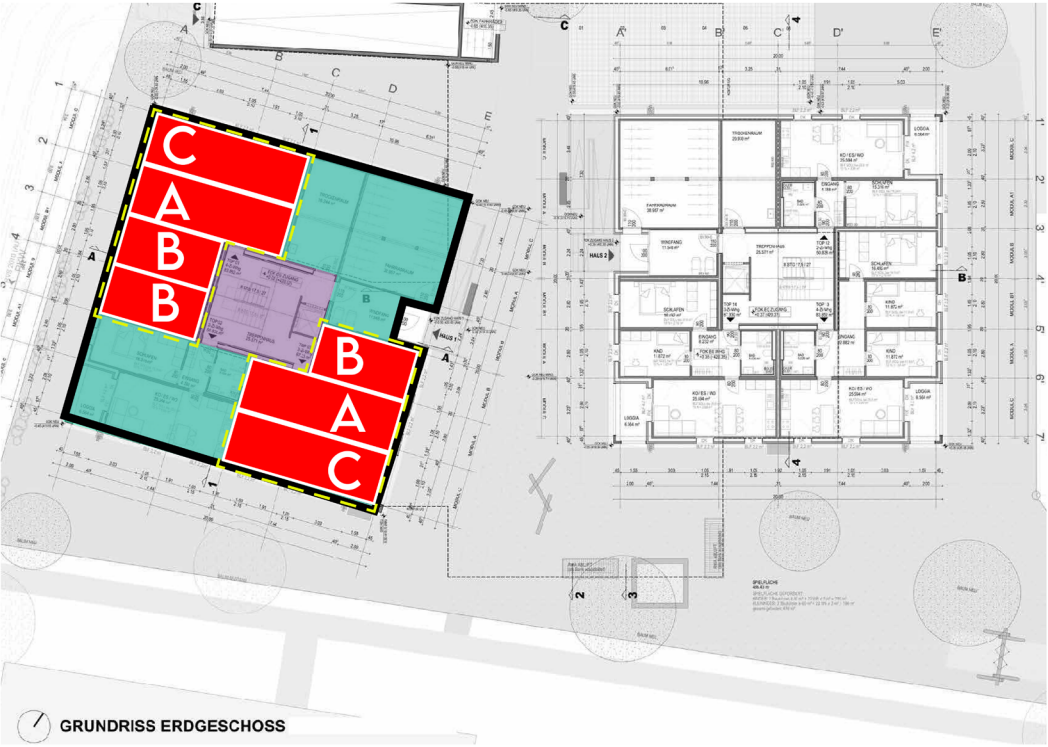
The Wohnen 550 program employs a series of three modules of varying sizes, each serving a consistent primary function, whether it involves an entrance, balcony, or wet core. Interior partition walls are flexible, allowing for the combination of modules to create units with a variable number of bedrooms. Additionally, balconies are attached externally to the building and are not integrated into the modular construction process.





Each module is semi-closed, with floors and ceilings consisting of 2.4-inch 3-ply CLT sandwiched between layers of mineral wool insulation, with additional acoustic padding beneath the finished floor. The module walls that separate individual units are constructed with 3.9-inch CLT panels on either side, augmented with insulation and an air layer to enhance acoustic performance. Within the unit interiors, gypsum wallboard is applied to provide acoustic and fire protection, concealing the underlying CLT structure. Module walls occurring within the unit are constructed with doubled-up 3.9-inch CLT panels, without any insulation.





WOHNEN 500

centralized

-  building footprint
-  non-modular construction
-  modular construction
-  one module
-  one unit

WOODIE



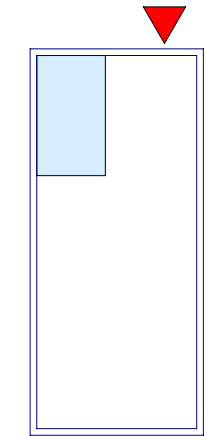
YEAR COMPLETED 2017
LOCATION HAMBURG, GERMANY
ARCHITECT SAUERBRUCH HUTTON
ENGINEER WETZEL & VON SEHT
MERZ KLEY PARTNER
MANUFACTURER KAUFMANN BAUSYSTEME

NUMBER OF MODULES 371
CONSTRUCTION TIME 10 MONTHS

The Woodie was erected in response to the scarcity of affordable student dormitories in Hamburg, Germany. The six-story building features a concrete base and is further supported by concrete stair and elevator cores, with the timber modules integrated into this concrete structure to facilitate the transfer of horizontal forces.

At Kaufmann Bausysteme in Austria, the production line consists of 17 stations capable of producing four complete modules per day. Due to limited storage and staging space on site, these modules are transported to Hamburg as needed. Twelve modules are mounted on site daily, with the facade added after all modules are in place.

Throughout the building, there is only one type of module, serving as a self-contained unit complete with plumbing, a bathroom, and a kitchenette.

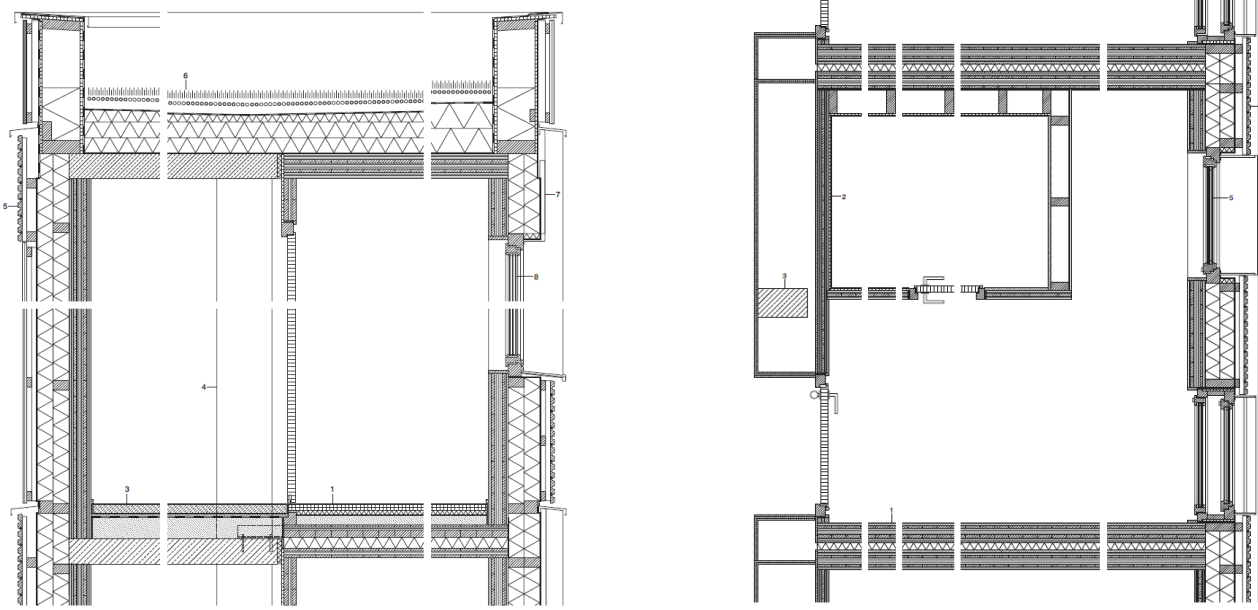


226 SF

UNIT ENTRY

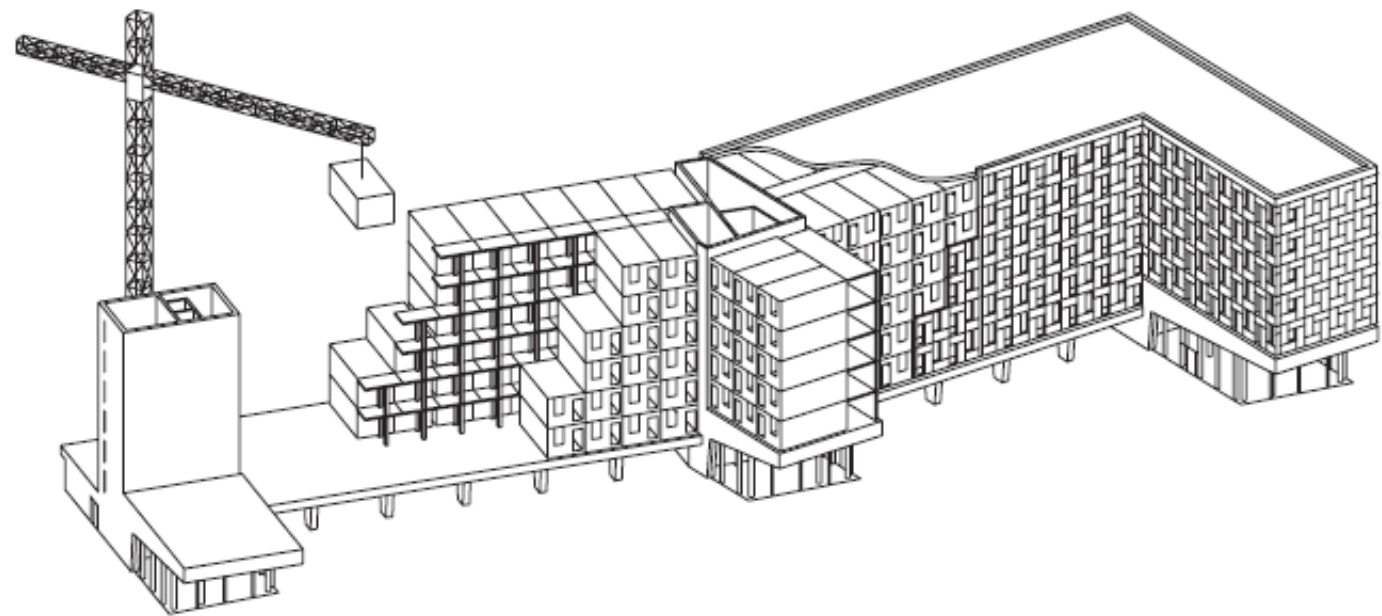
BATHROOM

BEDROOM



Each module is fully enclosed and encompasses the entirety of the living unit. The floors and ceilings consist of 3.1-inch 3-ply CLT panels with a 3-inch layer of mineral wool sandwiched between modules. The module walls are constructed with thicker 4.9-inch 5-ply CLT, featuring a sandwich of gypsum wallboard and mineral wool between modules to provide additional fire protection, thereby allowing the timber to be exposed on the walls inside the units. There are no mechanical connections between units; units are connected to the concrete structure. A plumbing chase runs along the long side of the module wall closest to the building circulation. Overhead lighting fixtures are integrated into the module ceiling.

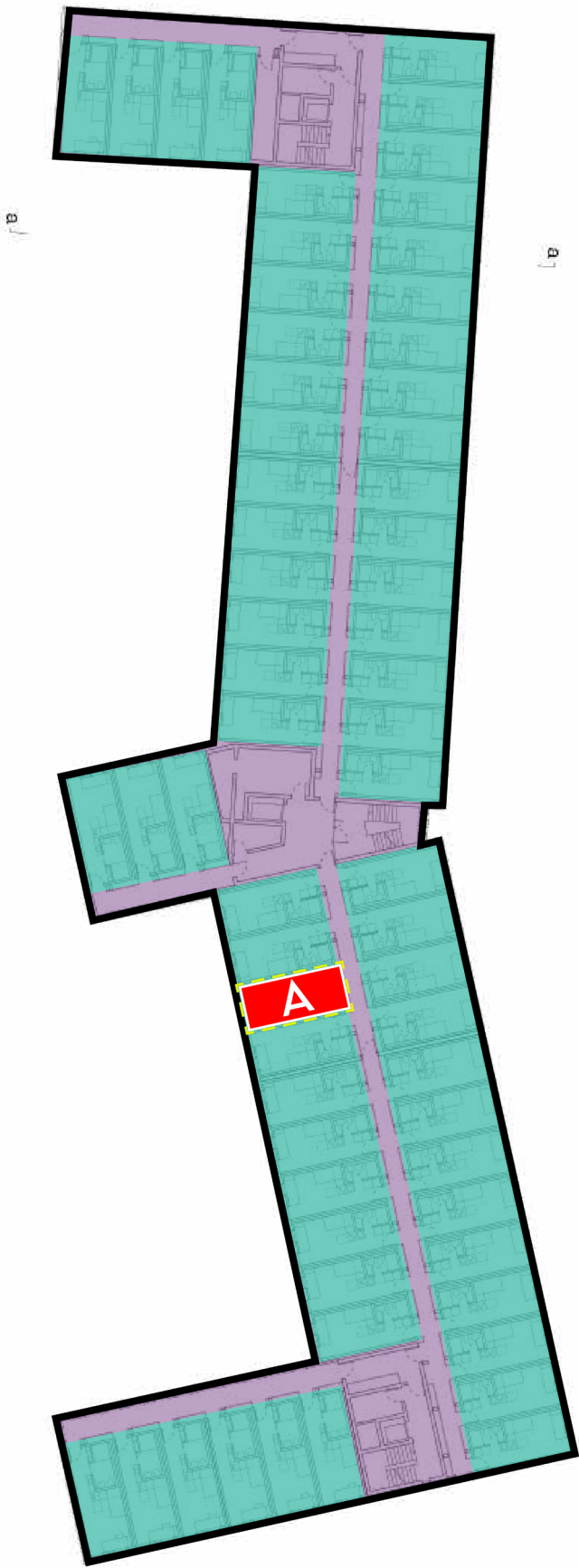




WOODIE

double-loaded

- building footprint
- non-modular construction
- modular construction
- one module
- one unit



PLATENSIEDLUNG/LIWOOD



YEAR COMPLETED 2020
LOCATION FRANKFURT, GERMANY
ARCHITECT STEFAN FORSTER ARCHITEKTEN
MANUFACTURER LIWOOD

NUMBER OF MODULES 1,102
CONSTRUCTION TIME 5 MONTHS PER BUILDING:
7-8 WEEKS FOR PRE-FABRICATION, 2
WEEKS FOR MODULE ASSEMBLY IN THE
FIELD FACTORY, 10-14 WEEKS FOR ON-
SITE WORK

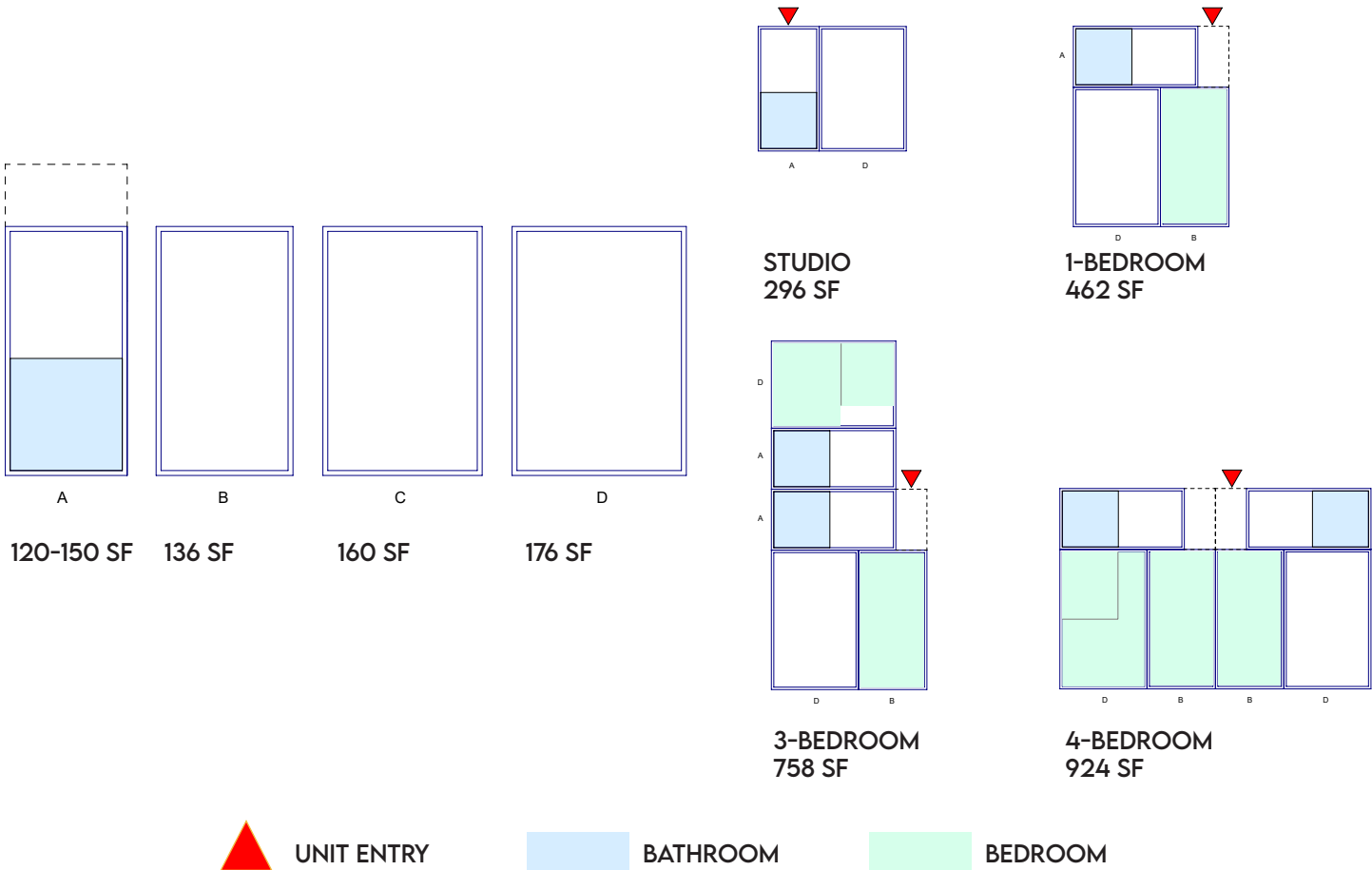
The Platensiedlung project in Frankfurt is a renovation of an existing complex, in which two stories of pre-fabricated mass timber modules were added on top of an existing structure. If masonry construction had been employed, only one story would have been possible due to the additional weight.

LiWood is a mass timber volumetric modular producer in Germany, focused on affordable housing units. The modular system they have developed consists of four modules in varying sizes that can be combined in different configurations from one to five bedrooms. Their flexible system allows for easy re-division in the future, adapting to the needs of the housing market. Panelized module components and bathroom modules are produced in the LiWood factories and then shipped to a field factory deployed next to or near the building site. In temporary warehouses, full volumetric modules are assembled and lifted into place. This model

retains many of the benefits of pre-fabricated modular design while reducing some of the impact from long-haul transportation.

While Platensiedlung is the largest example of LiWood's system, it has been employed in numerous housing projects. The diagrams and floor plans shown in this section for analysis represent a smaller project, Pointhouse, also located in Frankfurt.

The modular system contains four different module types in varying widths. Usually, the modules are the same length, with the exception of the A module containing the bathroom. While the sizes remain mostly consistent, variation is introduced through the orientation, penetrations, and interior partitions required depending on the unit type.







Fassadenansicht: Frankfurt PlattenSiedlung nach Aufstockung um zwei weitere Geschosse

Variable Grundrisse



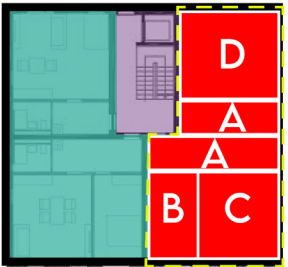
Standard-Grundriss

Variante mit 4-Zimmer Wohnung

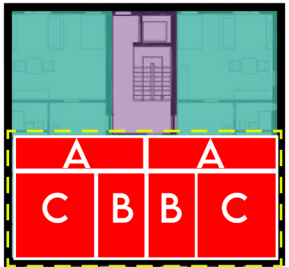
Variante mit 5-Zimmer Wohnung



Standard-Grundriss



Variante mit 4-Zimmer Wohnung



Variante mit 5-Zimmer Wohnung

PLATENSIEDLUNG

centralized

- building footprint
- non-modular construction
- modular construction
- one module
- one unit

HEIDELBERG STUDENT UNION



The Heidelberg Student Union, a dormitory project spearheaded by LiWood, exemplifies the efficient integration of modular construction principles. The design is centered around a modular system based on 240 square foot units, which can be stacked together to form larger configurations. With a total of 270 modules, the project includes 158 apartments, ranging from studios to three-bedroom units.

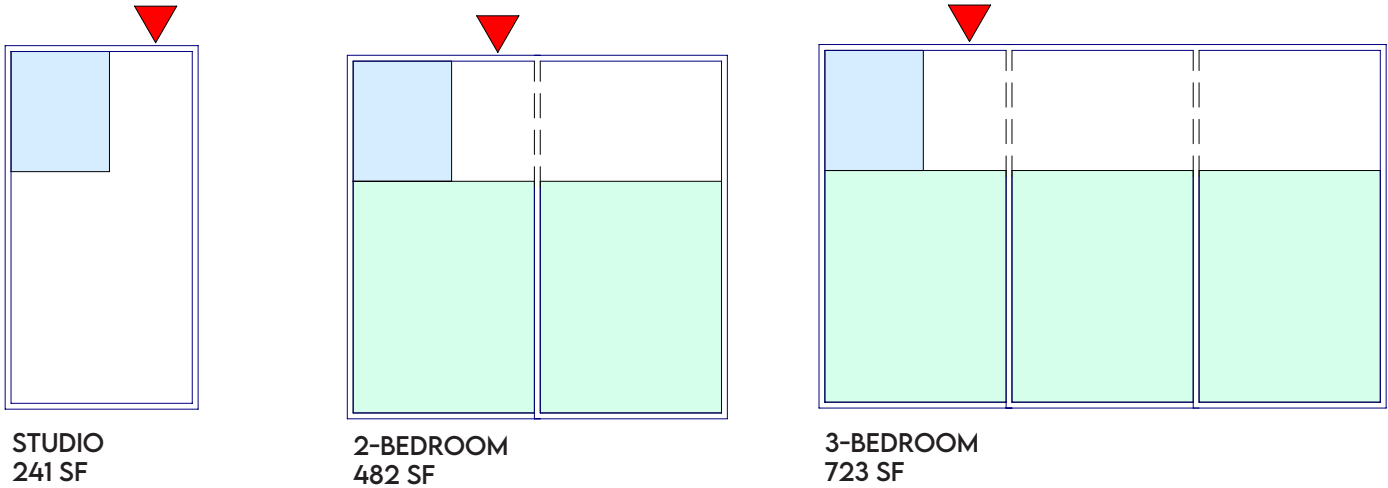
LiWood’s production model involves prefabricating panels at their home factory, which are then transported to an on-site field factory for module assembly. Once assembled, the modules are lifted into place using a truck crane, facilitating a streamlined construction process. After the modules were tied in, interior and exterior finishes were completed simultaneously. Construction time for this project was five months.

The building features a double-loaded corridor design, with a fiber cement panel finish for enhanced durability. Inside the units, the CLT walls are concealed for increased fire protection.

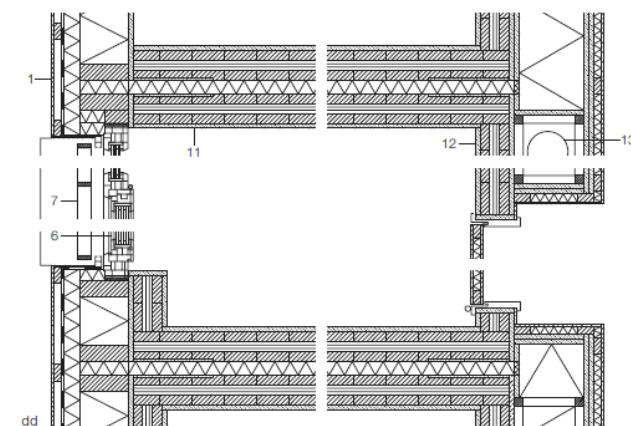
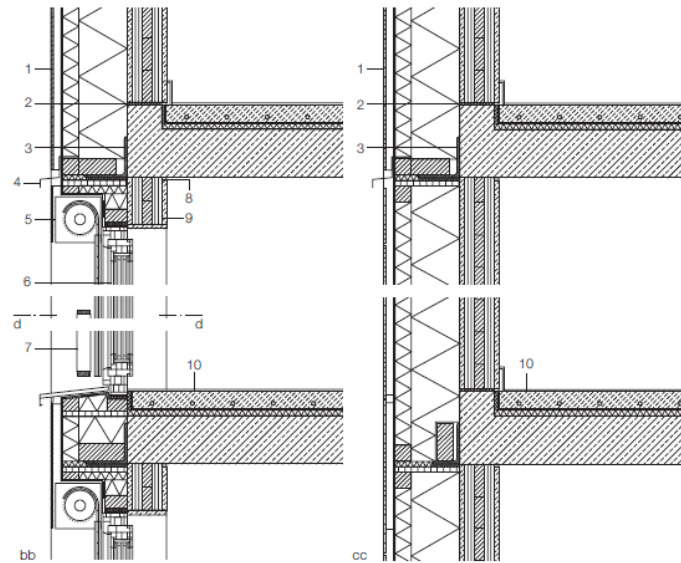


YEAR COMPLETED 2013
LOCATION HEIDELBERG, GERMANY
ARCHITECT LIWOOD
MANUFACTURER LIWOOD

NUMBER OF MODULES 270 MODULES
CONSTRUCTION TIME 6 MONTHS

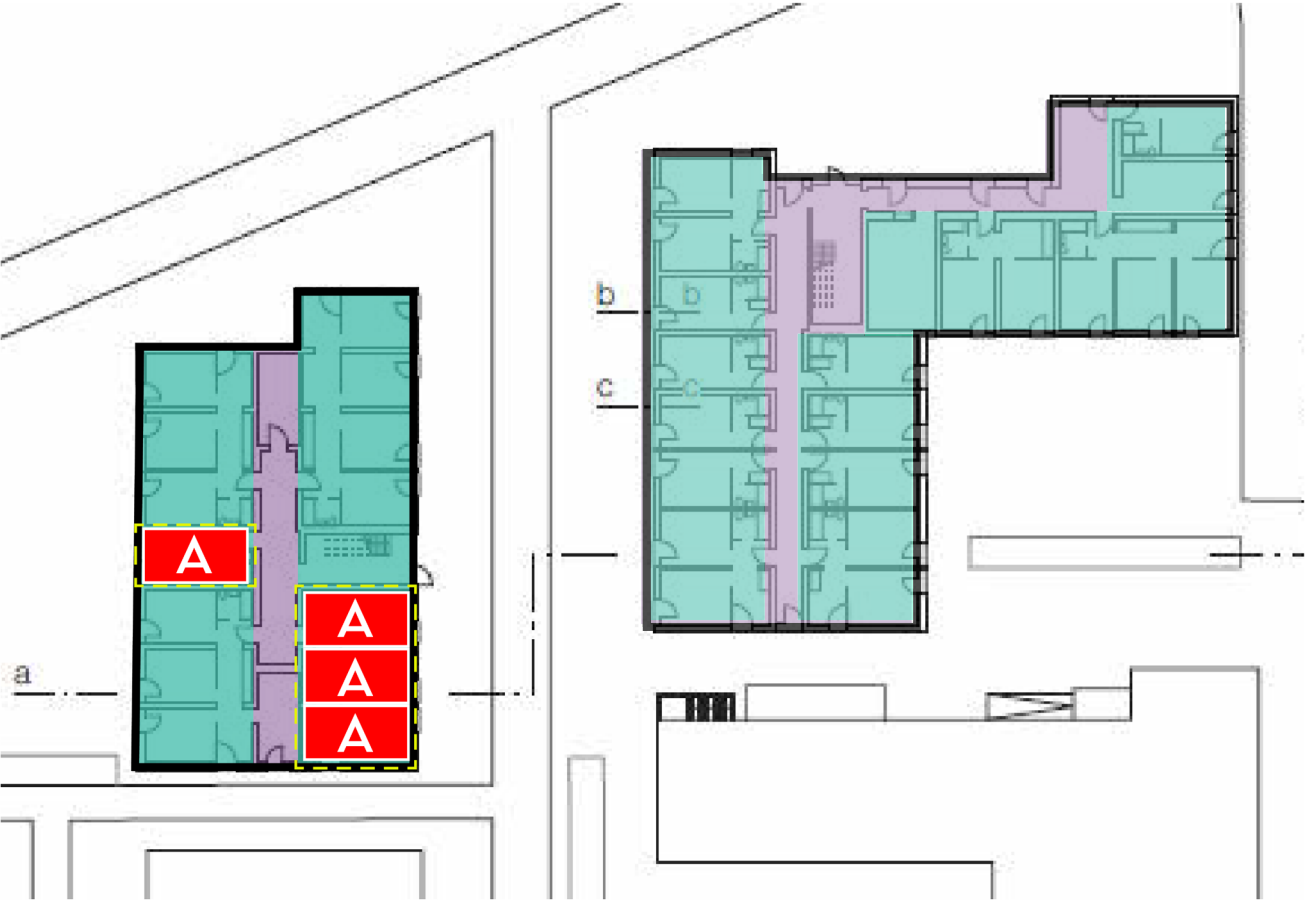
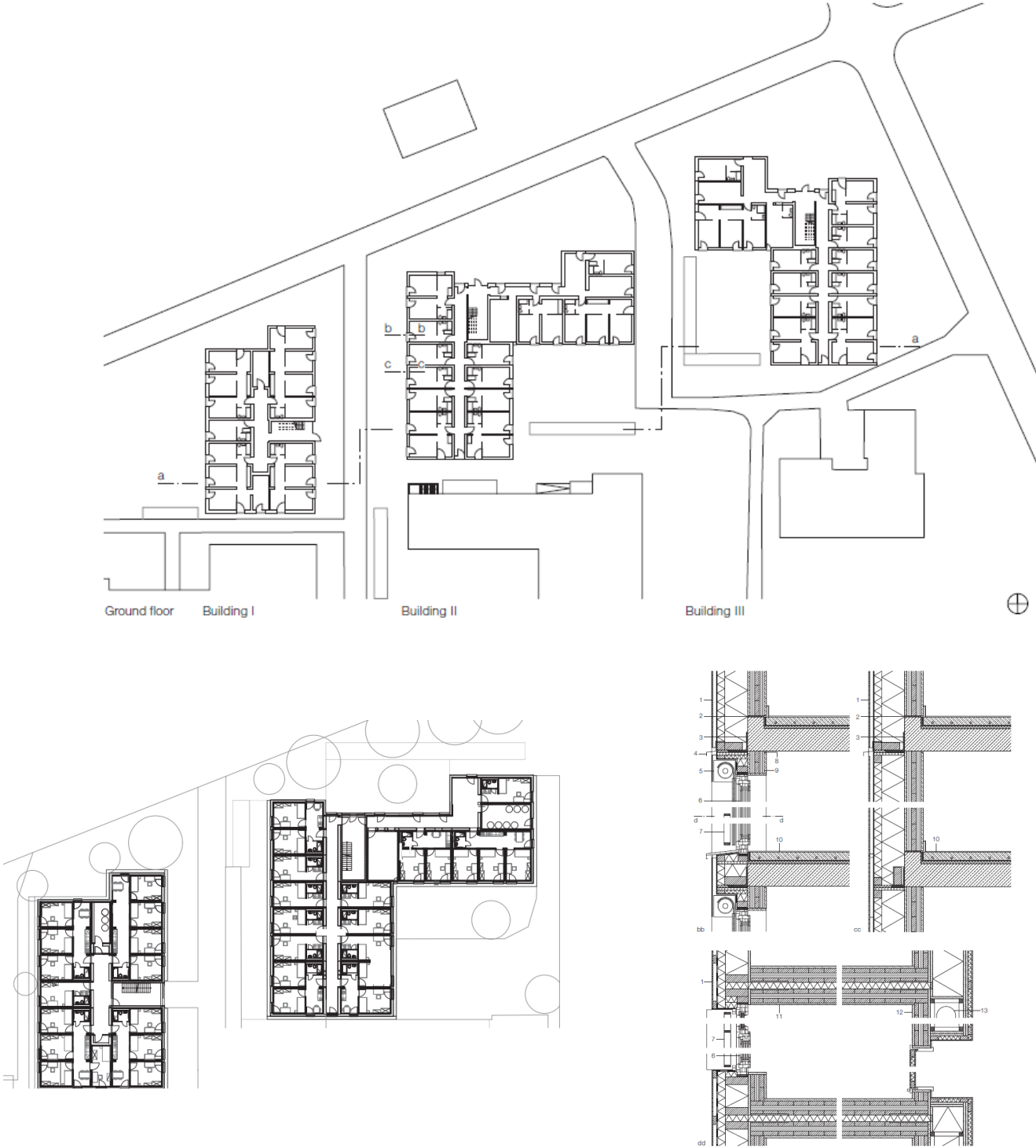


UNIT ENTRY BATHROOM BEDROOM



This project utilizes a semi-open, hybrid module, wherein the ceilings are constructed from prefabricated reinforced concrete components, and the walls consist of 3-ply CLT. The cavity between module walls contains mineral wool for insulation. Additionally, the floor assembly incorporates an integrated floor heating system and sound insulation measures. A unique conical dowel is situated on the top of each module wall, aiding in the alignment and positioning of modules during assembly in the field.





HEIDELBERG

double-loaded

- building footprint
- non-modular construction
- modular construction
- one module
- one unit

STUDENT RESIDENCE



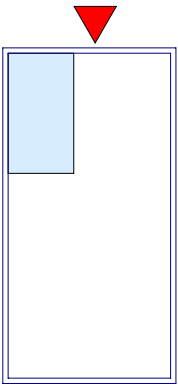
YEAR COMPLETED 2021
LOCATION GOTTINGEN, GERMANY
ARCHITECT LIMA ARCHITEKTEN
MANUFACTURER KAUFMANN BAUSYSTEME

NUMBER OF MODULES 265

This student dormitory project at the University of Göttingen in Germany comprises a modular hybrid structure. The ground floor and stair cores were constructed on site using reinforced concrete. The residences consist of prefabricated CLT modules, each equipped with bathrooms and kitchenettes. There is only one module type, and each module functions as a self-contained living unit.

The project spans five stories in total, with four of them consisting of timber modules. The majority of the wood is left exposed in each of the 265 modules, including walls and ceilings. Furniture and electrical fixtures were integrated into the units prior to their arrival at the site.

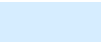
Modules are arranged in a courtyard building with the majority of units facing outward. An open-air walkway connects the inner courtyard to the exterior.



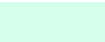
200 SF



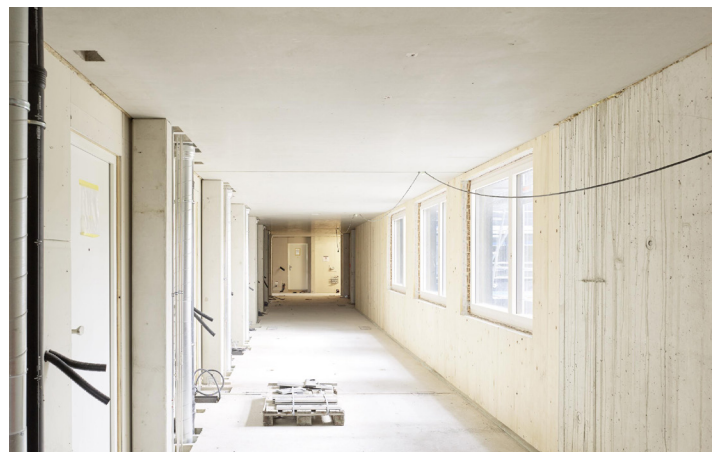
UNIT ENTRY

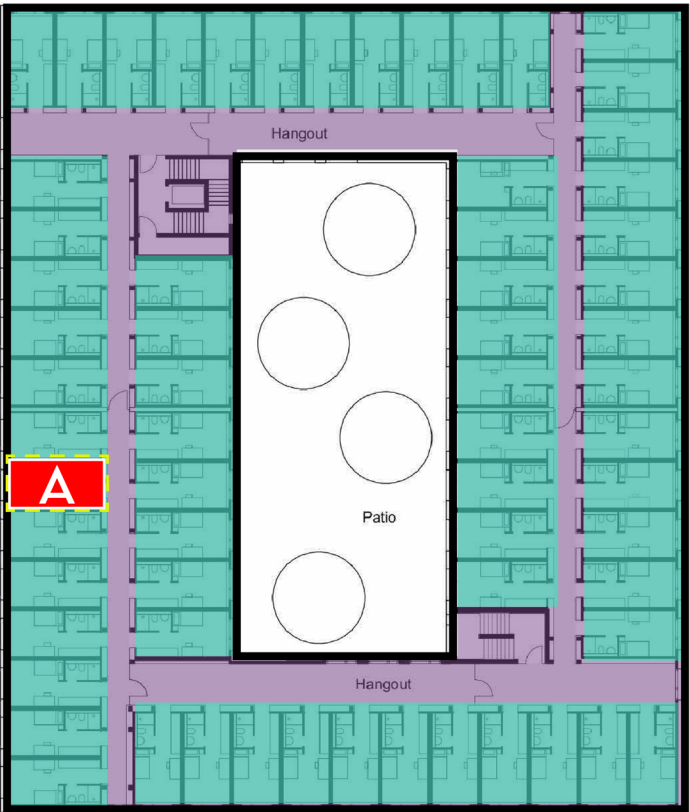
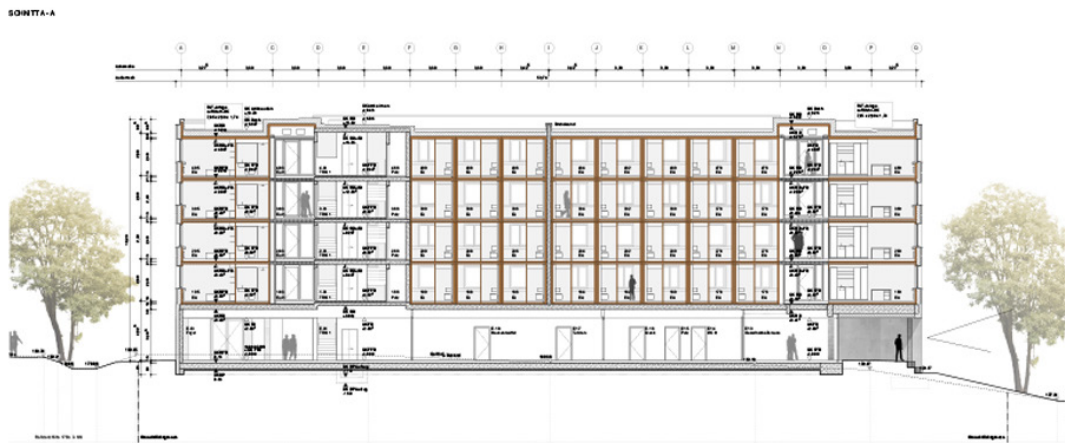
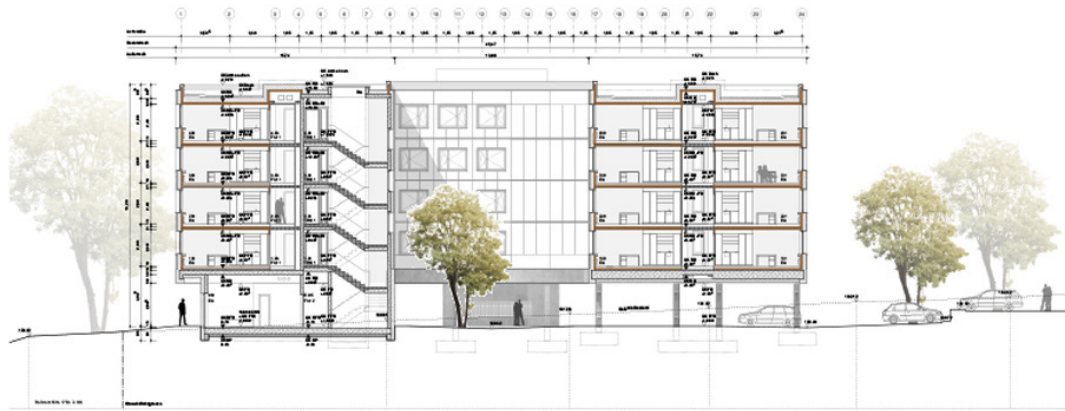
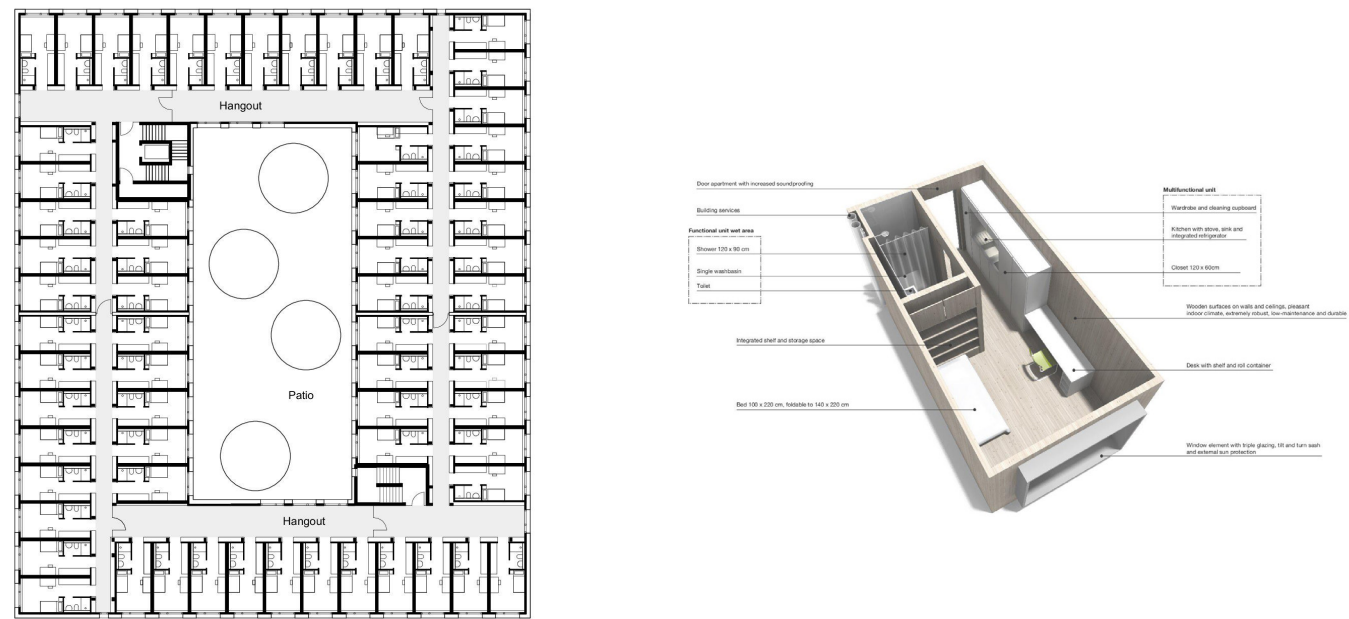


BATHROOM



BEDROOM





GOTTINGEN STUDENT HOUSING

double-loaded

- building footprint
- non-modular construction
- modular construction
- one module
- one unit

ADOMA APARTMENTS

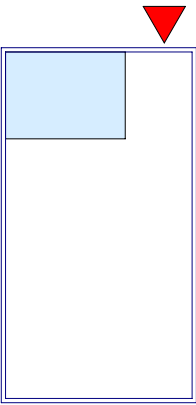


YEAR COMPLETED 2015
LOCATION TOULOUSE, FRANCE
ARCHITECT PPA ARCHITECTURES
MANUFACTURER WOODEUM (CLT)
TECHNAL (EXTERIOR JOINERY)

NUMBER OF MODULES 50
CONSTRUCTION TIME 9 MONTHS

Adoma Apartments utilizes CLT modules to blend efficiency and sustainability to meet affordable housing needs. The total construction cost was 2.4 million Euros, and it took nine months to complete.

The building organization relies on pushing and pulling to create a Z-shape, allowing for more exterior corner units. The four-story structure was built using mobile platforms and did not require any scaffolding.



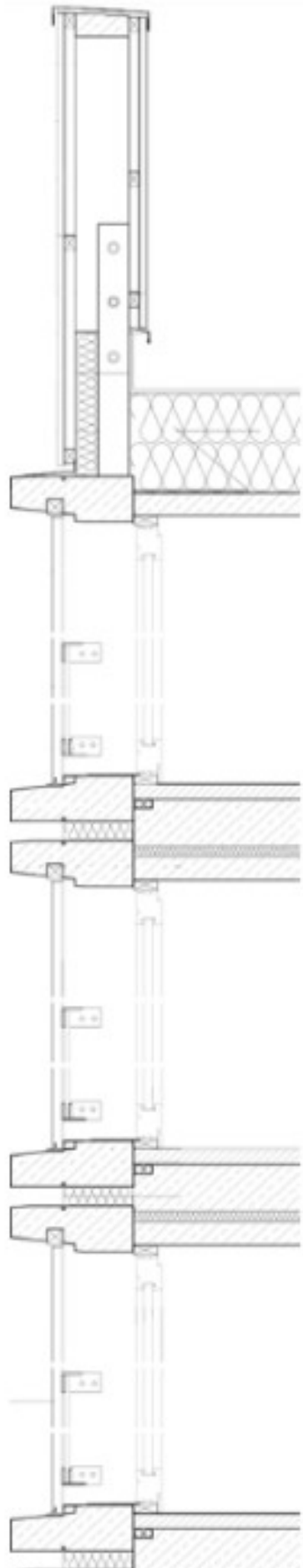
244 SF

UNIT ENTRY

BATHROOM

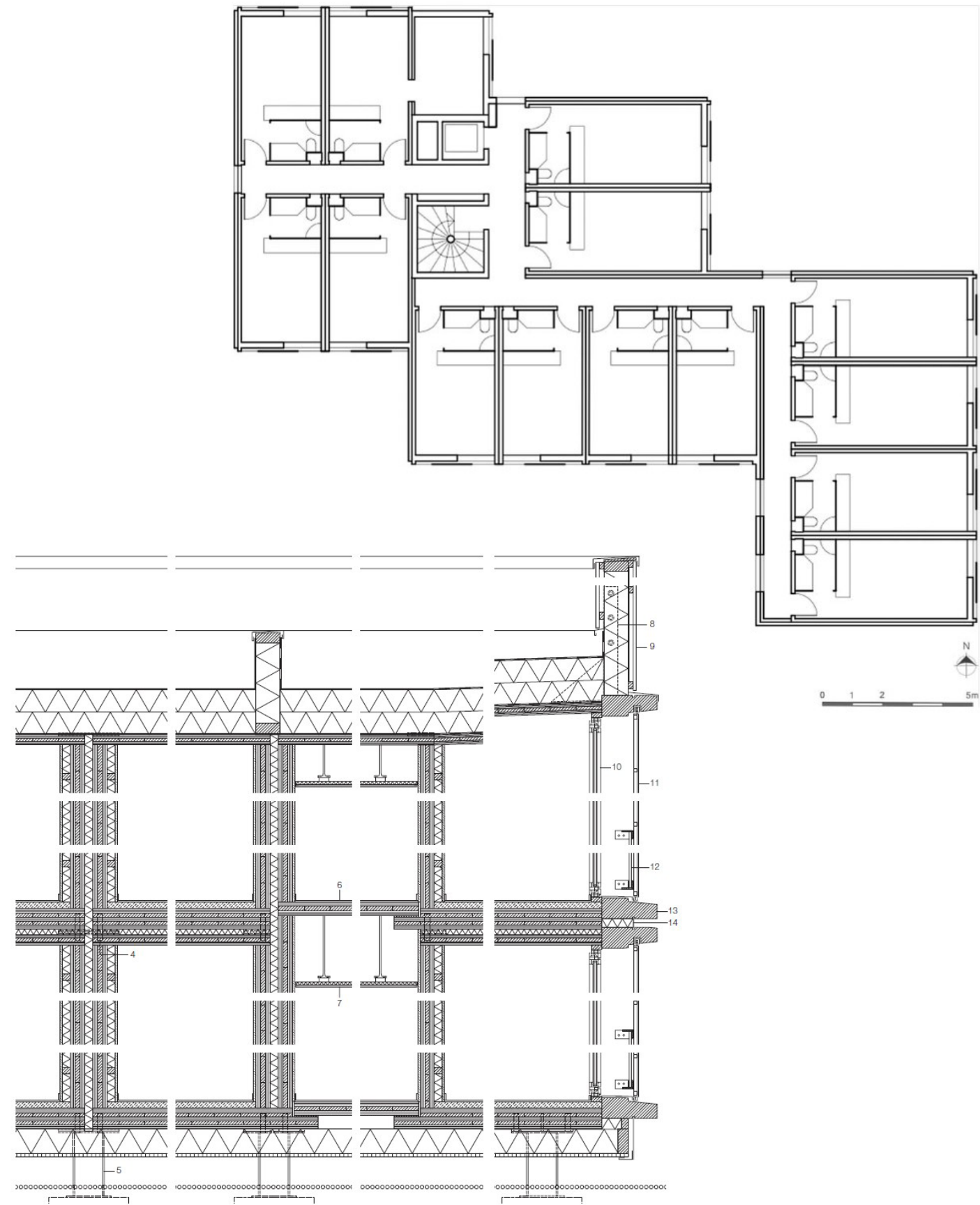
BEDROOM





The Adoma utilizes enclosed modules in which the CLT structure is almost completely concealed. The module walls consist of 3-ply CLT with mineral wool and gypsum plaster on the interior of the units; between the CLT module walls is another layer of mineral wool. The floors utilize a 4.7-inch 5-ply CLT panel with a concrete screed and PVC tiles adhered on top as a floor finish. The module ceilings are 2.3-inch 3-ply CLT with a varnish finish. While the corridors are not part of the modular system, they do utilize a 3-ply CLT panel with suspended aluminum panels for acoustic performance. Steel framed parapet walls sit on top of the modular system to complete the roof structure.





ADOMA

double-loaded

- building footprint
- non-modular construction
- modular construction
- one module
- one unit

BMW ALPENHOTEL

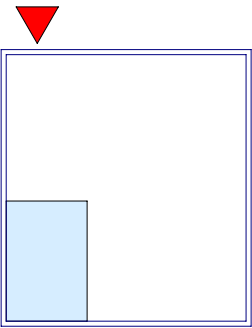


YEAR COMPLETED 2009
LOCATION AMMERWALD, AUSTRIA
ARCHITECT OSKAR LEO KAUFMANN
ALBERT RUF
MANUFACTURER KAUFMANN BAUSYSTEME

NUMBER OF MODULES 96
CONSTRUCTION TIME 31 DAYS TO PREFABRICATE MODULES
10 DAYS TO INSTALL MODULES

The BMW Alpenhotel in Ammerwald, Austria, is situated approximately two hours outside of Munich amidst the mountains. Its remote location makes it ideally suited for a modular construction approach. Once the modules, complete with bathrooms, interior furnishings, curtains, electrical, and plumbing, were finalized in the factory, it only took ten days to stack and assemble them on site. The upper three stories of modules were positioned on a concrete plinth, comprising the basement, ground level, and mezzanine.

This case study represents the oldest project examined and one that I had the opportunity to visit and observe firsthand. Upon arrival, the initial impression is that of a typical upscale hotel. Its modular or timber construction is not immediately evident until one enters the hotel rooms, where guests find themselves enveloped in a wooden enclosure from floors to walls to ceiling. Notably, even after 15+ years since its initial installation, the scent of wood remains distinctly potent. While minor scratches and dings are visible on the floors and corners, the rooms are remarkably well-preserved for their age.



242 SF

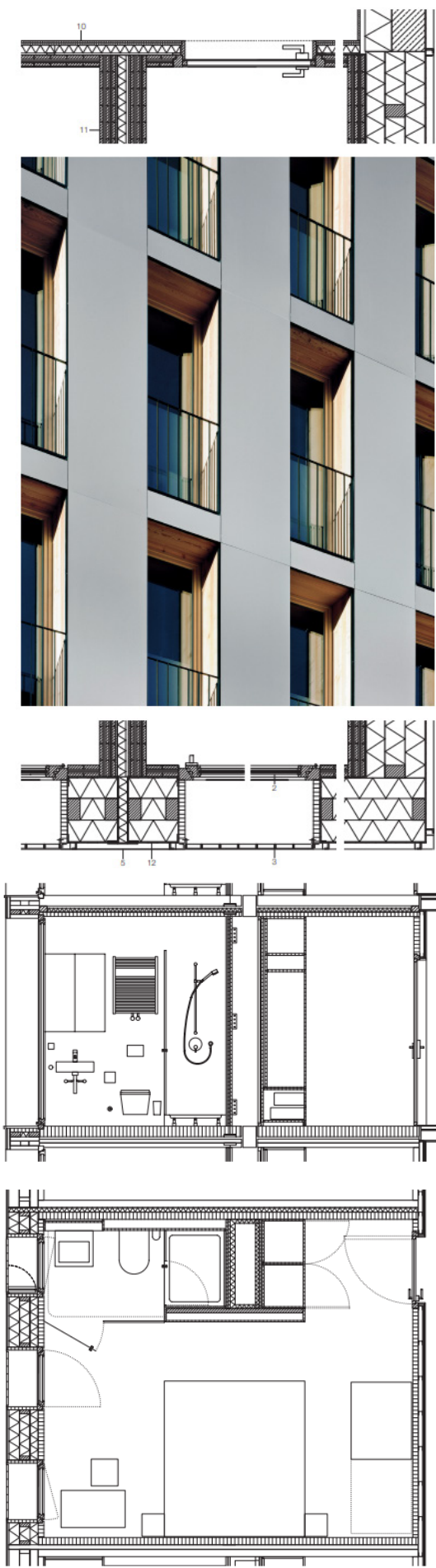
Each room features three floor-to-ceiling windows, operable twist-and-turn doors that open onto a Juliet balcony, offering breathtaking views of the surrounding mountains. Despite mirrored furnishings from room to room, the window pattern remains consistent across the modules. However, one door is rendered impassable as it collides with the bathroom sink, albeit still facilitating fresh air and passive ventilation. Additionally, it is intriguing to observe that the cross-laminated timber (CLT) is left exposed throughout the bathroom module, including the shower area. A noticeable difference in finish coats the bathroom floor and the shower enclosure, giving the wood a more whitewashed appearance. Nonetheless, the shower ceiling appears unfinished, and evidence of water or steam damage is discernible above the showerhead. This is only case study examined where the bathroom module is placed on the exterior wall as opposed to the interior corridor.



UNIT ENTRY

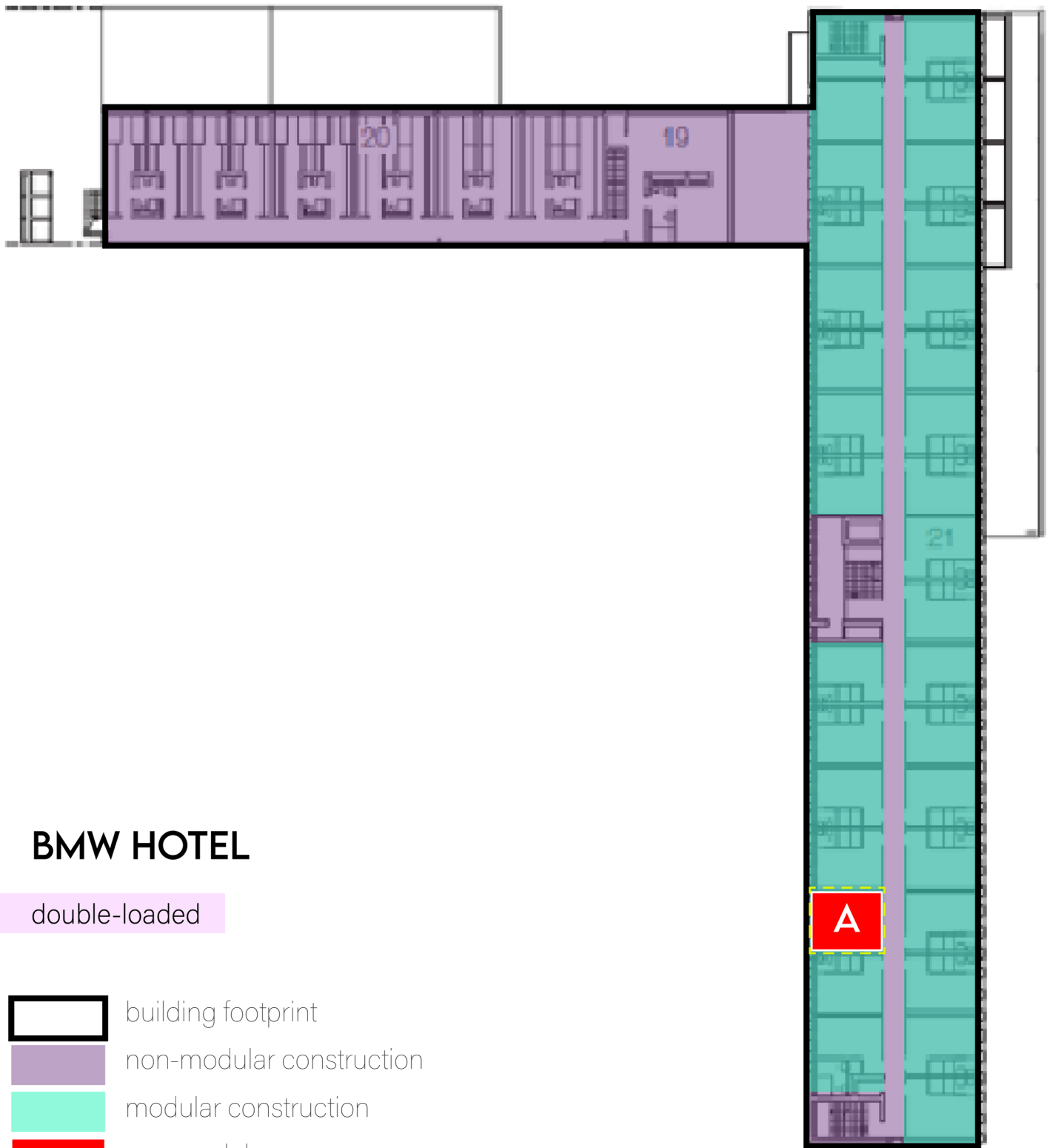
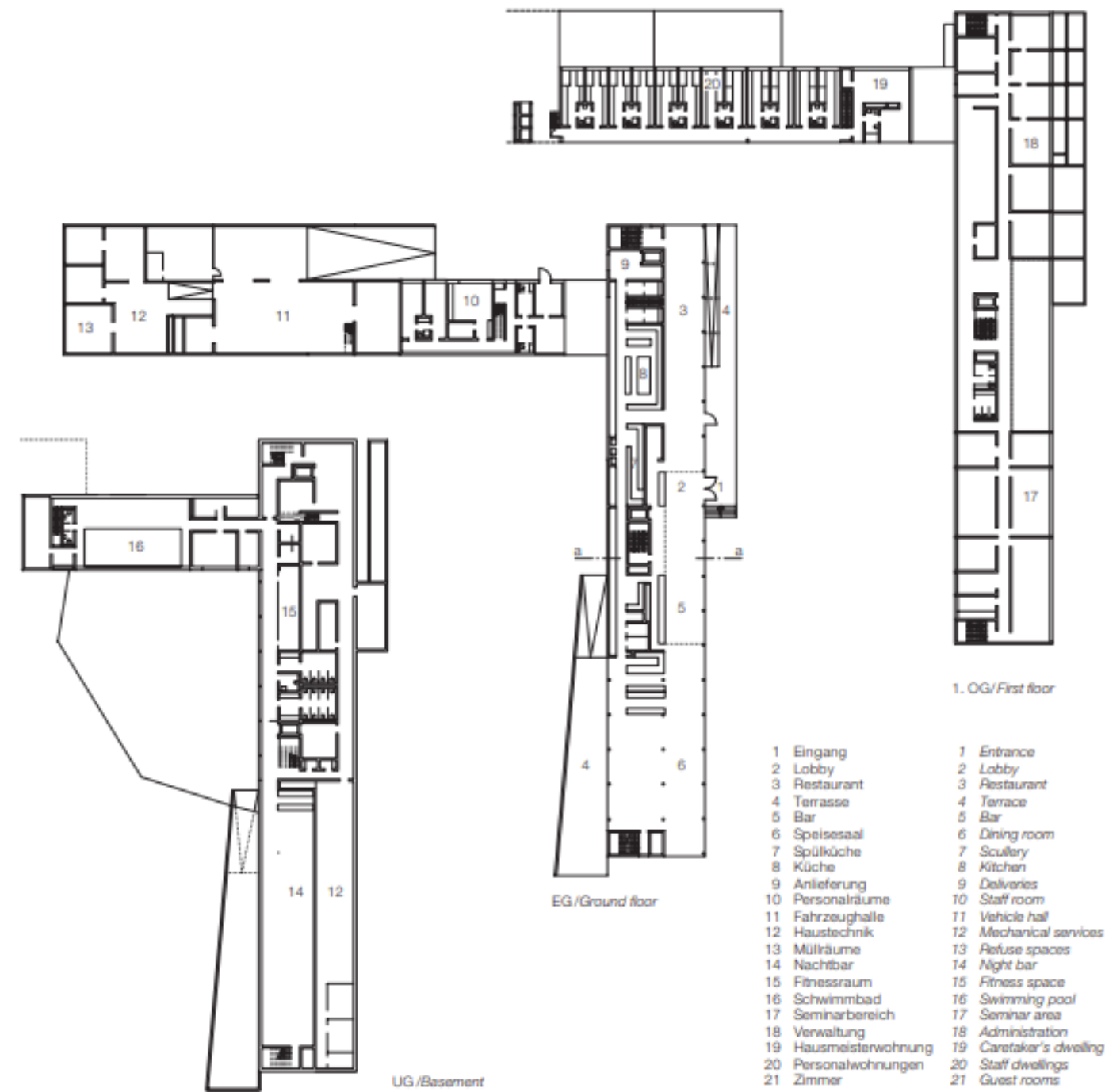
BATHROOM

BEDROOM



This project utilizes 3.9-inch 5-ply CLT panels for the module walls, incorporating gypsum wallboard, mineral wool, and an air layer between modules to enhance acoustic and fire performance. The module ceilings feature a thinner 2.3-inch 3-ply CLT panel, supplemented with mineral wool and an air layer on top. The floors consist of a thicker 5.5-inch 5-ply CLT construction.





HOTEL REVIER



YEAR COMPLETED 2017
LOCATION LENZERHEIDE, SWITZERLAND
ARCHITECT CARLOS MARTINEZ ARHICTEKTEN

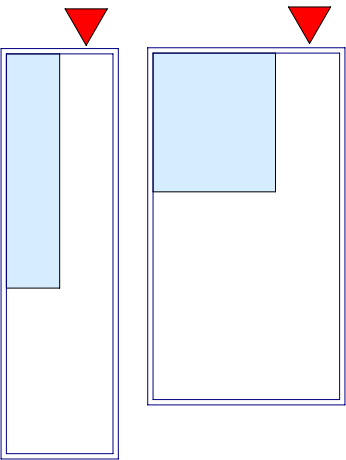
MANUFACTURER KAUFMANN BAUSYSTEME

NUMBER OF MODULES 96 MODULES

The Hotel Revier in Switzerland is a luxury modular hotel located in the mountains. While only one location was examined for this project, the hotel group has completed three other projects worldwide utilizing the same system, with two more coming soon. The pre-fabricated nature of volumetric modules, quick construction times, and minimal site disruption allow the hotel developer to build in beautiful, remote locations, and otherwise difficult-to-build sites.

The concrete ground floor serves as a podium for four stories of timber modules. Two concrete stair columns brace the building at the knuckles, allowing the modular portions to remain rectilinear. The concrete plinth and exterior facade are clad in non-structural timber, expressing the character of the interior structure on the exterior aesthetic.

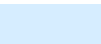
While the modules are diminutive in size, they maximize the space with one oversized, floor-to-ceiling, wall-to-wall window and efficiently optimized built-in furniture and storage. The timber is left exposed on all interior surfaces except the floor.



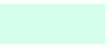
160 SF - 244 SF



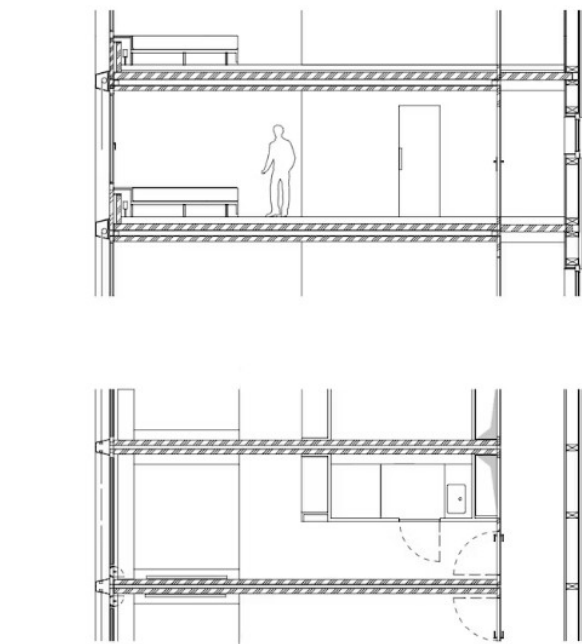
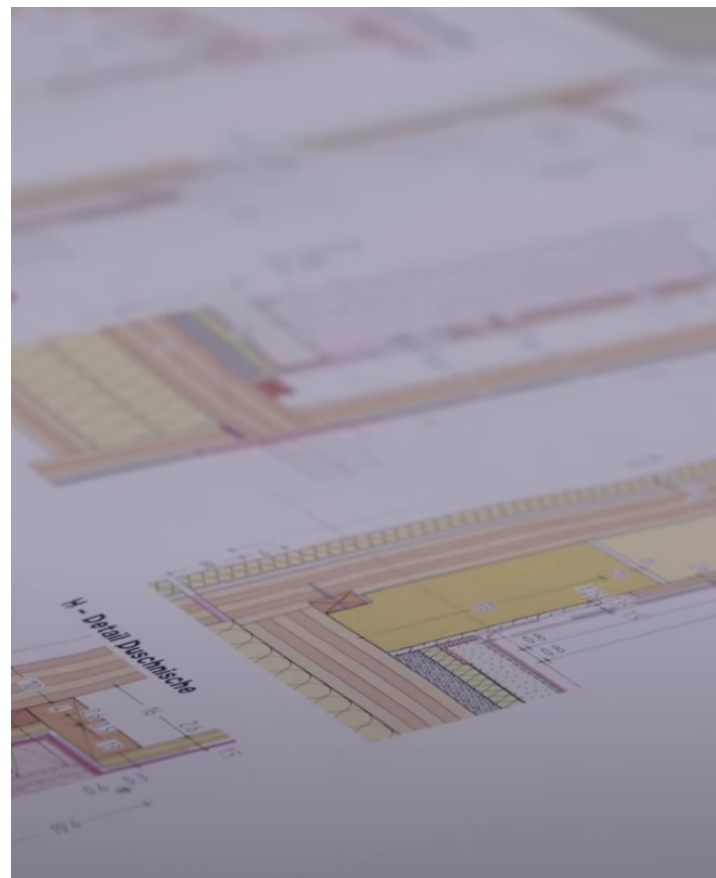
UNIT ENTRY

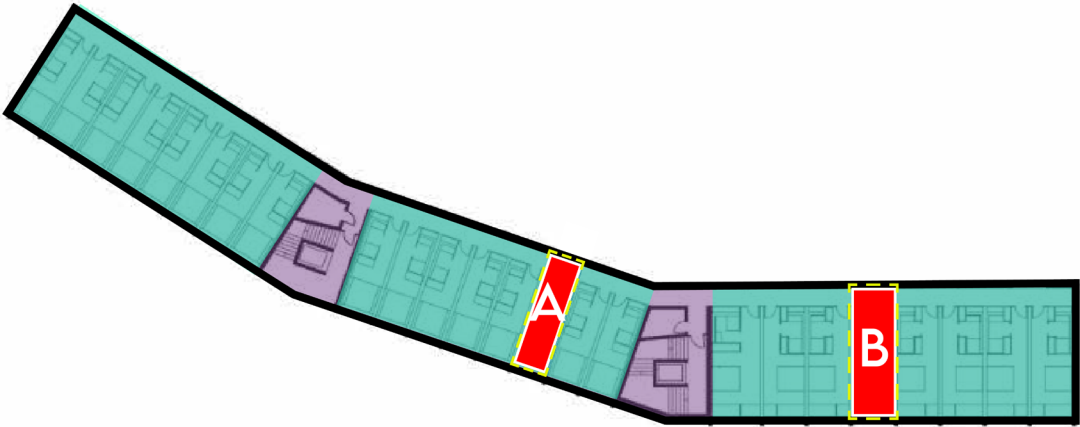
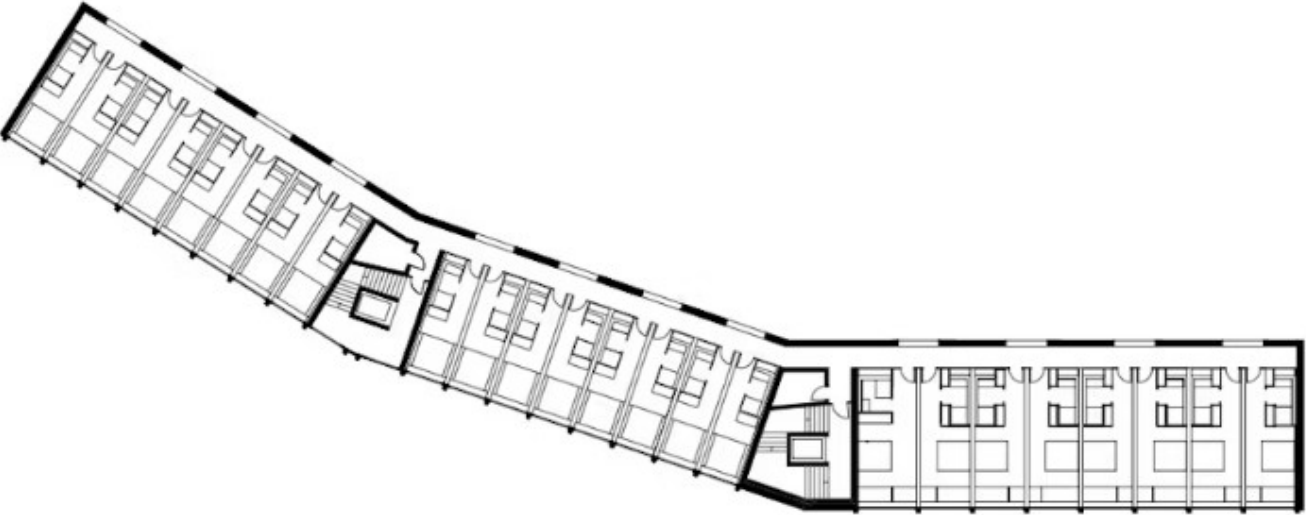


BATHROOM



BEDROOM





HOTEL REVIER

single-loaded

corridor in module

- building footprint
- non-modular construction
- modular construction
- one module
- one unit

SARA KULTURHUS

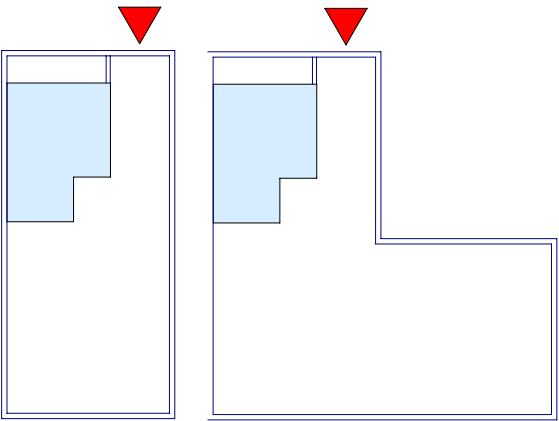
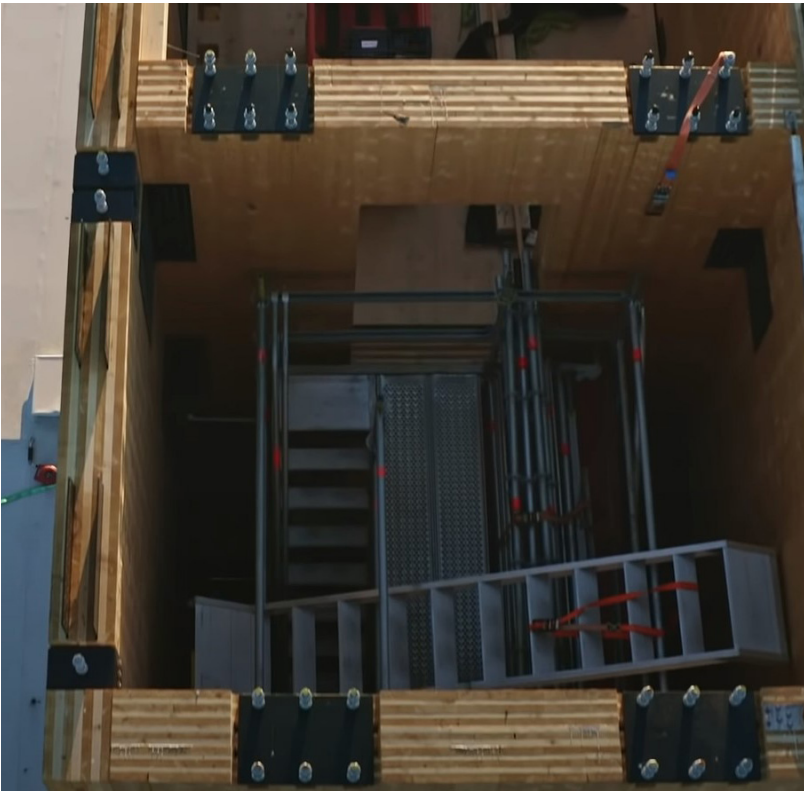


YEAR COMPLETED 2021
LOCATION SKELLEFTEÅ, SWEDEN
ARCHITECT WHITE ARKITEKTEN
MANUFACTURER DEROME
MARTINSONS TRÄ AB

NUMBER OF MODULES 205

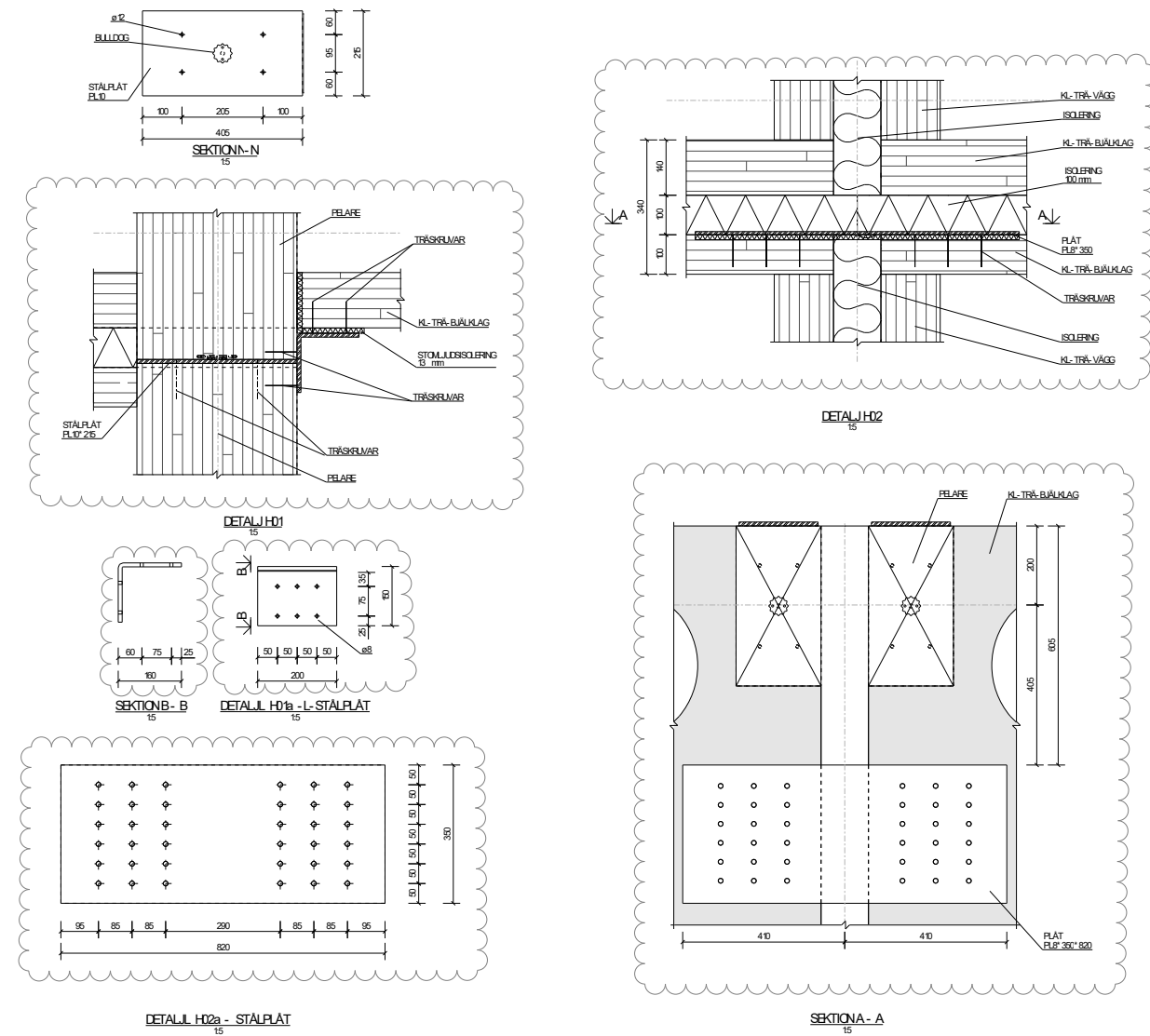
Sara Kulturhus is a 323,000 square foot cultural center with a hotel tower. The modular portion of the building is seen in the 205 hotel rooms sitting on top of a six-story post and beam mass timber structure. Timber and steel hybrid trusses are paired with CLT decking in long span areas. Concrete slabs on the 5th, 6th, 19th, and 20th floors help dampen noise and reduce the effects of wind. Two CLT elevator cores at each end of the building act as a lateral system.

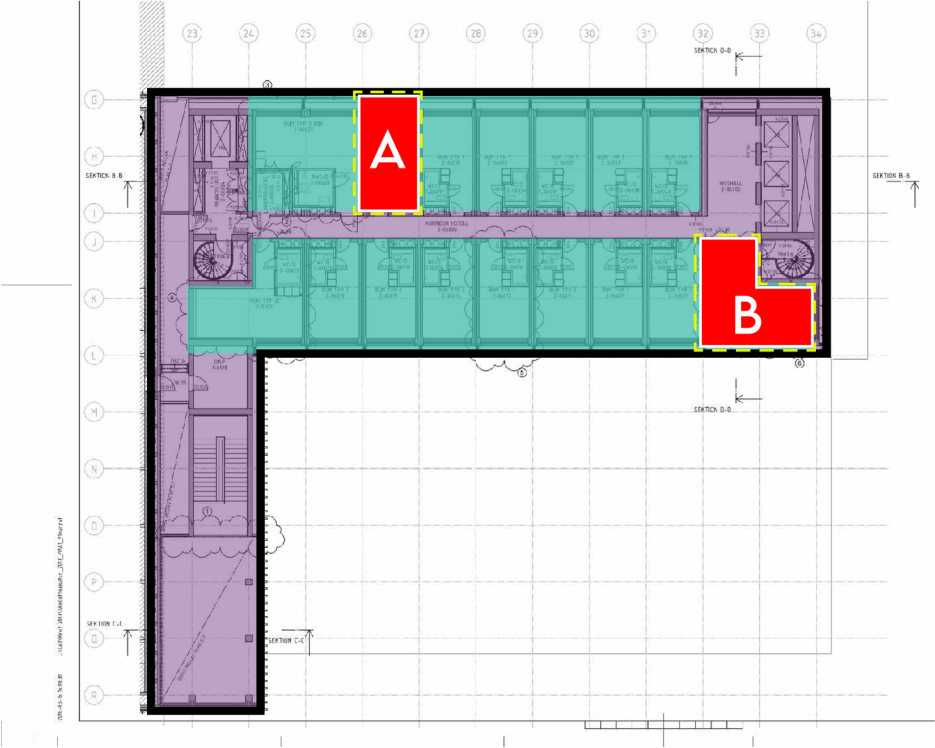
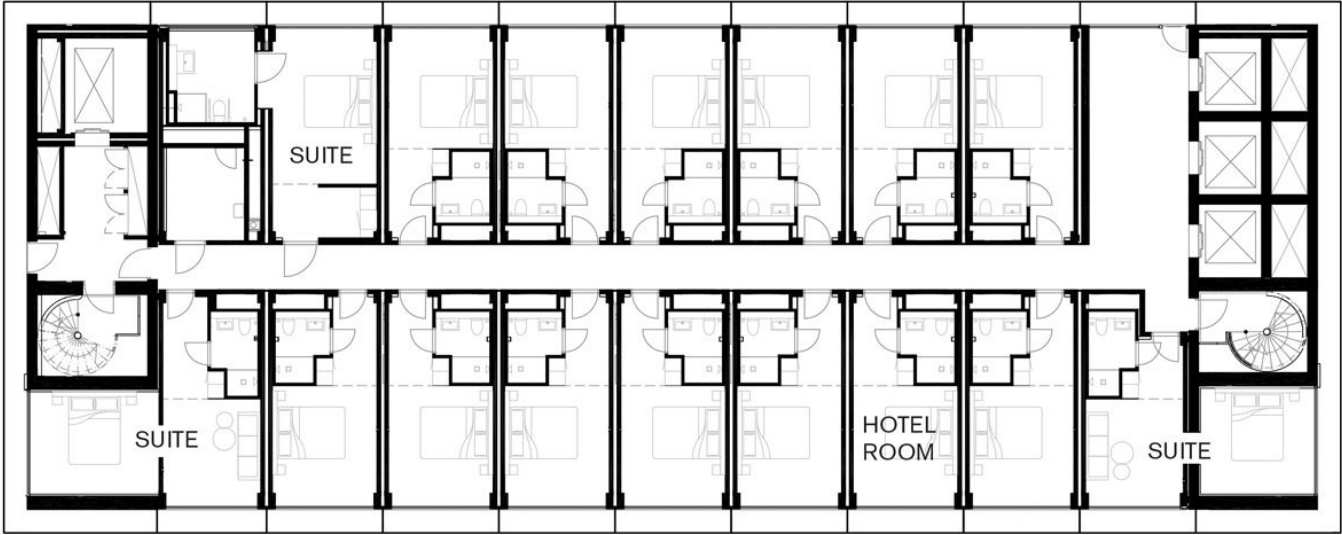
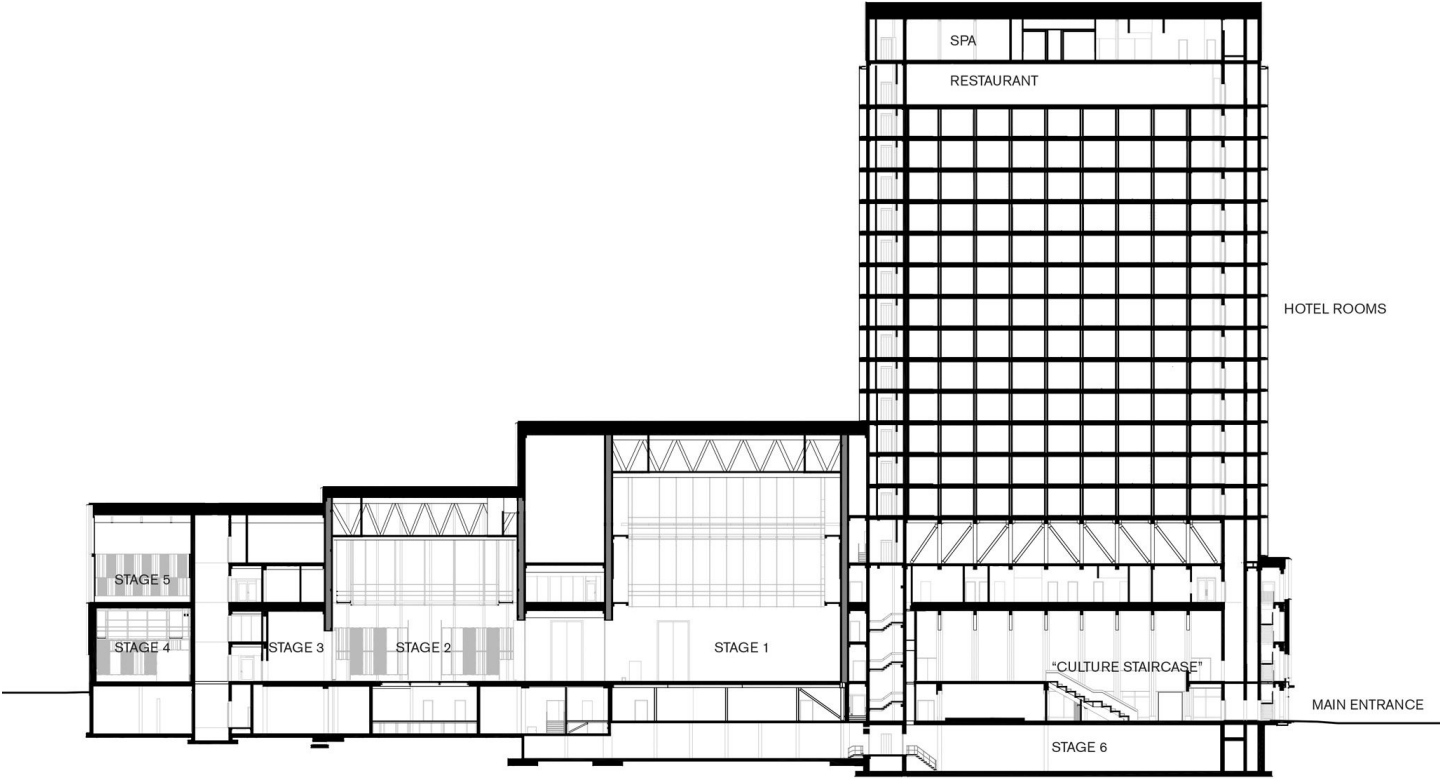
At 262 feet in height, Sara Kulturhus is one of the tallest timber towers in the world. The design team credits the modular construction system of the 13 top floors with saving one year in construction time for the overall project.



216 SF - 330 SF

UNIT ENTRY BATHROOM BEDROOM





SARA KULTURHUS

double-loaded

- building footprint
- non-modular construction
- modular construction
- one module
- one unit

SCHOOL EXPANSION



YEAR COMPLETED VARIES
LOCATION MULTIPLE LOCATIONS, FRANKFURT
ARCHITECT NKBK
MANUFACTURER KAUFMANN BAUSYSTEME

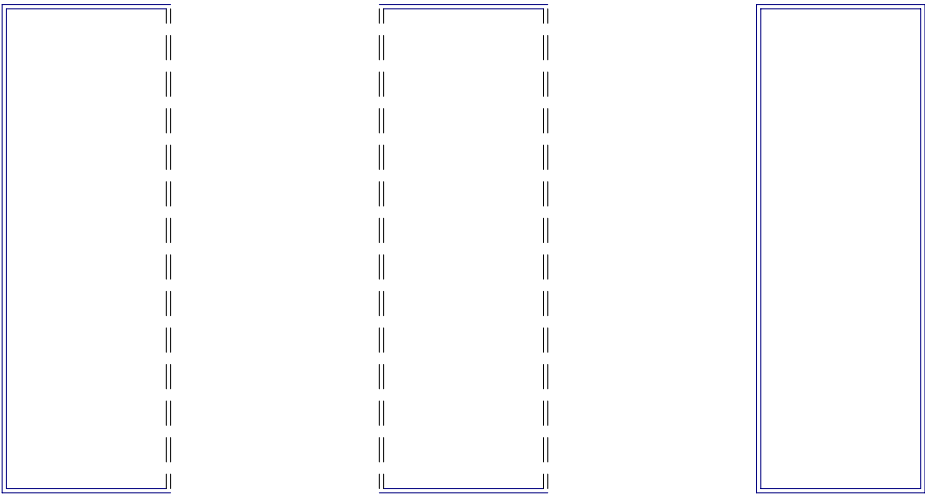
NUMBER OF MODULES VARIES



This modular system originated from a short-term need for additional classrooms in Frankfurt, Germany. The first project was completed in 17 months (from planning to use) and was only intended as a temporary structure. Since the first project, four more have been developed utilizing the same system. The modules are all sized exactly the same at 290 square feet but with different levels of open and closed sides. Where walls have been removed, LVL beams provide structural stability and allow for large, open spaces. This same module size is used to house stairwells, ancillary spaces, and restrooms.

The non-modular portion of the buildings houses the corridors, which consist of CLT panels positioned between modules or resting on glue-laminated timber columns. For the most part, the timber is left exposed and untreated on the walls and ceilings, with the exception of wet areas and stairways, where resilient floor covering is used throughout.

Despite a strictly standardized system, there is still room for flexibility in programmatic elements and building organization allowing for uniquely site-specific projects.



ONE SIDE OPEN
290 SF

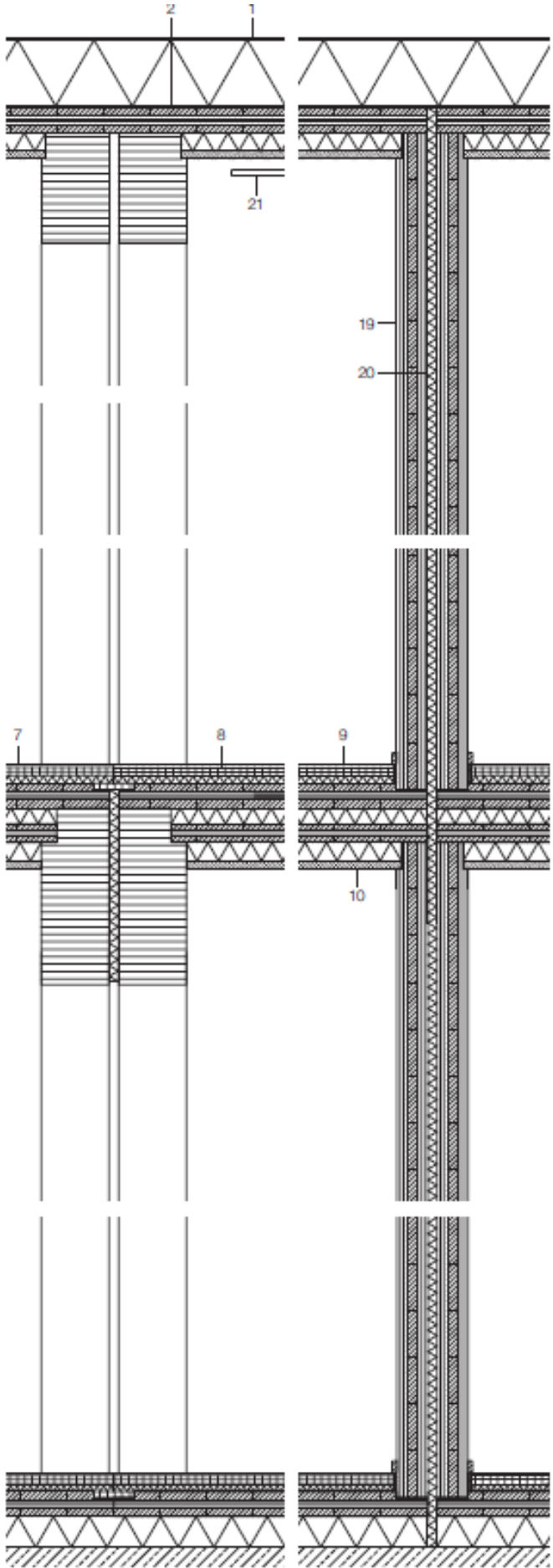
TWO SIDES OPEN
290 SF

CLOSED
290 SF

UNIT ENTRY BATHROOM BEDROOM



The module walls, ceilings, and floors all utilize a 3.14-inch 3-ply CLT panel. Between module walls, there is 1 inch of mineral wool, while 2 inches are seen between floors and ceilings. For better acoustic performance, a layer of acoustic panels is used on both the floor and ceiling panels. Radiant ceiling panels are suspended from the ceiling CLT to heat the classroom spaces along with suspended linear lighting fixtures.





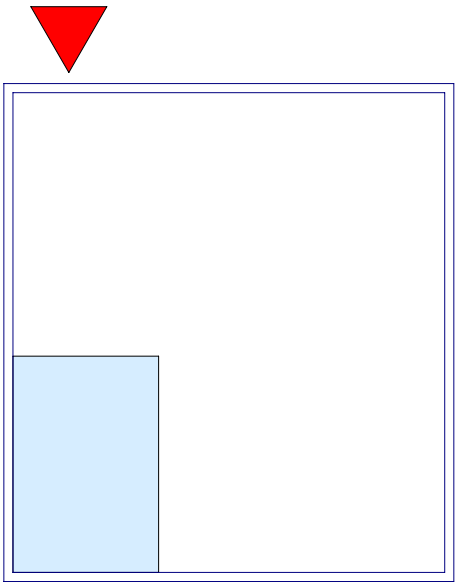
SCHOOL EXPANSION

single-loaded

- building footprint
- non-modular construction
- modular construction
- one module
- one unit

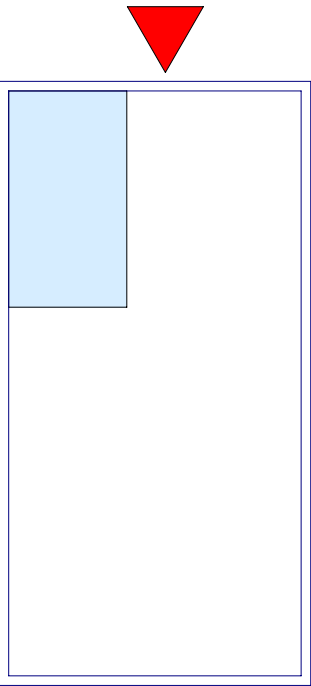
A: ONE WALL OPEN
B: TWO WALLS OPEN
C: CLOSED MODULE
(STORAGE, OFFICE, LAV.)

CASE STUDY ANALYSIS



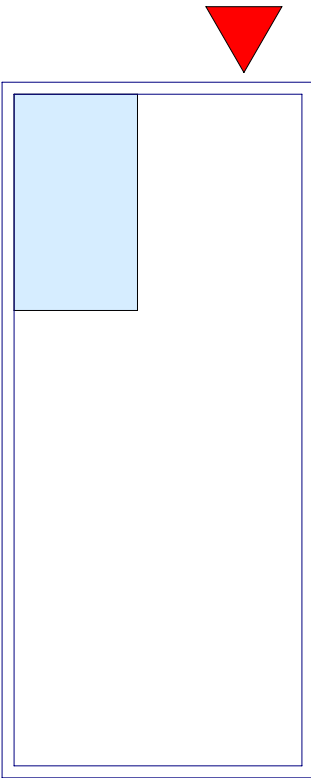
BMW HOTEL

242 SF



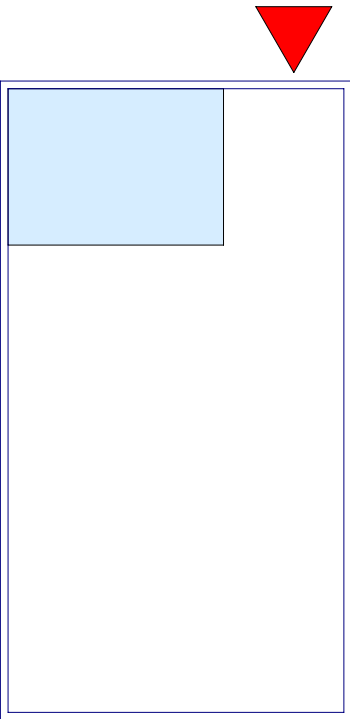
STUDENT RESIDENCE
GOTTINGEN

200 SF



WOODIE

226 SF



ADOMA APARTMENTS

244 SF

As I delved into the examination of the ten case studies, I discerned four distinct categories of unit types:

- 1. Single size module, self-contained
- 2. Multiple size module, self-contained
- 3. Single size modules, combined
- 4. Multiple size modules, combined

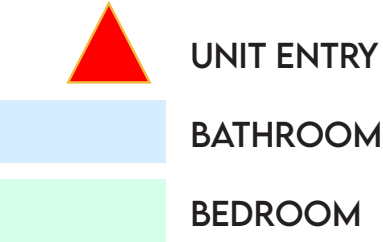
In the first two categories, the module itself serves as the living unit. Each module encompasses a sleeping area, bathroom, and, in certain instances, a compact kitchenette. These configurations are predominantly employed in hotel rooms and student dormitories.

When multiple size modules are utilized, it is typically to accommodate various conditions within the building, such as circulation cores.

In nearly all cases, the wet core is situated along the building’s circulation, facilitating a plumbing chase that remains separate from the unit itself. However, the BMW Alpenhotel deviates from this convention by positioning the wet core along the exterior facade of the building. Another notable exception to layout patterns is observed in the modules at Hotel Revier, where the building corridor is incorporated within the module design.

MODULE TYPE 1:

SINGLE-SIZE MODULE
SELF-CONTAINED



MODULE TYPE 2:
MULTIPLE SIZE MODULE
SELF-CONTAINED

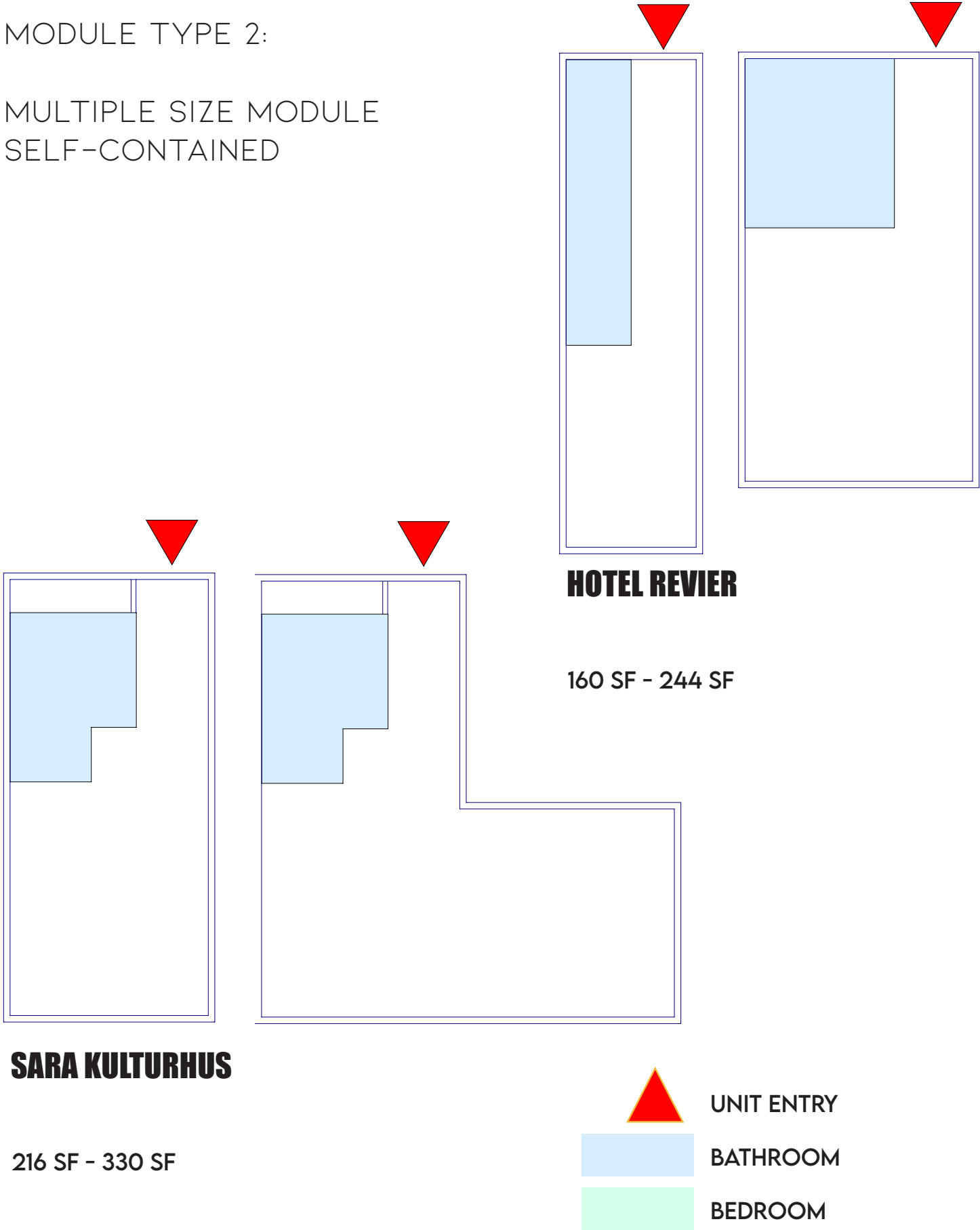
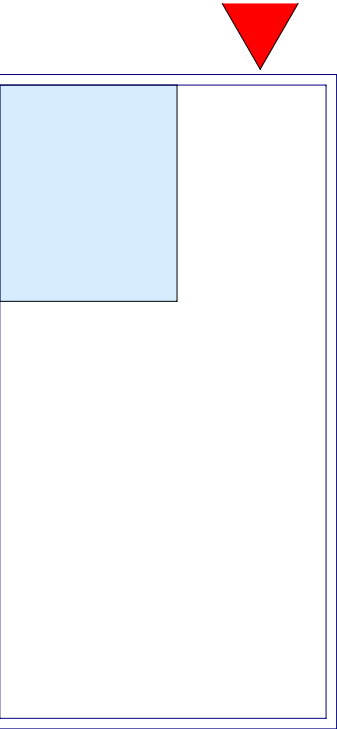
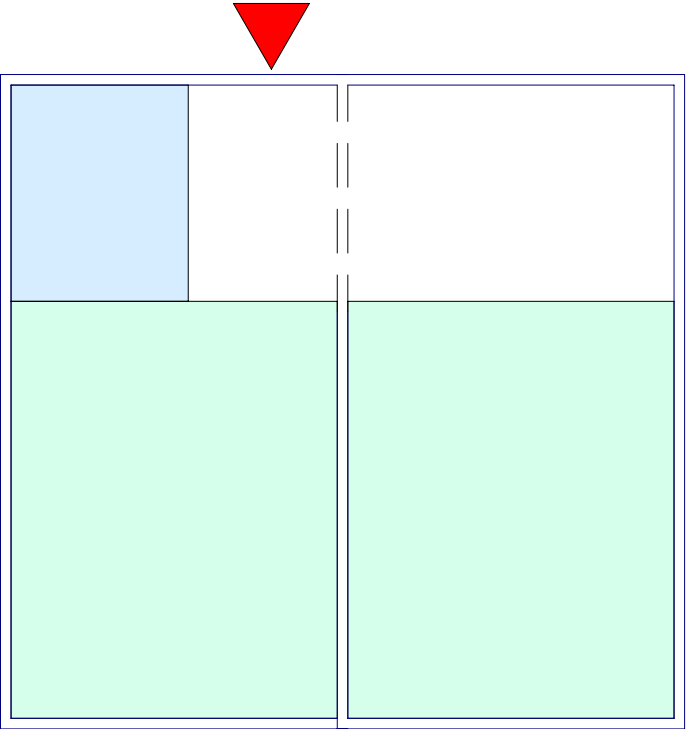


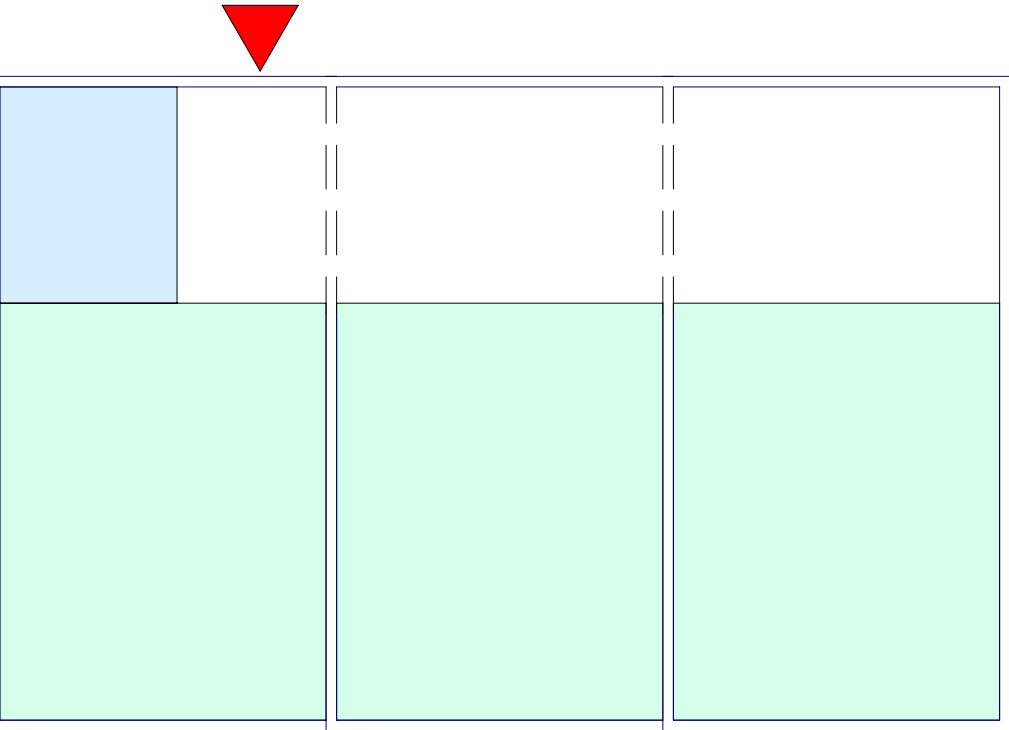
Fig 6: Hotel room interior, Sara Kulturhus



STUDIO
241 SF

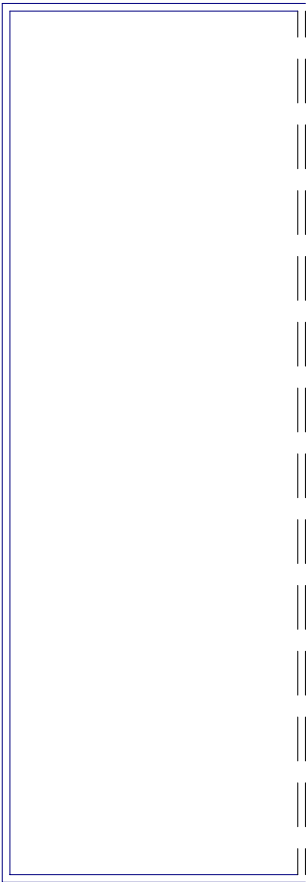


2-BEDROOM
482 SF

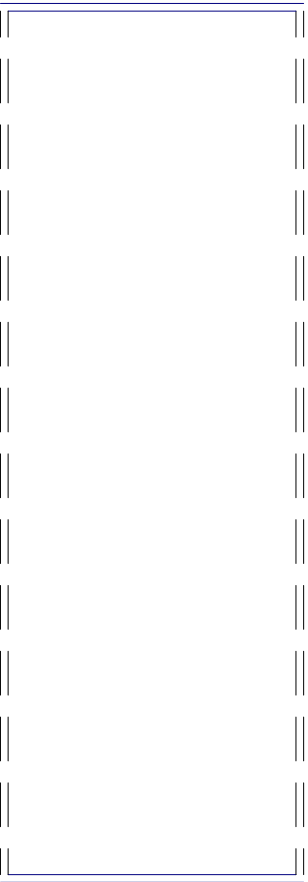


3-BEDROOM
723 SF

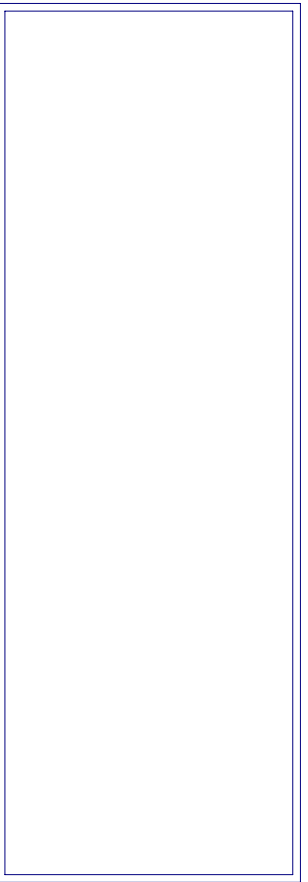
HEIDELBERG STUDENT UNION



ONE SIDE OPEN
290 SF



TWO SIDES OPEN
290 SF



CLOSED
290 SF

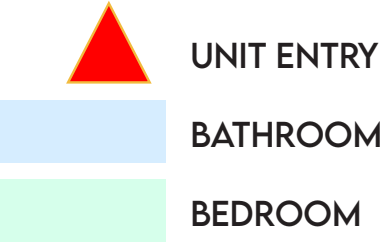
SCHOOL EXPANSION

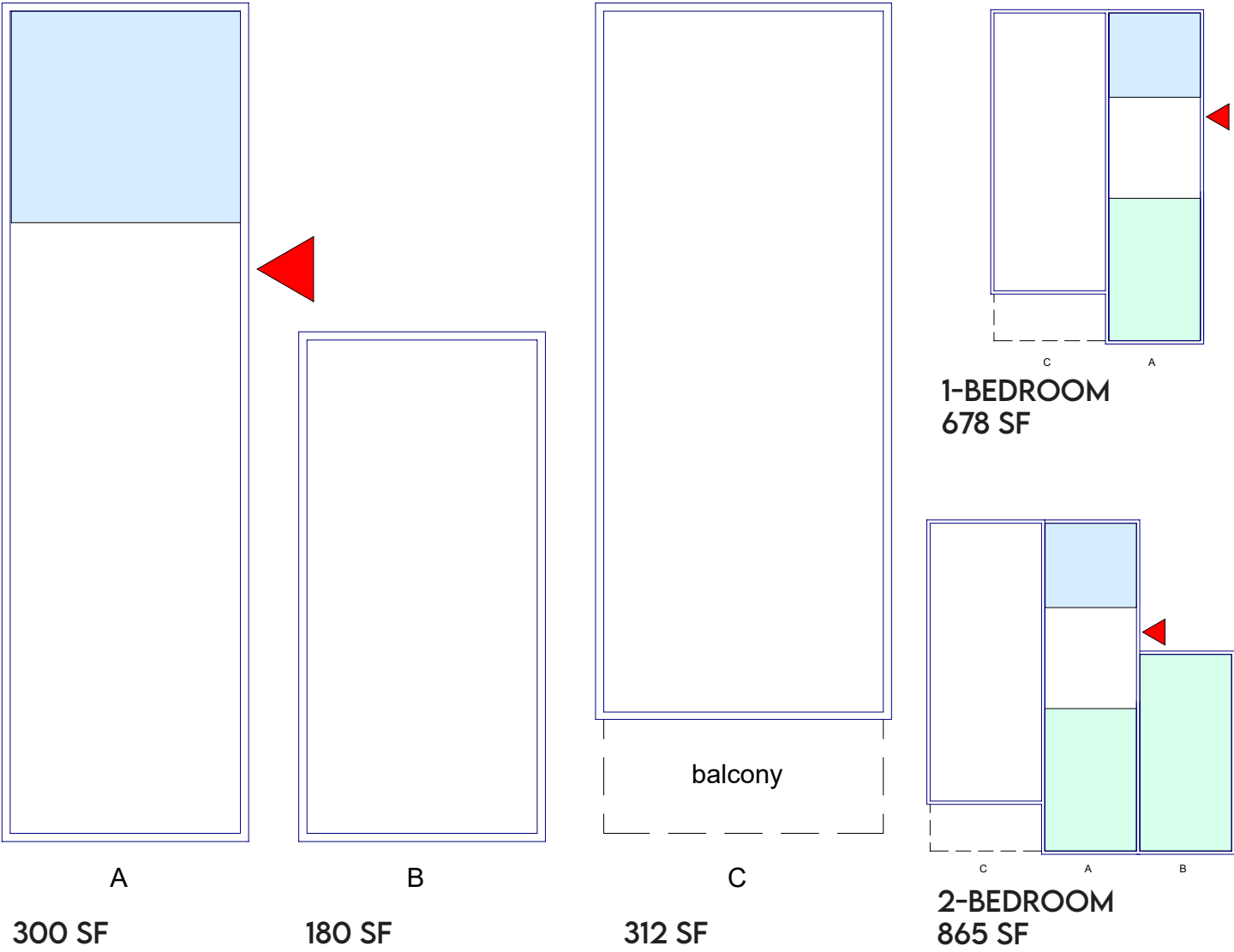
Two projects fell within the third category, employing modules of uniform size but opening sections of the walls to create larger units.

In the Heidelberg Student Union example, the wet core consistently occupied the first module, while subsequent dry modules were added as bedrooms. In the School Expansion project, the module size remained constant, but the connecting walls were at times substituted on one or both sides with LVL beams, yielding large, open classrooms. Furthermore, this standardized module size was utilized to house other essential programmatic elements within the building, such as staircases and bathrooms.

MODULE TYPE 3:

SINGLE SIZE MODULES
COMBINED





WOHNEN 550

MODULE TYPE 4:
MULTIPLE SIZE MODULES
COMBINED

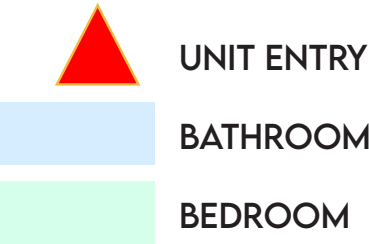
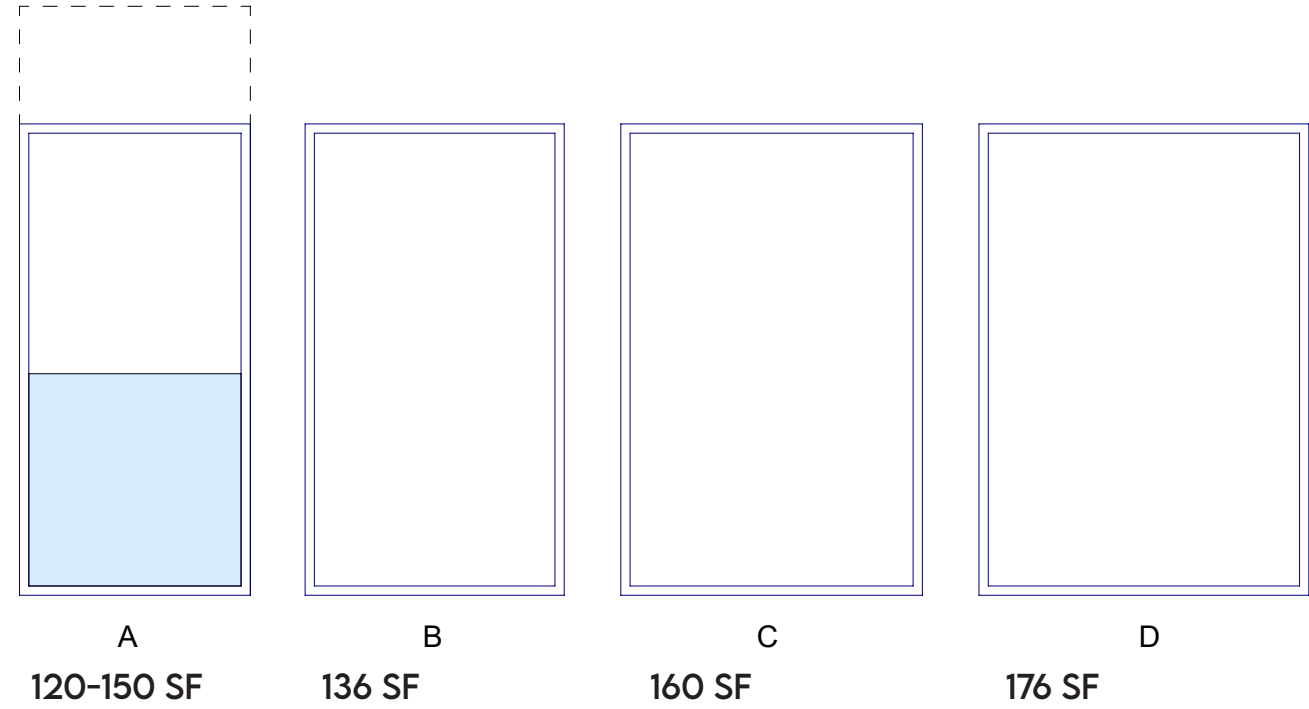
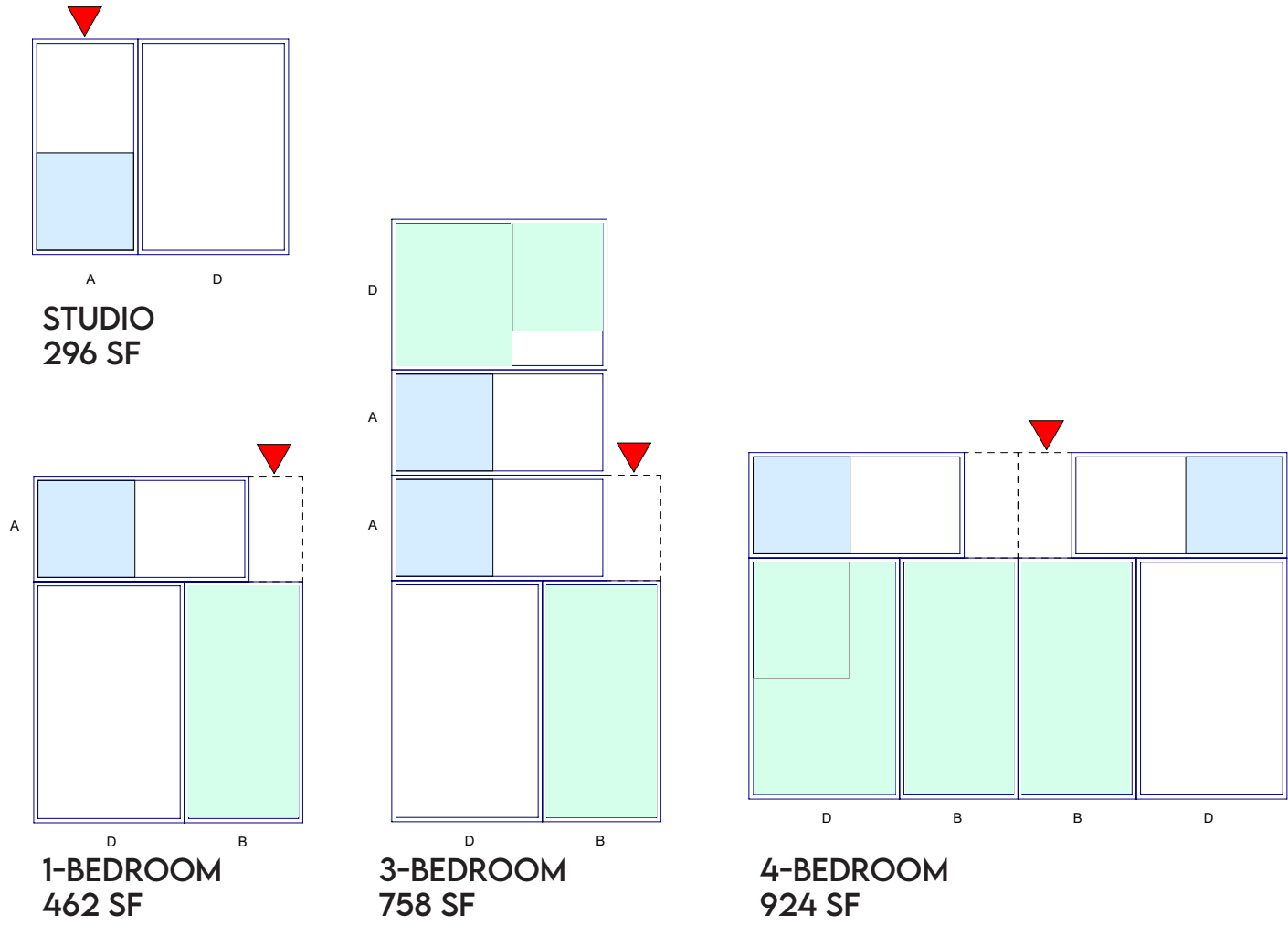


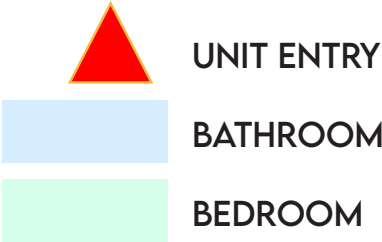
Fig-7: Wohnen 550 balconies



PLATENSIEDLUNG/LIWOOD



MODULE TYPE 4:
MULTIPLE SIZE MODULES
COMBINED



Two projects fell within what ostensibly constitutes the most intricate category: the combination of multiple module sizes to create apartments suitable for individuals to families. Both of these projects serve as replicable systems for affordable housing. The sophisticated construction of these systems facilitates the creation of flexible unit types, catering to a diverse range of needs within apartment buildings. Typically, these buildings housing such units are smaller in scale and organized around a single, central core.



Fig 8: Module assembly in a field factory, LiWood

Patterns emerged in the organization of modules at the building scale, mirroring those found within individual modules themselves.

The predominant architectural configuration was a linear-style building, often incorporating variations such as L- and E-shapes. Alternatively, buildings were arranged around a central circulation core or courtyard. Within buildings centered around a core, multiple size modules were combined to form apartments, typically resulting in smaller, walk-up style structures.

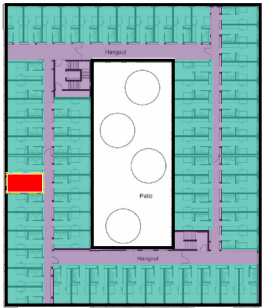
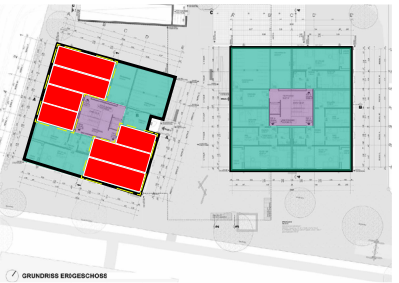
In terms of circulation within the buildings, the majority adopted a double-loaded corridor scheme, with a lone exception being the Hotel Revier, where the circulation walkway was integrated directly into the module design.

Concrete cores, housing vertical circulation, were commonly implemented to serve as structural bracing for the mass timber modules. Notably, only one instance involved integrating stair cores directly into a module, the Frankfurt school expansion, which also incorporated public bathrooms and other programmatic elements into the standard module size.

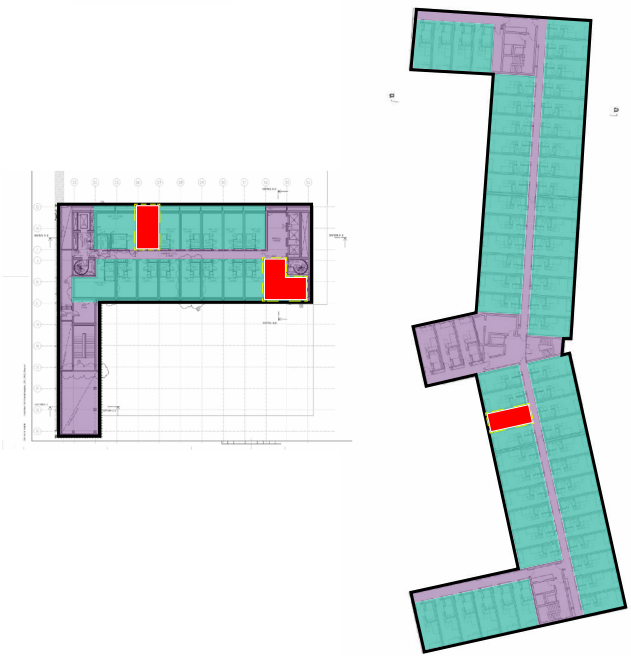


Fig 9: Modular school, Frankfurt

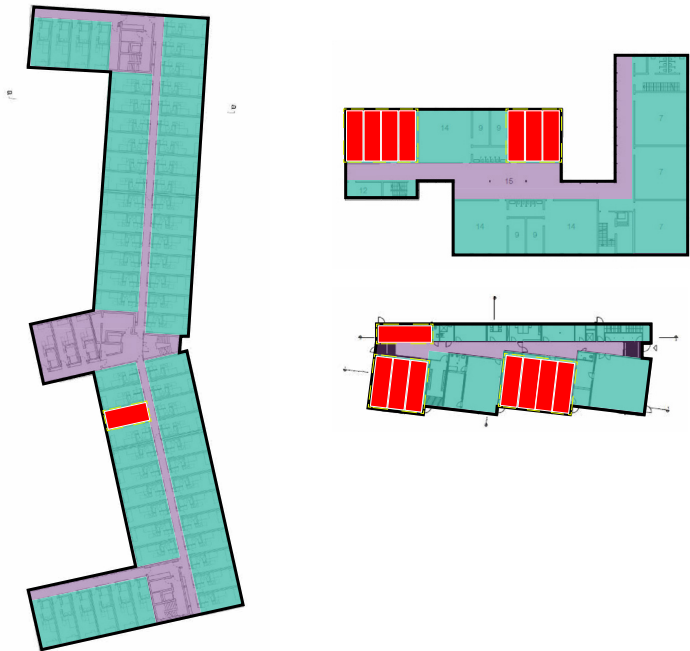
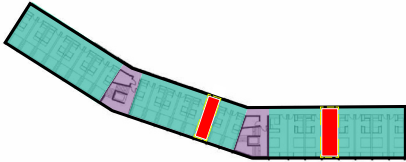
COURTYARD/CENTRAL CORE



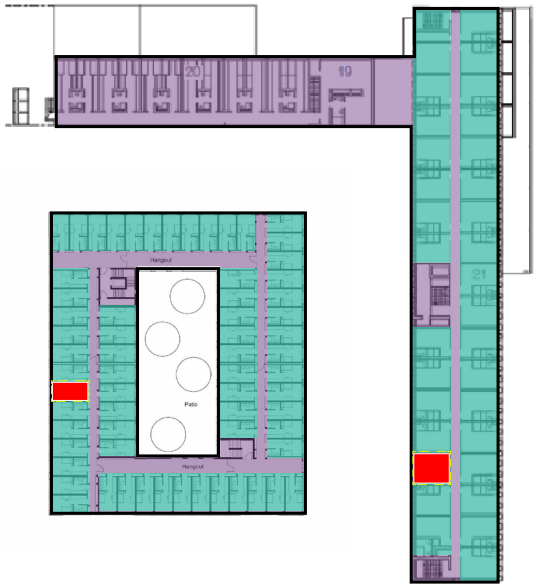
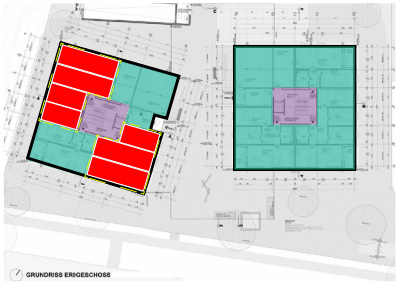
LINEAR/L-SHAPE VARIATION



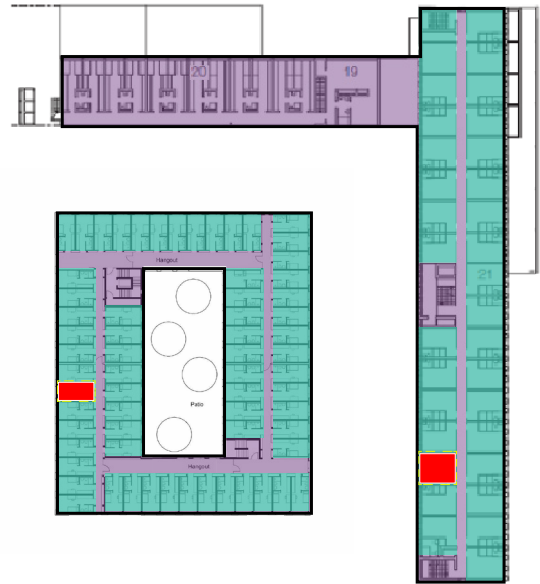
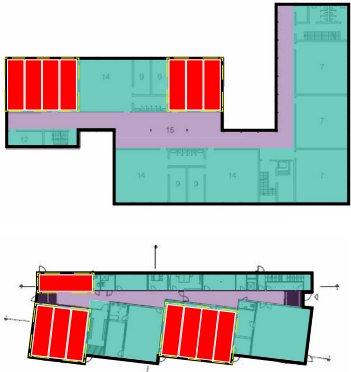
SINGLE-LOADED



CENTRALIZED



DOUBLE-LOADED





DESIGN APPLICATION

After conducting thorough background research and analysis, I began the design process. Rather than selecting specific sites for this project, the goal was to develop a modular system adaptable to various conditions found on military bases. It was assumed the site would be located within the continental US, guiding certain material choices.

The module design was largely influenced by specific requirements outlined for Unaccompanied Personnel Housing in the Department of Defense's facilities guide, FC 4-721-10N. The goal was to employ a novel construction approach and materials while still meeting the federal government's rigorous standards.

UNIT GUIDELINES

PROVIDING OUR UNACCOMPANIED MILITARY PERSONNEL WITH **ADEQUATE, COMFORTABLE HOUSING** IS A MAJOR GOAL FOR THE NAVY AND MARINE CORPS, AND A CRITICAL ELEMENT IN **ATTRACTING AND RETAINING HIGH CALIBER PERSONNEL**. THUS, THE MINIMUM STANDARDS SET FORTH IN THIS DOCUMENT MAINTAIN THE FOCUS OF PROVIDING HOUSING FOR **A COMFORTABLE LIVING ENVIRONMENT**.
- FC4-721-10N, 19 May 2022

Fig 10: 2016 CLT blast testing

FC 4-721-10N outlines comprehensive guidelines for the design and construction of military dormitories, aimed at ensuring optimal living conditions for service members. This document emphasizes the importance of creating functional and comfortable living spaces that promote well-being and productivity. Dormitory units are subject to several design requirements aimed at optimizing comfort, functionality, and sustainability. These requirements typically include specifications for the size and layout of individual units, as well as standards for materials and amenities.

In this study, particular attention was given to three of the most prevalent unit types found across different branches of the military: 2+0, 1+1E, and 2+2 Market units. While there may be slight variations in their locations and assignments based on branch-specific needs, the square footage requirements and design guidelines remain consistent. This consistency ensures uniformity and adherence to standards, regardless of the specific branch or location of the dormitory units.

Amidst growing concerns over aging infrastructure, dormitory improvements and

renovations have become a focus of attention for the military, drawing significant attention and funding. This heightened focus is underscored by initiatives such as the “Dorm Response Program,” which has allocated resources for 170 enlisted member dorm projects through 2027. In parallel, substantial funding amounting to \$227 million has been earmarked for 14 large-scale dorm renovations scheduled for 2024 alone.

Moreover, the “Quality of Life Investment Focus Fund” has emerged as a cornerstone initiative, committing \$300 million annually through Fiscal Year 2026. This initiative aims to enhance dormitories and other communal spaces and buildings, with the overarching goal of improving the quality of life for service members.

These concerted efforts reflect a recognition of the critical role that well-maintained and modernized dormitory facilities play in supporting the welfare and morale of military personnel. By prioritizing investments in dormitory infrastructure, authorities are not only addressing immediate concerns related to aging facilities but also laying the groundwork for long-term improvements that align with the evolving needs and expectations of service members.

EXISTING CONDITIONS



Fig 11: New furniture in Barrack 100 at Fort Cavazos, 2024 (US Army)

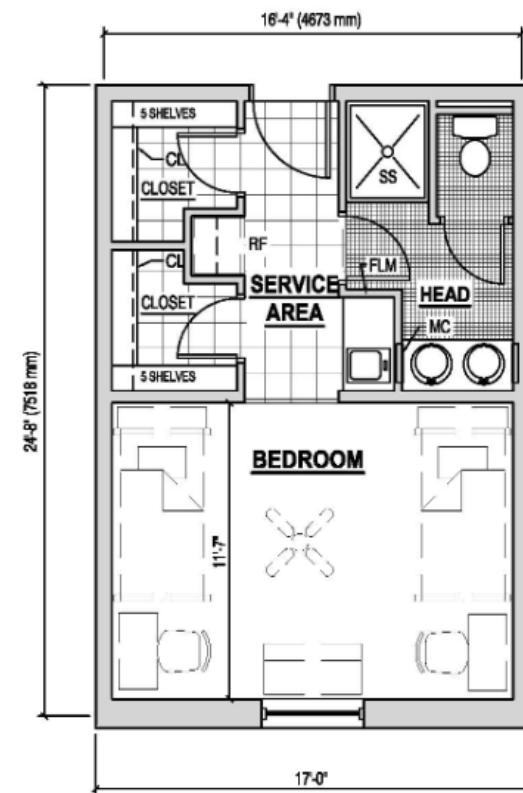


Fig 12: Army barracks room, 2021 (Reddit)



Fig 13: Before and after: prototype showing upgrades to a kitchen at Fort Polk (Humphreys)

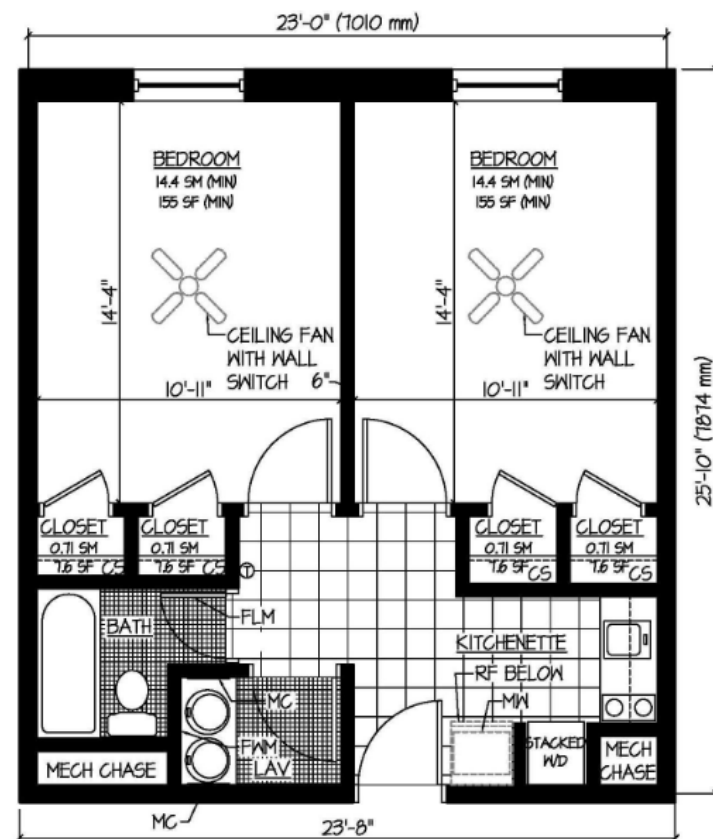
Figure B-7 Marine Corps 2+0 Room



2+0 Unit Requirements

2Occupants
380Gross Module Area
1 x 180 SFBedrooms
2 x 22 SFClosets
Add'l Req'sfull-size shower
separate sink area
10.3 cf fridge
microwave
kitchen sink

Figure B-6 Marine Corps 1 + 1E Plan – OCONUS Use Only



1+1E Unit Requirements

4	Occupants
600 SF	Gross Module Area
2 x 155 SF	Bedrooms
4 x 7 SF	Closets
Add'l Reqs	double vanity
	full-size shower
	separate sink area
	10.3 cf fridge
	microwave
	kitchen sink

NAVY FLOOR PLAN EXAMPLE.

Figure A-1 Navy Market Style Example



2+2M Unit Requirements

4	Occupants
850 - 1290 SF	Gross Module Area
2 x 144 SF	Bedrooms
4 x 4 LF hanging	Closets
Add'l Reqs	in-unit laundry
	4' min. vanity
	full-size shower
	separate sink area
	full-size fridge, 4-burner cooktop, 75 cf
	cabinet space, kitchen sink
	living/dining rooms sized for all occupants

MATERIAL CONSIDERATIONS

Although there are no defined sites for this project, assumptions were made that the intended site would be located in the continental US. Mercer, a US-based CLT manufacturer has multiple facilities with different plant capabilities. At the MMT Conway factory, panels widths range from 7'-10.5" to 12'-0", while the MMT Spokane factory can produce panels from 9'-9" to 11'-9" in width. All panels can be made up to 60' in length (Mercer).

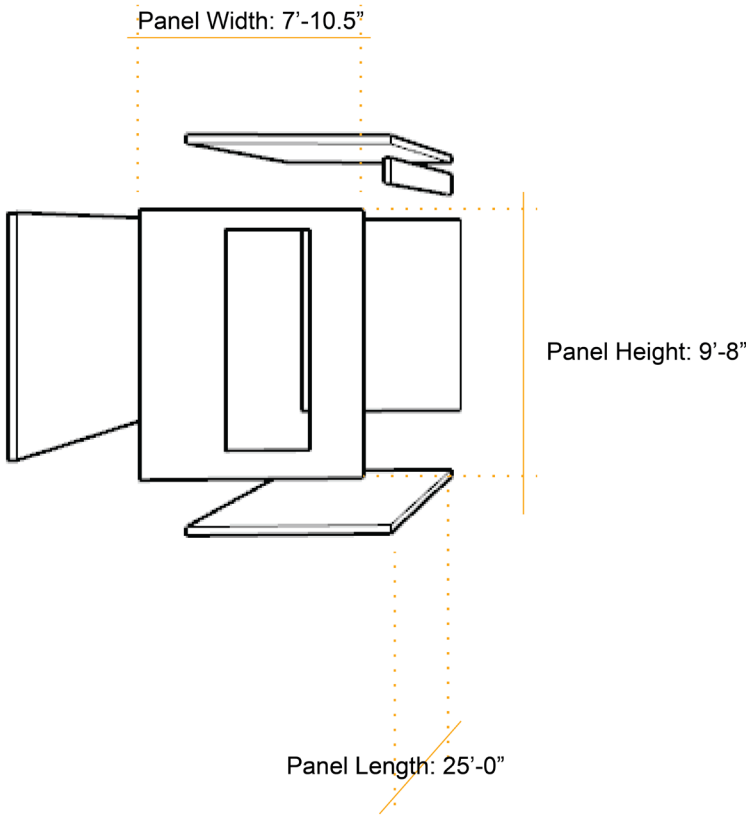
Fabrication is one of the biggest cost considerations when it comes to mass timber projects, using standard production sizes reduces the need for CNC programming and use thus reducing costs as well as reducing waste.

Additionally, transportation logistics and restrictions were considered in sizing the units.

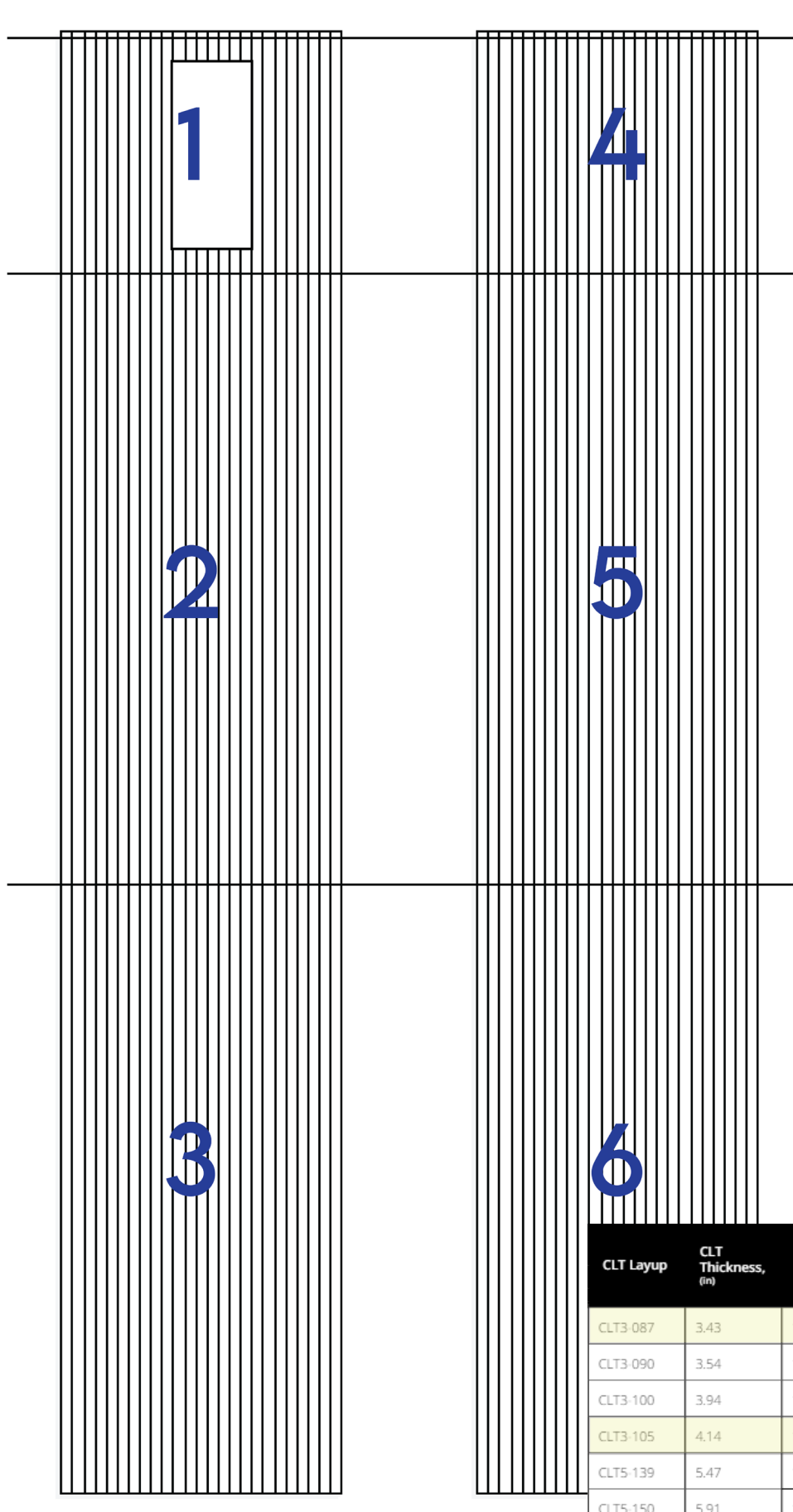
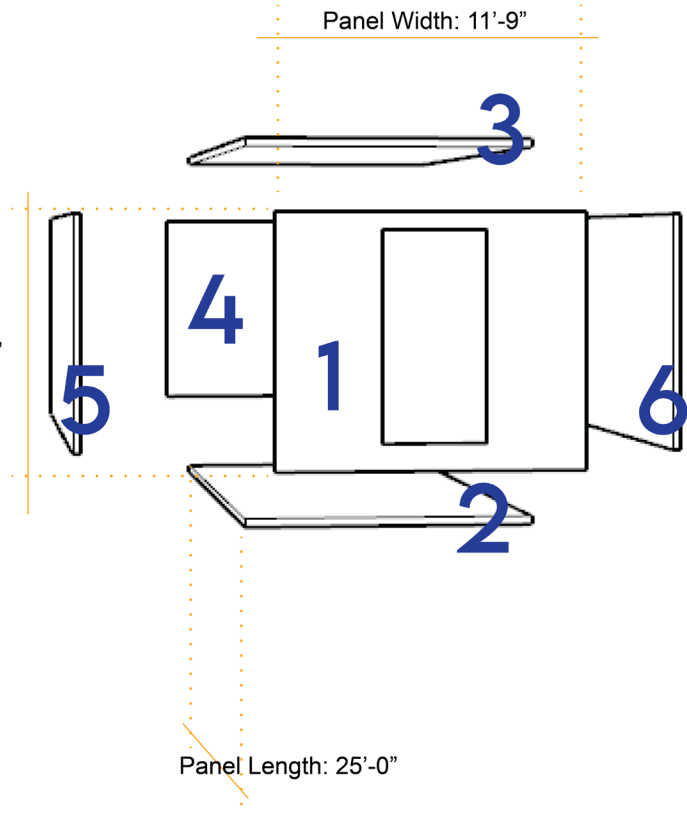
in the state of Oregon, truck load widths under 8'-6" do not require any permits, fees, or entail any restrictions. Although widths up to 12' require additional fees and permitting, there are fewer instances where pilot cars are required then for wider loads and no restrictions on travel times. When loads are wider than 12' there are significant requirements and restrictions which make transportation more difficult and expensive (ODOT).

Using the Mercer panel dimensions and the unit requirements set by the DoD, two module sizes were determined as shown below. Keeping both modules the same length allows for both types to be combined within the same building, allowing for more flexibility of programming. Preliminary cut mapping on the panels shows how efficiently each billet can be utilized with these dimensions.

MODULE A (7'-10.5" WIDTH)



MODULE B (11'-9" WIDTH)



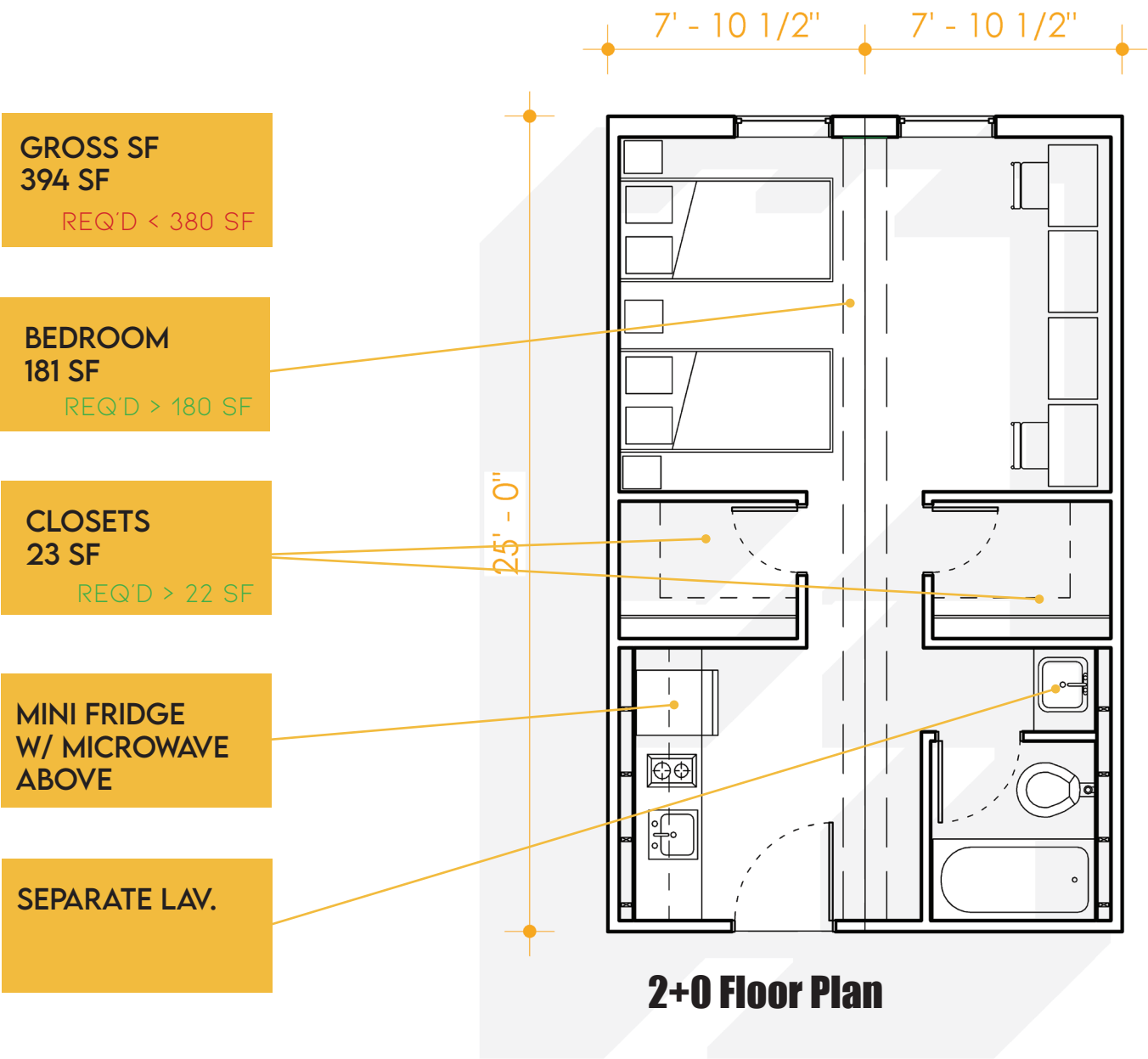
CLT Layup	CLT Thickness, (in)	Lamination Thicknesses in CLT Layup (in)				
		=	⊥	=	⊥	=
CLT3-087	3.43	1.38	0.67	1.38		
CLT3-090	3.54	1.18	1.18	1.18		
CLT3-100	3.94	1.38	1.18	1.38		
CLT3-105	4.14	1.38	1.38	1.38		
CLT5-139	5.47	1.38	0.67	1.38	0.67	1.38
CLT5-150	5.91	1.18	1.18	1.18	1.18	1.18

Mercer CLT thicknesses

MODULE DESIGN

The subsequent pages outline the reimagining of DoD guidelines and floor plans for 2+0, 1+1E, and 2+2 Market units into a mass timber volumetric modular structure. Emphasis was placed on functionality, user comfort, and system integration. A deliberate decision was taken to expose as much CLT material as possible to capitalize on the proven benefits of biophilic design elements. To realize this goal, only the floors would be covered, with minimal areas of the ceilings dropped. A further advantage of minimal finishing is the reduction in costs and the avoidance of harmful, toxic substances and VOCs. Through meticulous design and planning, mass timber modules present a contemporary and sustainable solution to dormitory living on US military installations.

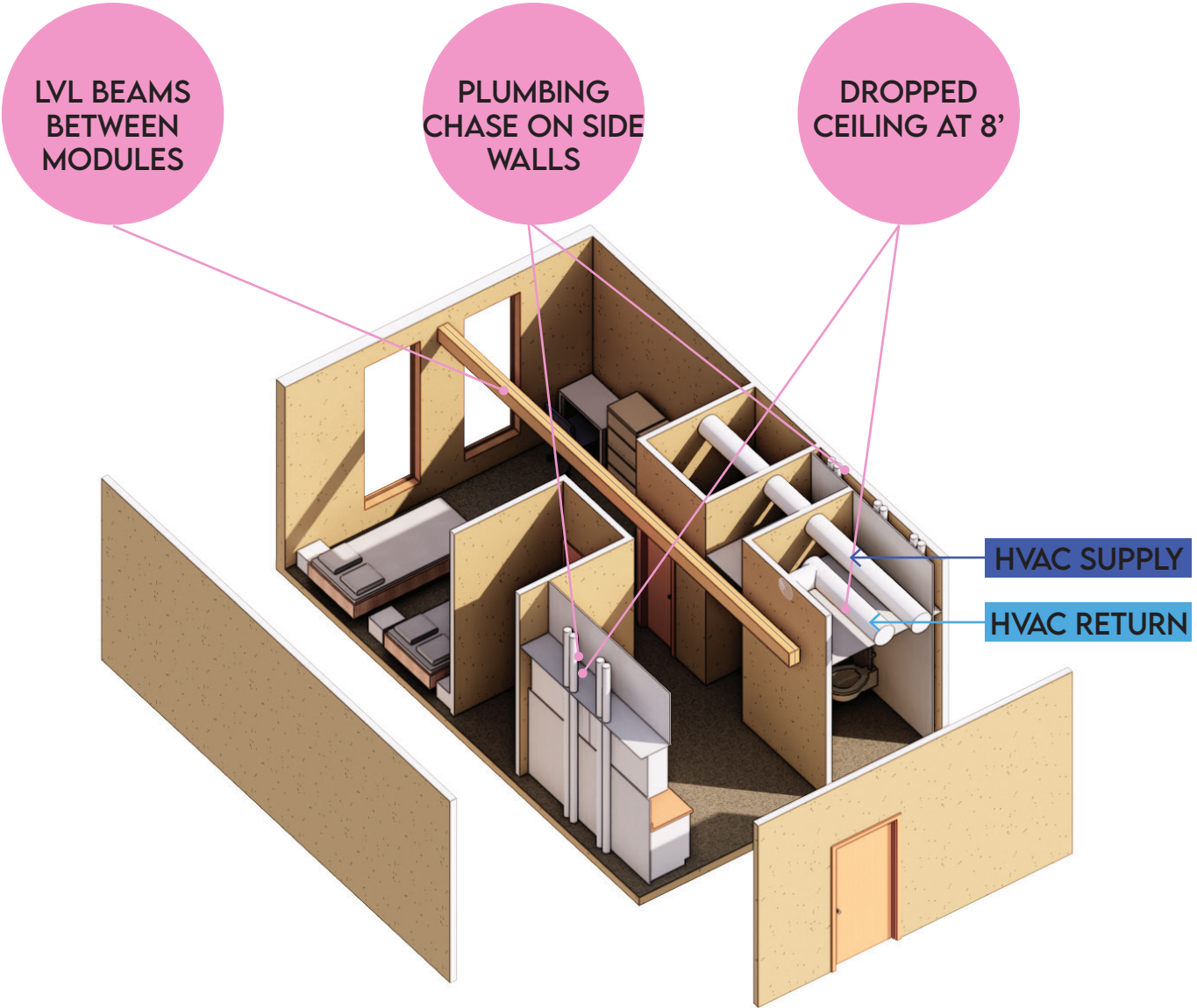




Single or Double Occupancy

Module Size = 7'10.5" x 25'-0"

Two Modules = 1 Unit

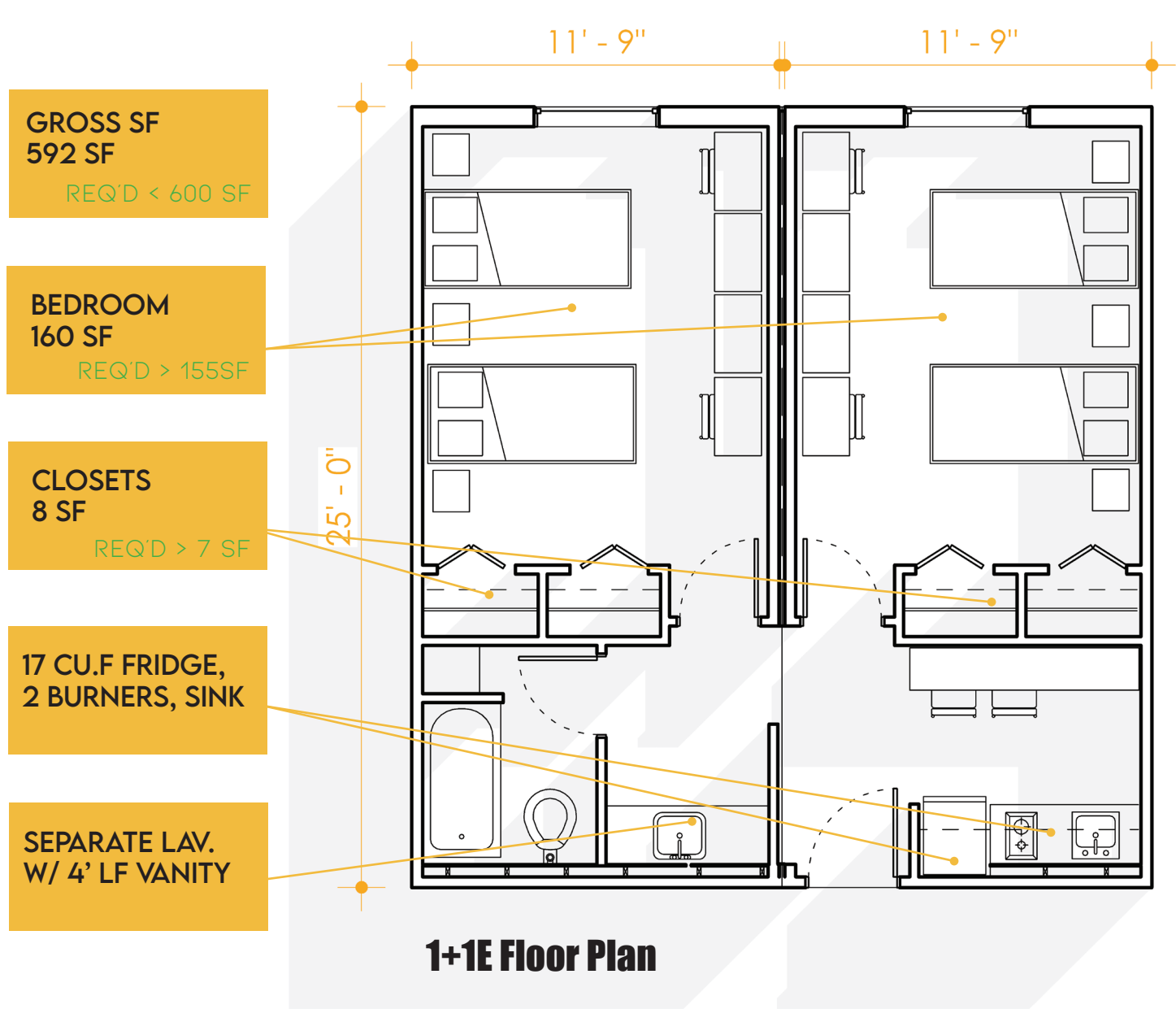


The 2+0 unit was designed with two semi-open modules, each utilizing Mercer’s 7’-10.5” width panel. These modules are interconnected with LVL beams that run along the central spine of the unit. Although adhering to the standardized width results in the units exceeding the DoD requirement of 380 square feet by 14 square feet, it was determined that the cost savings achieved by not trimming the panels would ultimately benefit the project.

However, to accommodate necessary HVAC runs, a dropped ceiling at an 8’ height has been incorporated in the bathroom, lavatory, and above the kitchen cabinets.

Additionally, two framed plumbing chases, situated on either side of the unit, house plumbing for the bathroom and kitchen utilities.

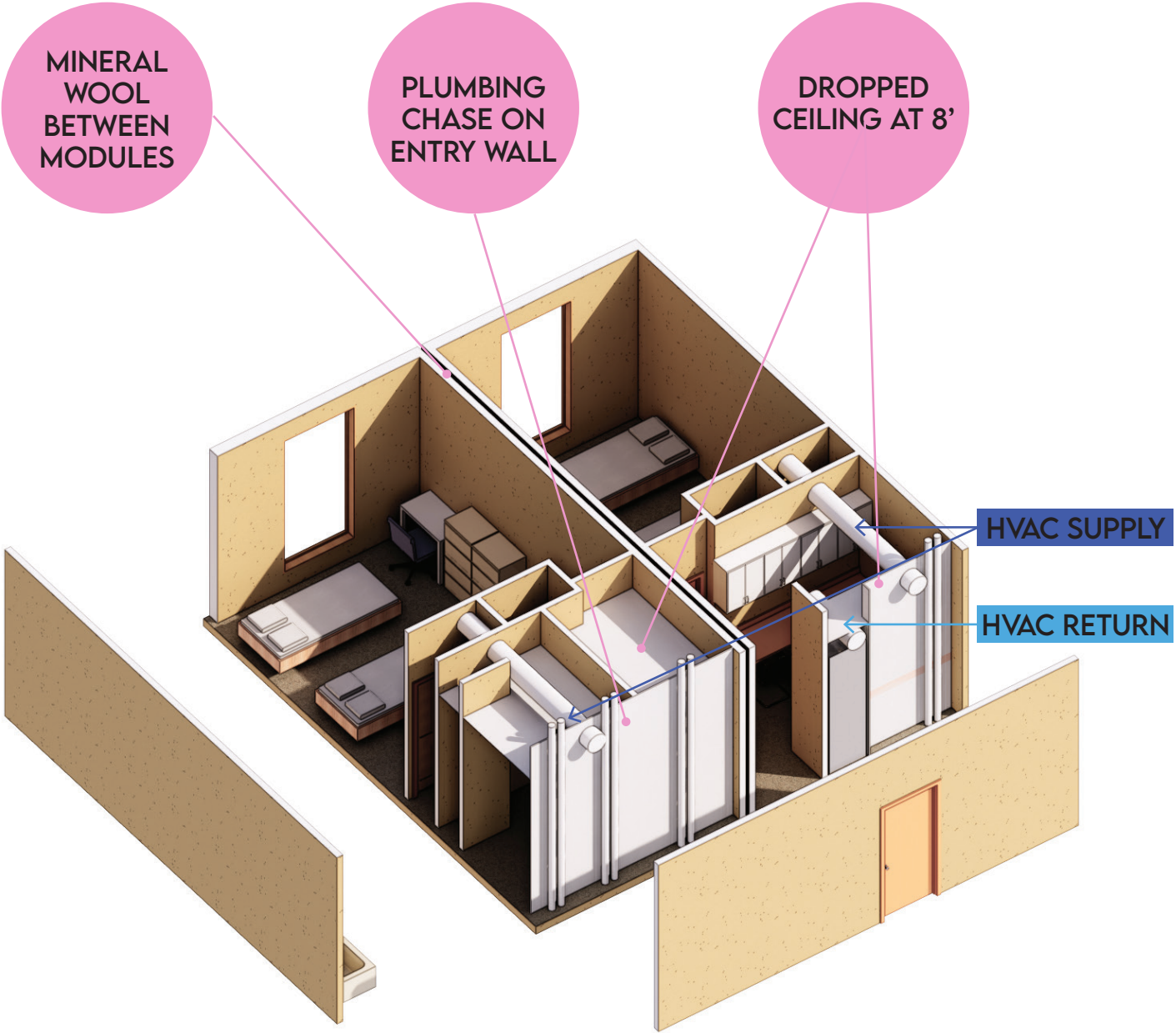
Part of the design intent is to maximize the exposure of CLT, allowing for biophilia benefits.



Double or Quad Occupancy

Module Size = 11'-9" x 25'-0"

Two Modules = 1 Unit

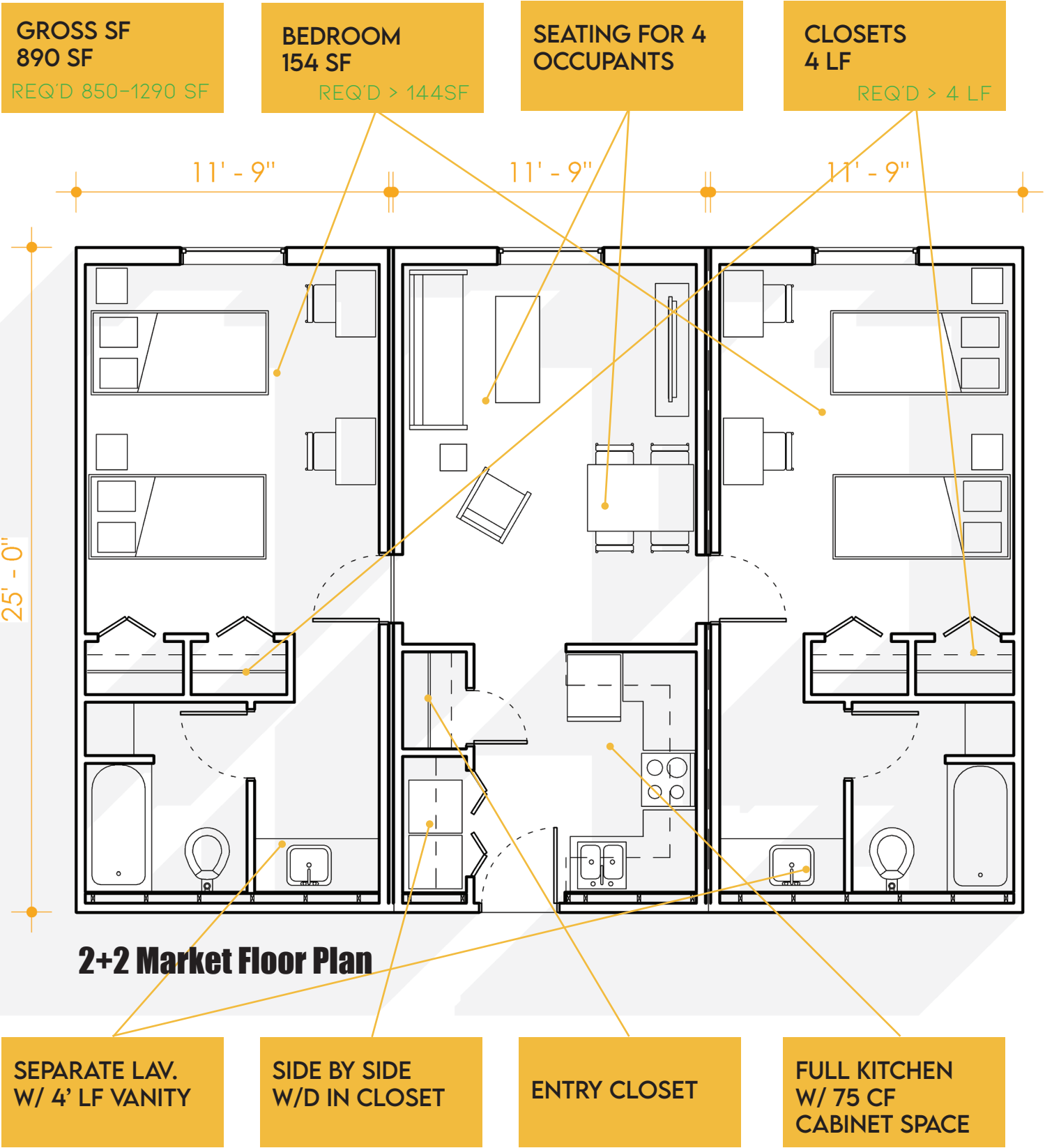


The 1+1E unit was devised with two enclosed modules, employing Mercer’s 11’-9” width panel. Where the two modules connect, mineral wool fills the cavity, ensuring enhanced sound isolation between the two bedrooms.

An 8’ dropped ceiling has been implemented in the bathroom, lavatory, and above the kitchen cabinets, partially concealing the HVAC supply and return runs. Within each module, a supply duct extends into the sleeping area, while a return is positioned in the kitchen, alongside a stove exhaust. Furthermore, a plumbing chase extends

along the building circulation wall to meet unit plumbing needs.

Although the floor plan depicts double occupancy in each bedroom, the rooms can also accommodate single occupancy with a queen-size bed. Additionally, there is flexibility to upgrade from a single to a double lavatory if required.



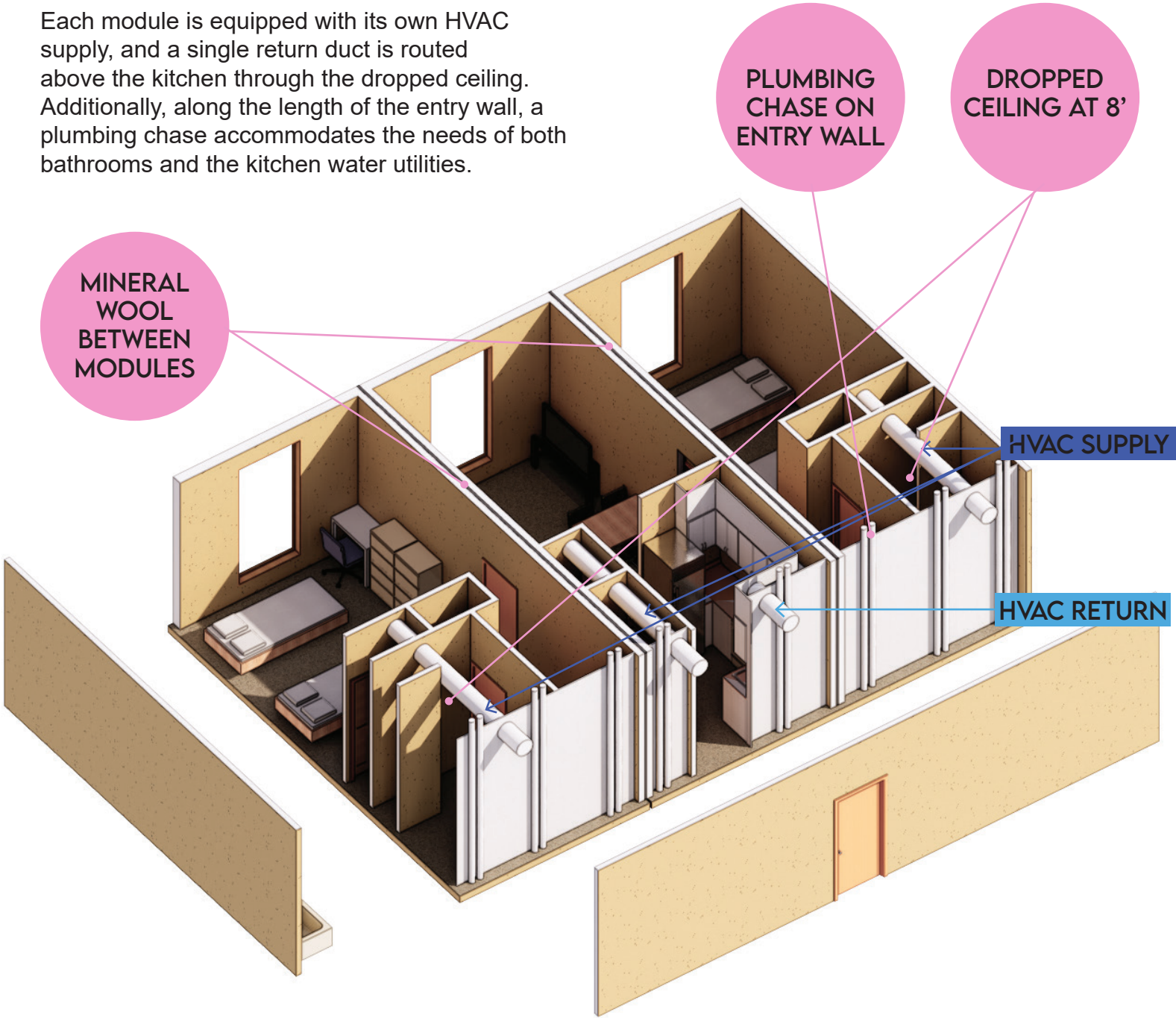
The 2+2 Market Unit closely resembles a typical apartment found in the private market with amenities such as a washer and dryer, a full kitchen, and a communal living area. Constructed from three 11'-9" width modules, these units provide more space per occupant than the previous units.

The end modules are mirrored, featuring a bedroom and bathroom layout akin to the 1+1E bedroom module. Meanwhile, the central module houses the kitchen and common area. To ensure optimal acoustic performance, the cavities where the modules meet are filled with mineral wool. Each module is equipped with its own HVAC supply, and a single return duct is routed above the kitchen through the dropped ceiling. Additionally, along the length of the entry wall, a plumbing chase accommodates the needs of both bathrooms and the kitchen water utilities.

Double or Quad Occupancy

Module Size = 11'-9" x 25'-0"

Three Modules = 1 Unit

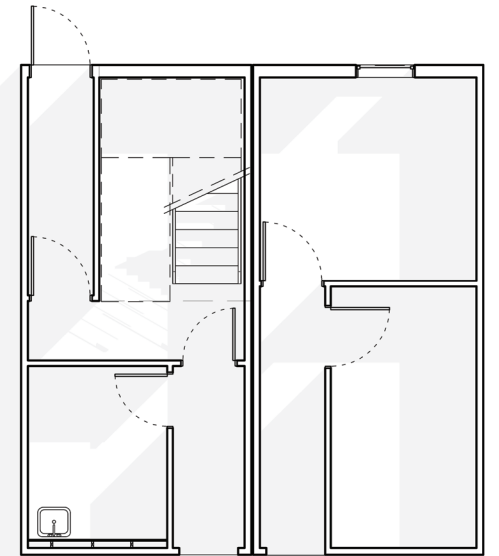


ADDITIONAL PROGRAM

Expanding my focus beyond the living units, I carefully considered the programming requirements for the entire building and used the established module size of 11'-9" x 25', in the design of other essential spaces.

In some instances, the modules are crafted as single, enclosed units, offering flexibility in placement. Conversely, in other scenarios, an open wall design with LVL beams—similar to the structure utilized in the narrower 2+0 living unit—is employed. These larger open spaces accommodate communal gathering areas, including common laundry facilities, shared kitchens, game rooms, and multi-purpose spaces, fostering a sense of community within the building.

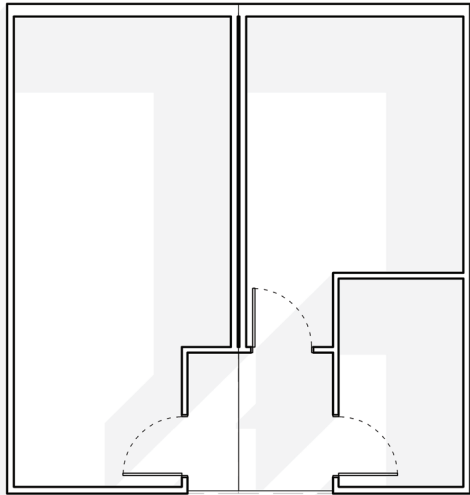
Deliberately, the design of these non-residential units minimizes exterior openings, allowing for efficient lateral and seismic bracing. This uniform approach ensures consistency across all residential modules, thereby promoting equity among occupants.



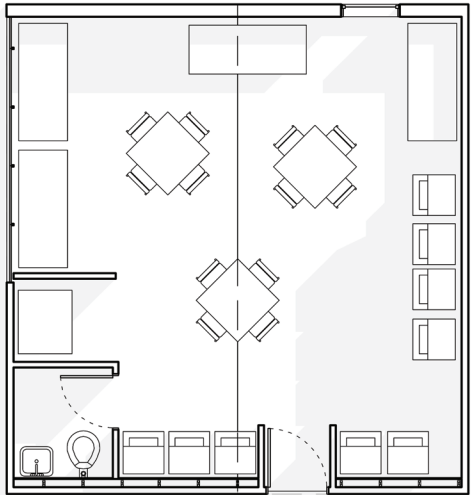
Stair, Janitor, Comm., Storage



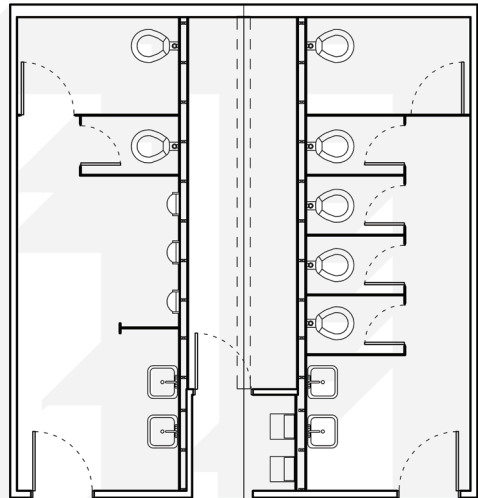
Stair, Janitor, Comm., Lounge



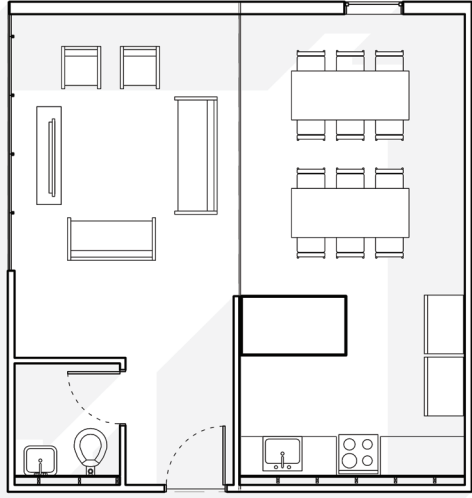
Mech., Comm., Housekeeping



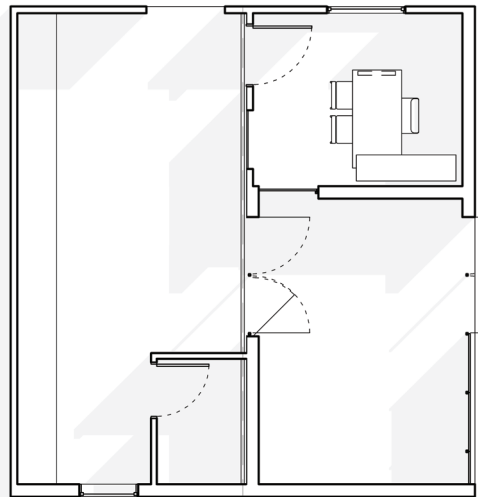
Common Laundry



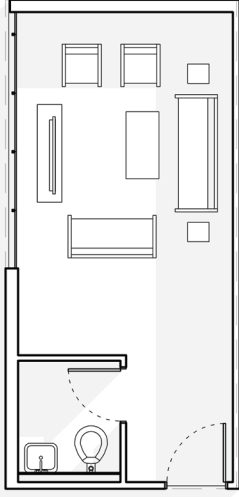
Public Restroom



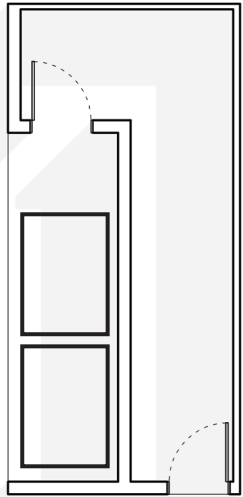
Multi-purpose, Kitchen



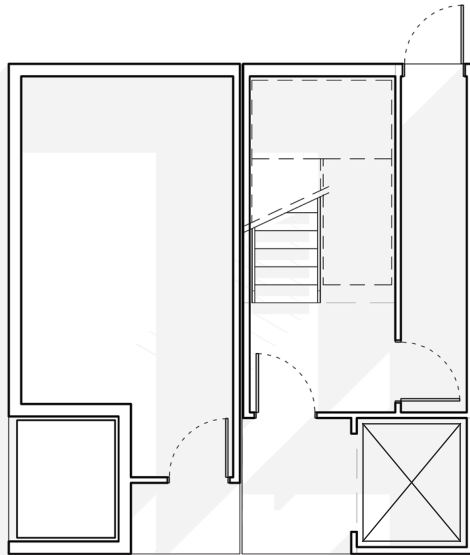
Lobby, Mail, Reception



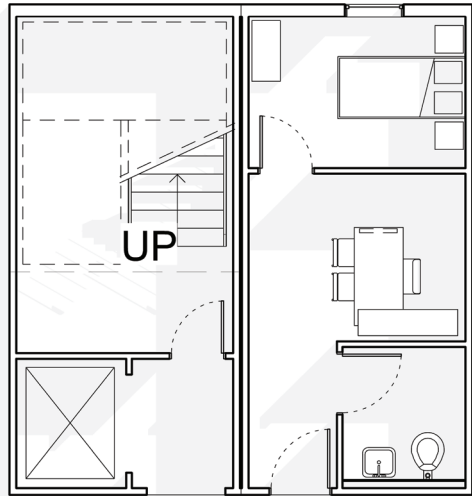
Game Room



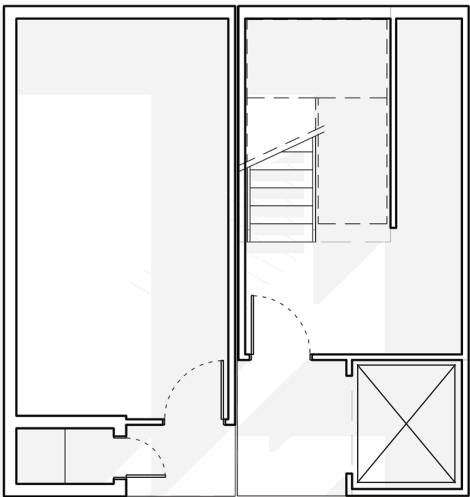
Garbage Rm.



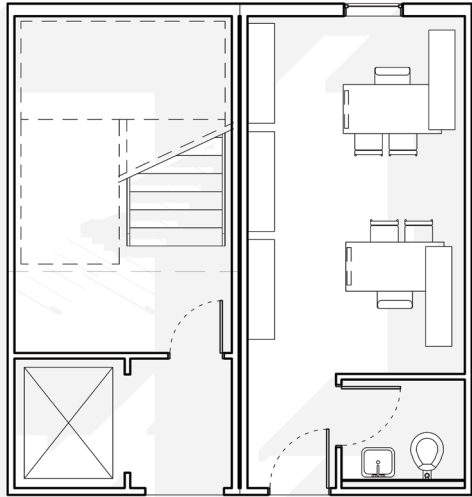
Stair, Elevator, Mech., Trash



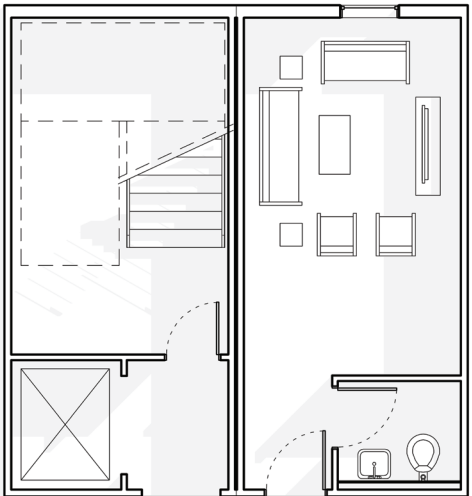
Stair, Elevator, Duty Bunk



Stair, Elevator, Mech., Trash



Stair, Elevator, Admin.



Stair, Elevator, Game Room

BUILDING GUIDELINES

In military dorm buildings, it's typical to find only one type of living unit. The maximum allowable gross building area (which includes common areas) is determined by the unit type. For instance, 2+0 plans allow for 595 square feet per unit, while the 1+1E type permits 875 square feet per unit, and the market unit type allows for 606 square feet per bedroom based on a two-bedroom unit. If the building exceeds three stories, an additional 21.5 square feet per story is granted.

It's important to note that the gross unit area includes perimeter walls and their thickness.

Additional requirements include 8' exterior entry walkways, a single public entrance complete with a weather-protected vestibule, and 6' corridors within the interior. While separate service entrances for mechanical areas are preferable, they are not strictly mandated.

For buildings exceeding two stories but falling short of five stories, two elevators are mandated along with emergency stairs to meet IBC standards for sprinklered buildings.

Certain program elements are subject to minimum square footage requirements, detailed as follows:

- Duty Office: 125 sq ft, with Duty Bunk: 80 sq ft
- Unisex Restrooms (single stall): 45 sq ft
- Elevator: 85 sq ft
- Vending Area: 85 sq ft
- Janitor Closet: 90 sq ft (with plumbing)
- Housekeeping Area: 250 sq ft (with plumbing)
- Telecommunication Room: 80 sq ft per floor

All requirements referenced from FC 4-721, UFC 3-580-01, UFC 3-41-01, and UFC 3-101-01

2+0 Unit Building Requirements

Corridors	Restroom
Stairways	Bulk Storage
Office/Admin	Janitorial
Elevators	Trash Room
Lobby/Reception with weather vestibule	Housekeeping/Linen
Mech/Elec./Telecom	Common Laundry
Multipurpose Room(s)	Vending
Public Toilets + Unisex	Duty Office
	Duty Bunk

1+1E Unit Building Requirements

Corridors	Housekeeping/Linen
Stairways	Common Laundry
Elevators	Vending
Mech/Elec./Telecom	Duty Office
Multipurpose Room(s)	Duty Bunk
Unisex Restroom	
Bulk Storage	
Janitorial	
Trash Room	

2+2M Unit Building Requirements

Corridors	Unisex Restroom
Stairways	Bulk Storage
Office/Admin	Janitorial
Elevators	Trash Room
Lobby/Reception with weather vestibule	Housekeeping/Linen
Mech/Elec./Telecom	
Multipurpose Room(s)	
Public Toilets	

EXISTING CONDITIONS

Existing dormitories often exhibit an institutional aesthetic, characterized by the use of neutral earth tones and durable materials. Emphasis is placed on cultivating inviting outdoor areas and providing shaded circulation pathways. Entrances are clearly defined with prominent signage for easy navigation.

Recent guidelines underscore the significance of sustainable design principles, advocating for the integration of features such as rooftop solar panels and passive energy strategies. Moreover, there is a growing focus on enhancing occupant quality of life through thoughtful design choices.



Fig 15: Joint Base Lewis-McChord



Fig 16: UH Campus (FC 4-721-10N)



Fig 17: Eglin Air Force Base (USAF)

BUILDING DESIGN GOALS

A core goal in designing these modular buildings is to create light-filled walkways, fostering an environment where natural light permeates through circulation areas. Double-loaded corridors with repetitive entry doors can be gloomy and uninviting, affecting occupant’s moods on their walk to their unit. By ensuring light can penetrate every corridor, it not only enhances the aesthetics of the space but also has significant implications for human health and well-being. Exposure to natural light has been linked to improved mood, productivity, and overall mental health among building occupants. Additionally, it reduces reliance on artificial lighting, thereby promoting energy efficiency and sustainability (Heschong).

Another key objective is to incorporate secondary gathering spaces along circulation routes. These areas serve as hubs for informal interactions and socialization, facilitating community building and strengthening social bonds. This idea is especially

important in military dormitories where young men and women are at risk of social isolation leading to higher rates of negative mental health episodes and suicide (Kelly). By promoting social engagement, these spaces contribute to a sense of belonging and connectedness among occupants, fostering a supportive and inclusive community atmosphere.

Additionally, positive outdoor spaces are integral to building design, offering residents opportunities for relaxation, recreation, and connection with nature. Access to outdoor environments has been associated with numerous health benefits, including stress reduction, improved mood, and increased physical activity levels (Hartig).

- Light-Filled Walkways
- Dispersed Social Areas
- Secondary Gathering Spaces Along Circulation
- Positive Outdoor Space



Fig 18: Frankfurt school expansion



Fig 20: Adoma apartments



Fig 19: Student residence, Gottingen



Fig 21: Hotel Revier

BUILDING DESIGN: 2+0 LINEAR BUILDING

12,868 SF Building Footprint
38,604 GSF
63 Units
126 Residents
612 GSF/Unit
306 GSF/Person



Vertical
Circulation

First Floor

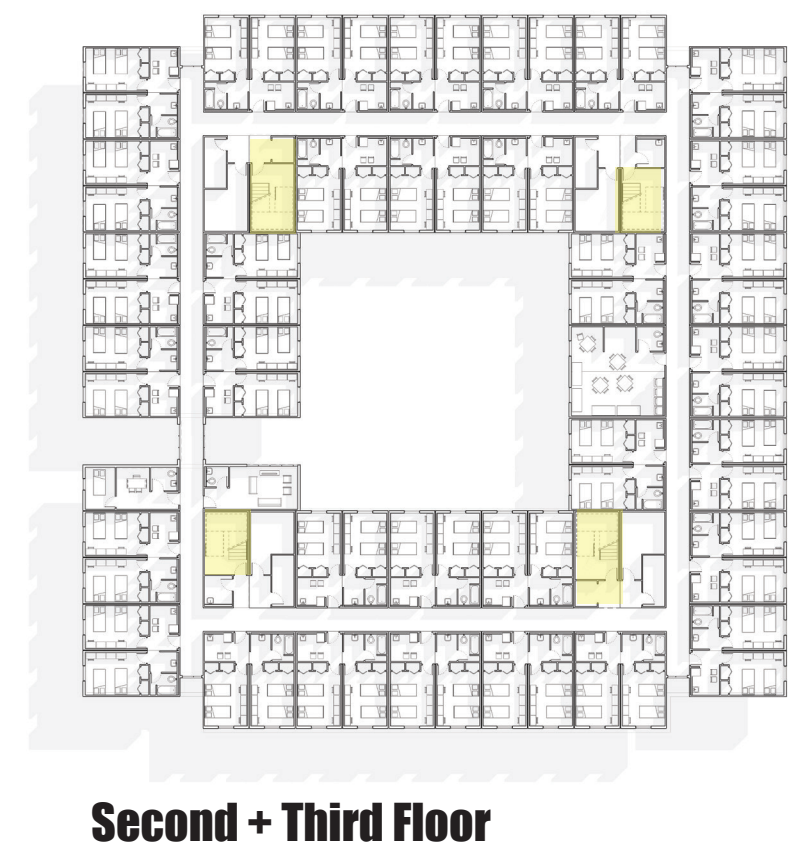


Second Floor



Third Floor

BUILDING DESIGN: 1+1E COURTYARD BUILDING



26,418 SF Building Footprint

79,542 GSF

98 Units

392 Residents

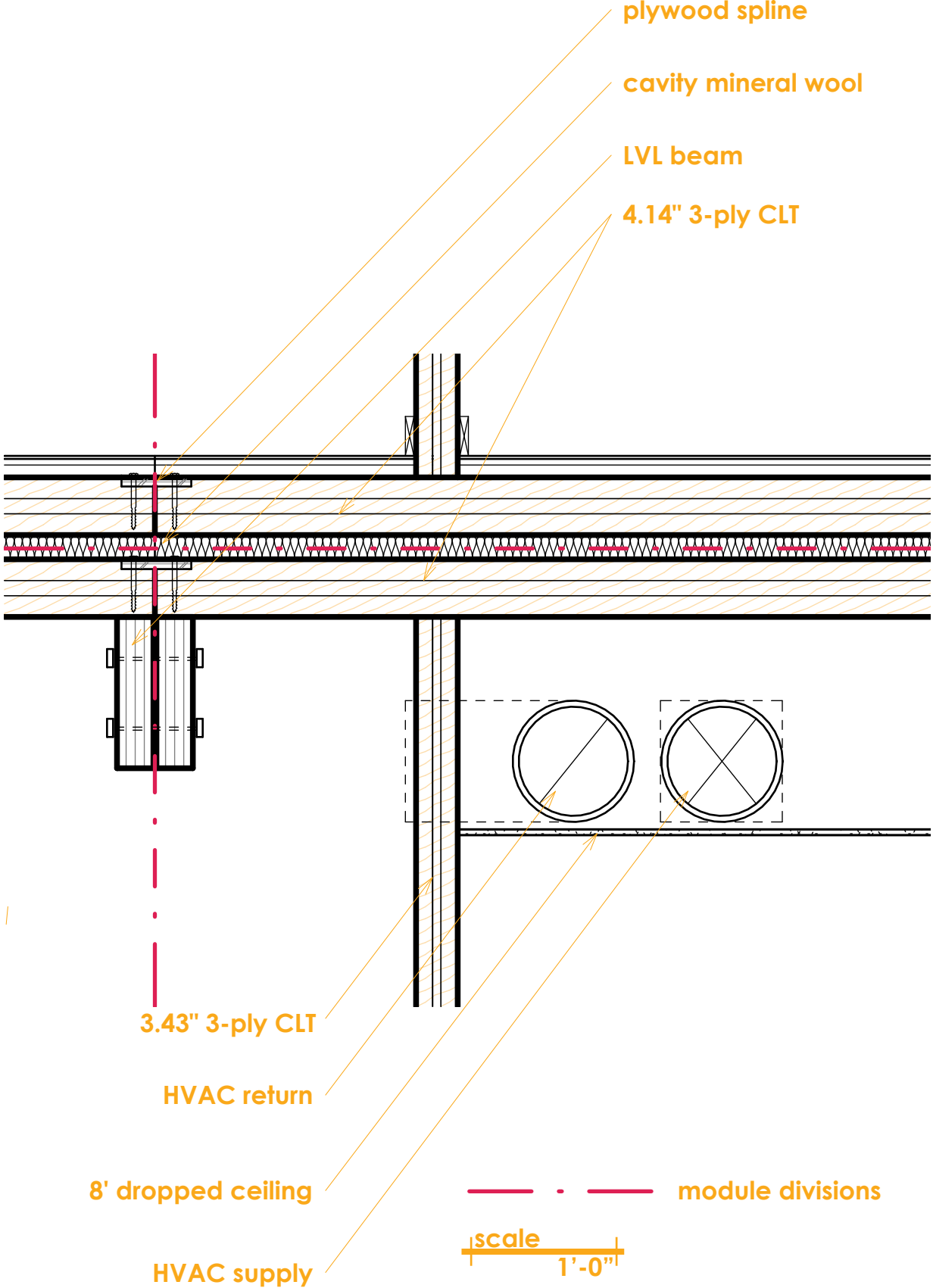
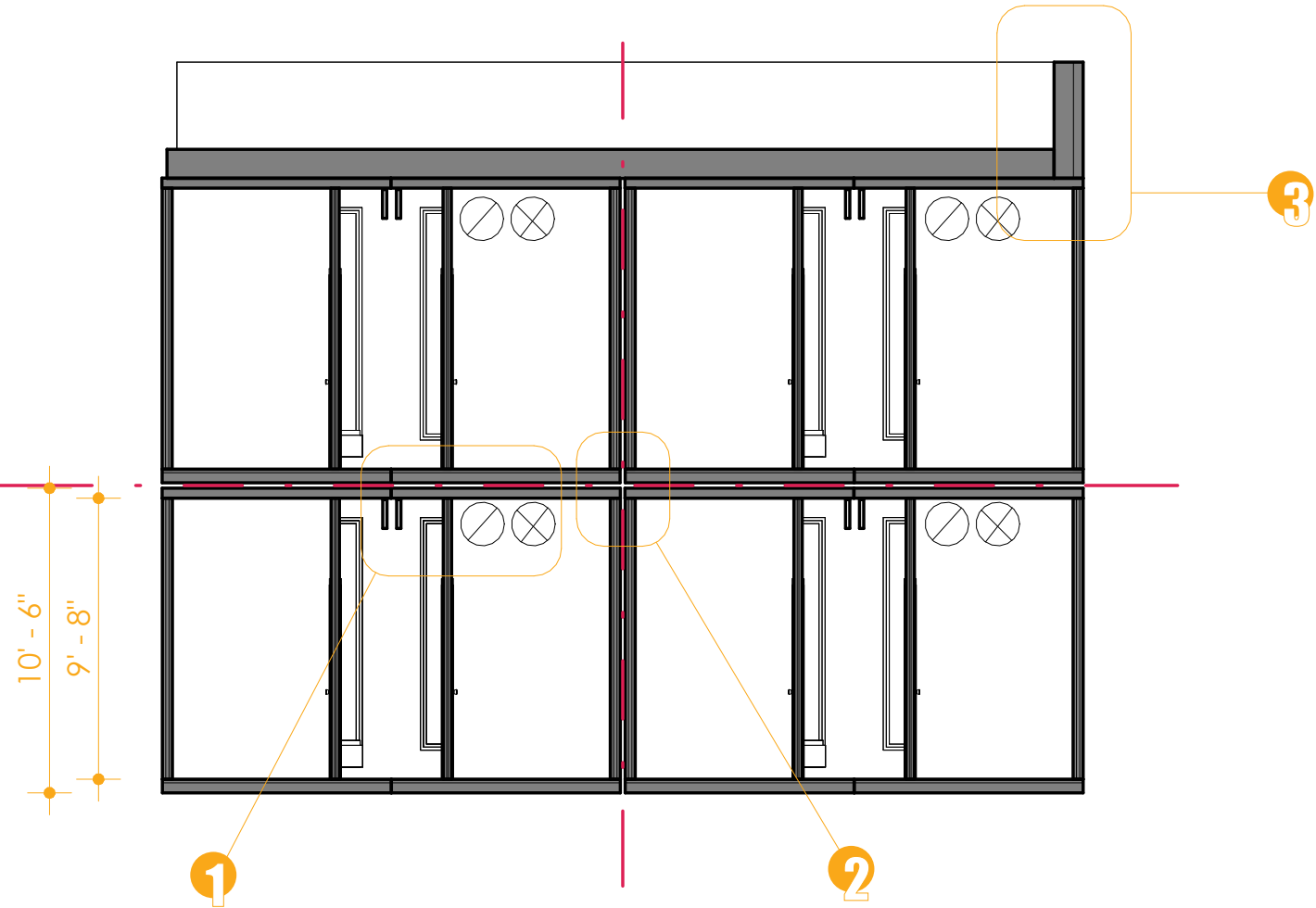
811 GSF/Unit

202 GSF/Person

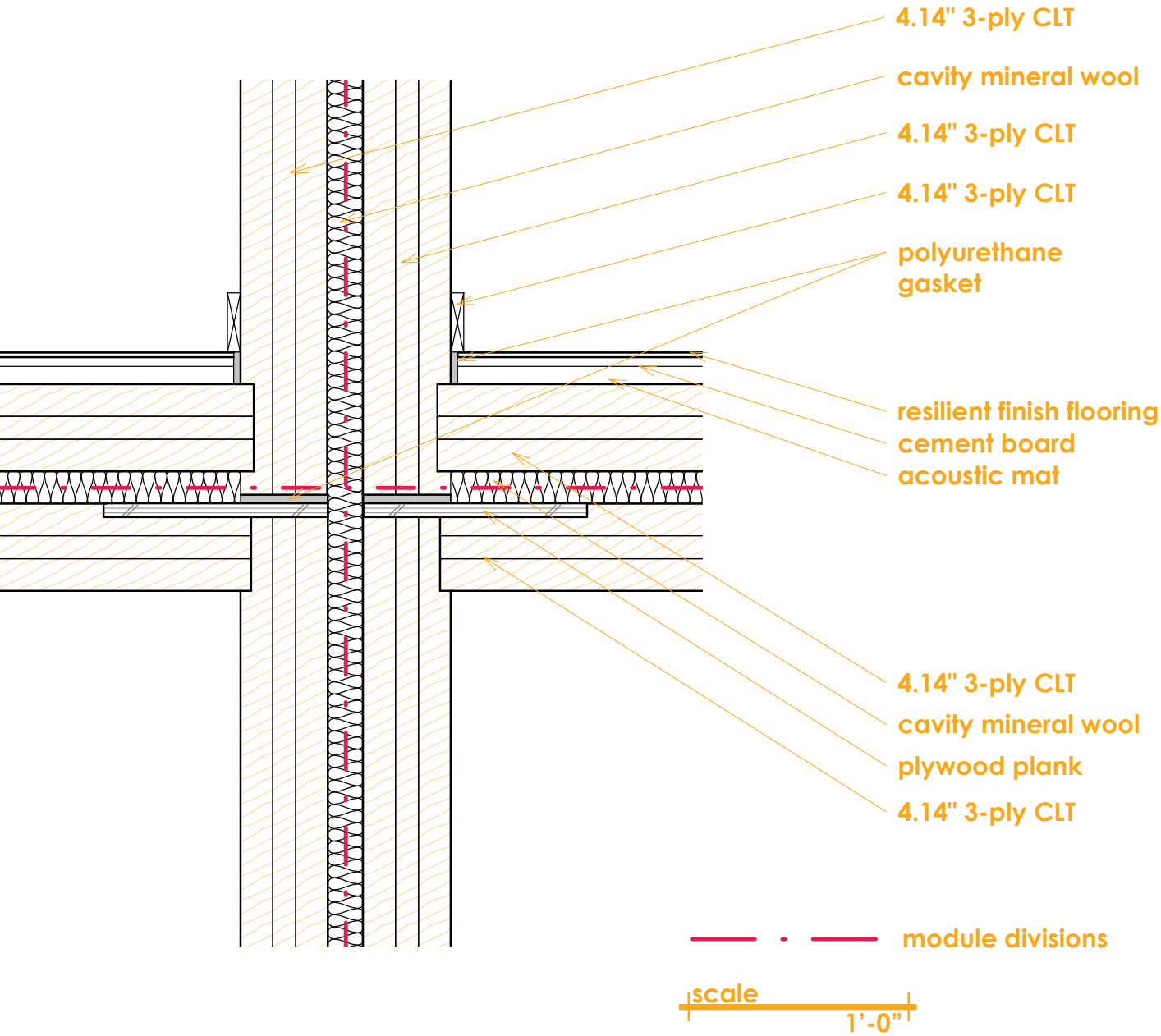
CONNECTION DETAILS



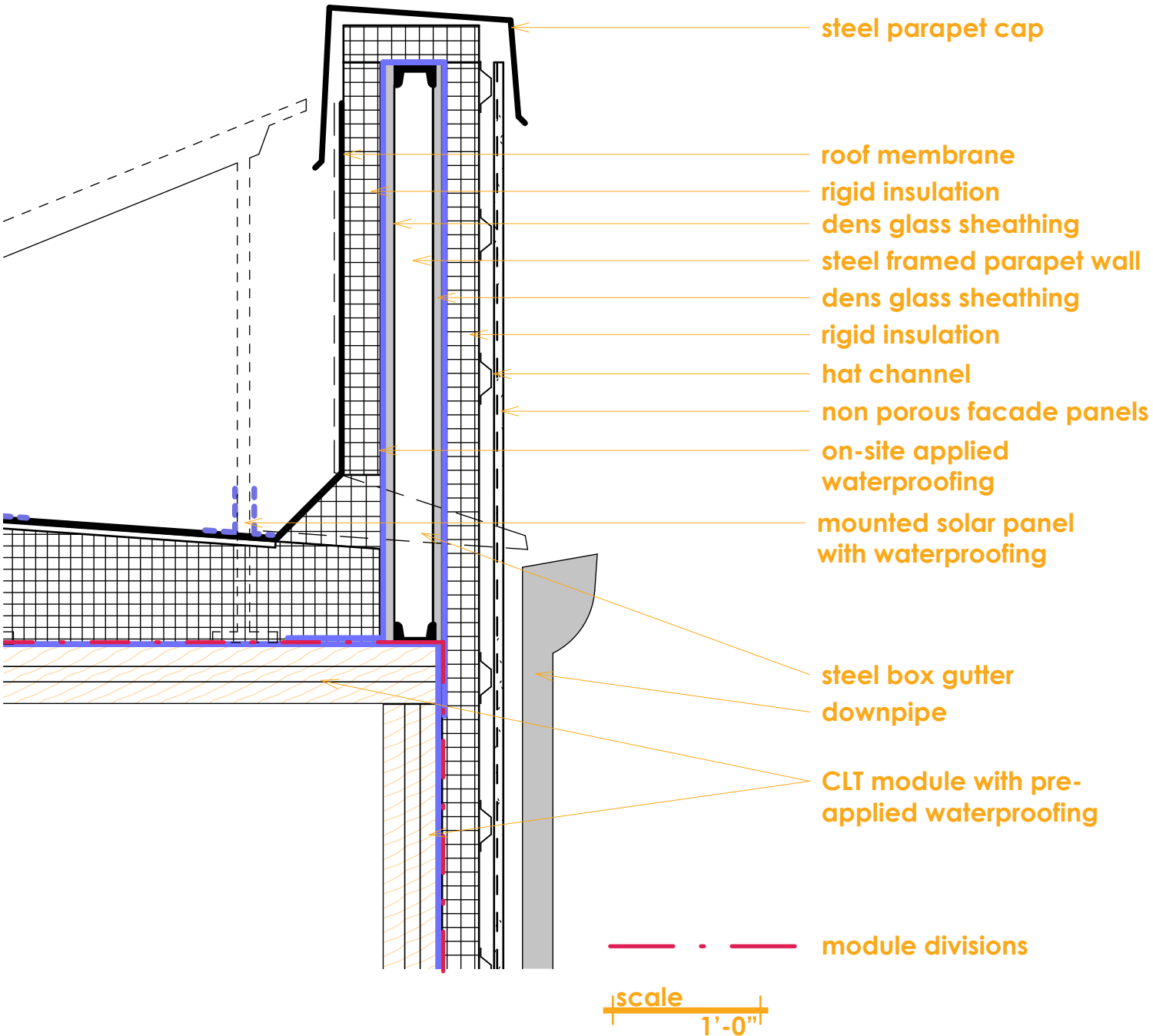
While further consultation with a structural engineer would be necessary to fully comprehend the connection details of the modules, the following pages present conceptual drawings. Mineral wool would be deployed between all modules, whether they are situated between or within units, to enhance acoustic isolation within living spaces and provide a buffer during unit placement. Plywood splines would be employed to connect panels and also where modules stack, aiming to evenly distribute loads and prevent crushing. This detail was adapted from the unrealized Wadajir housing project developed by Mithun for Forterra (refer to the Appendix). Additionally, a 4-foot parapet wall was implemented on the roof to conceal solar panels, aligning with DoD sustainability objectives.



1 LVL Beam Connection

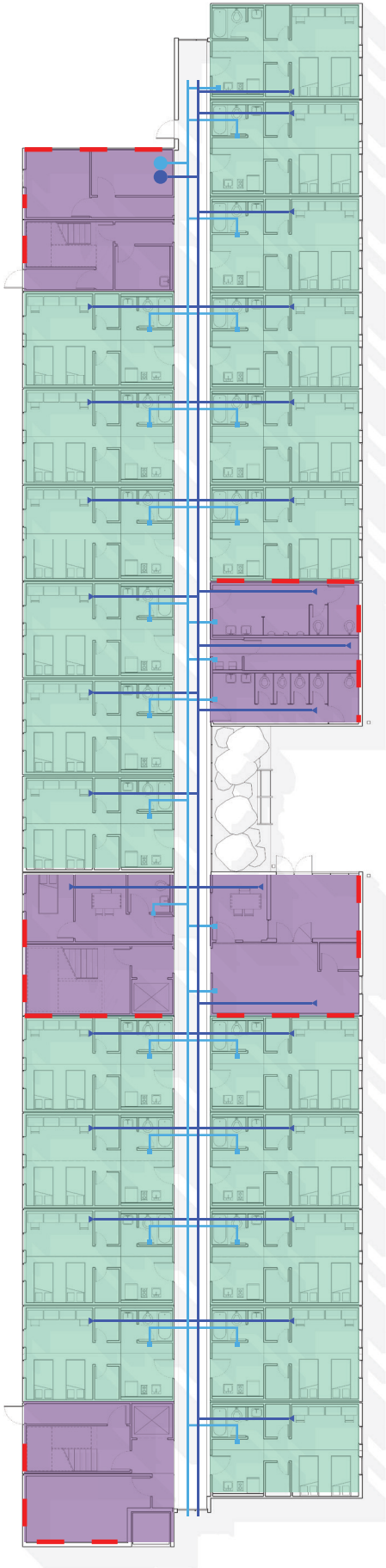


2 Four Module Corner



3 Module to Parapet

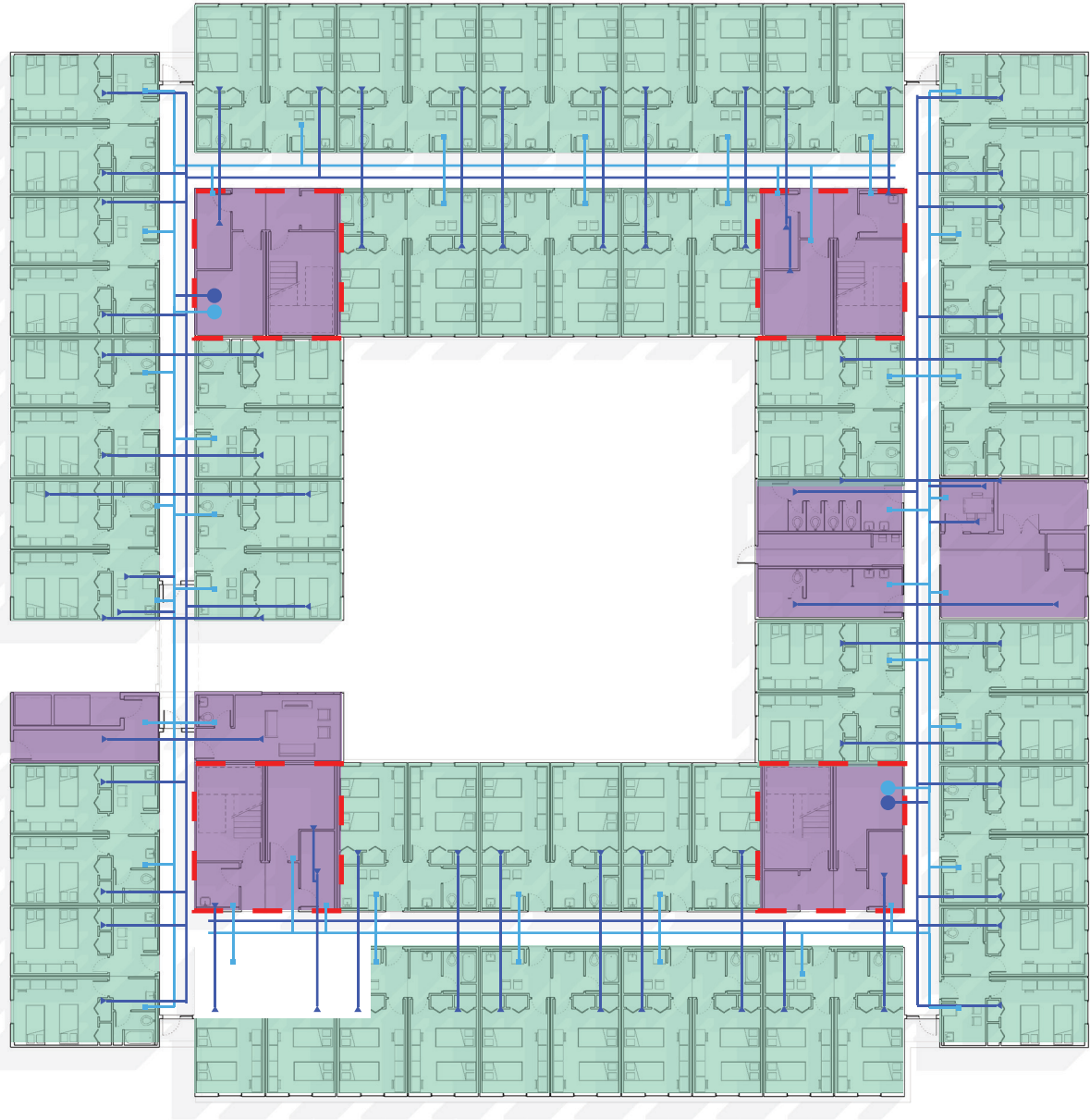
SYSTEMS + BRACING



While no calculations have been completed to determine the size of mechanical runs, the floor plans here detail how the main supply and return ducts would run through the main corridor, with branches extending into each module. A dropped ceiling over the bathroom, lavatory, and partially in the kitchen would help conceal ducts supplying the bedrooms and living spaces closer to the exterior walls.

Seismic and lateral bracing requirements necessitate calculation based on site-specific jurisdictional standards. However, the overarching strategy involves confining such bracing elements to non-residential units. Highlighted in purple on the floor plans, these non-residential modules are strategically positioned with minimal exterior penetrations to accommodate lateral bracing. Within the courtyard scheme, the four interior corners serve as fully internal spaces, offering potential as core areas for bracing the building structure.

- non-residential modules
- residential modules
- lateral bracing
- HVAC supply
- HVAC return



- non-residential modules
- residential modules
- lateral bracing
- HVAC supply
- HVAC return

CONSTRUCTION COSTS

While there is interest in using mass timber for volumetric modular projects, there is still limited information on constructions costs as there are limited projects and none currently built in the US.

However, if we look at the modular construction industry there are several cost-saving methods as compared to conventional construction methods due to the following which could also be applicable to mass timber as a material:

More Efficient Manufacturing

Modules are typically constructed in a controlled factory environment, where materials are precisely measured and assembly-line techniques streamline production. This controlled setting minimizes material waste and labor costs associated with traditional on-site construction. According to a report by McKinsey & Company, modular construction can reduce construction costs by 20% to 50% and construction time by 30% to 50% compared to traditional methods.

Reduced Site Labor Costs

Modular construction requires fewer on-site workers and shorter construction durations, resulting in lower labor costs. Additionally, labor productivity tends to be higher in factory settings due to optimized workflows and reduced weather-related delays. A study published in the Journal of Construction Engineering and Management found that modular construction can achieve labor cost savings of up to 20% (MBI).

Minimized Site Disruption

Because the majority of construction activities occur off-site in a factory, on-site disruption is significantly reduced. This can lead to cost savings associated with site management, logistics, and temporary facilities. A report by the Modular Building Institute suggests that modular construction can result in 90% fewer vehicle movements and up to 80% fewer on-site deliveries, reducing traffic congestion and site disturbances

In 2022, the modular construction industry reported a market size of \$12 billion, representing approximately 6% of all building starts (Finkel). This sector has experienced remarkable growth, tripling in size since 2015. According to the 2023 Modular Building Institute report, the average size of pre-fabricated and modular projects is around 24,000 square feet, comprising an average of 367 modules. The typical completion time for such projects is 309 days, with an average cost of \$278.84 per square foot. These statistics were derived from an analysis of 62 one to ten-story modular projects across the USA.

In a specific examination of 15 modular multi-family projects, findings revealed an average building height of four stories, an average size of 60,000 square feet, and an average of 81 units per project. The completion time for these projects averaged 380 days. Avalon Building Systems highlighted the growing appeal of modular construction, citing the increasing difficulty in finding skilled tradespeople and the efficiency in terms of cost and speed that modular methods offer.

A notable example is Charles Bloszies’ project in Redwood City, which utilized modular construction to create a 250-unit affordable housing block. The project, featuring 200 square foot units with bathrooms in a campus setting, was completed in less than one year. The cost per door was \$230,000, significantly lower than the \$600,000 to \$800,000 range for conventional construction methods (Finkel).

Modular construction provides accurate and reliable cost estimates giving stakeholders cost predictability throughout the project cycle. Mass timber offers the opportunity for high-quality, durable materials pre-fabricated with precision leading to a tighter construction envelope and potentially lower operating costs. The cost implications of mass timber volumetric modular construction are speculative and would require further research.



Fig 22: Modules being built in a temporary factory for Heidelberg Student Union



Fig 23: Wall panel being assembled for Sara Kulturhus

CONCLUSION

As I concluded my design exploration, I affirmed that it is possible to adapt the floor plan standards and design requirements laid out by the DoD for Unaccompanied Personnel Housing with a standard CLT panel dimension being produced in the US. Utilizing pre-fabricated mass timber modules could effectively address many of the known issues with current dormitory design as introduced at the beginning of this study:

Unsatisfactory Conditions

Wood, as a high-quality and durable material associated with nature and healing, offers an opportunity for higher-quality and tighter construction. Modules pre-fabricated in a factory before being shipped to a site enhance construction quality.

Lack of Equity

A standardized modular system for units across all bases can mitigate feelings of unfairness and provide a baseline quality standard for all military members. Familiar floor plans can also facilitate easier transitions for members on frequent rotation.

Poor Mental and Social Health

The biophilic properties of exposed timber have been shown to have positive effects on mental health and well-being. Thinner floor plates without beam supports allow for taller windows, providing occupants with more daylight, crucial for circadian rhythms and good health.

Retention and Recruitment

In their 2023 report on dormitories, the GAO noted that many enlisted members interviewed were not favorable towards their living conditions in the dorms. By offering higher quality accommodations that are standardized across the country, members will anticipate a certain level of design and finish, which can alleviate negative feelings about dormitories and barracks.

Labor and Construction Issues

Finding skilled construction workers willing and able to work on military bases, often located

far from city centers, can be challenging. Each person arriving on base must undergo screening and pass background checks, adding a layer of complexity. By front-loading the work to off-base factories, many of these challenges can be mitigated. Fewer days of necessary on-site construction also reduce the likelihood of construction delays due to bases being shut down for security reasons.

Meeting Sustainability Goals

Wood, a renewable resource, is generally seen as a more environmentally friendly option compared to steel and concrete. However, a full lifecycle analysis (LCA) would need to be performed to validate these claims for this use case, which is beyond the scope of this study.

While conducting hard cost comparisons between mass timber volumetric modular construction and conventional practices is also beyond the scope of the study, given that bases are spread out across the US and construction projects are subject to regional pricing trends, there is potential for more price predictability with a standardized, modular approach, enabling more accurate financial planning. As the DoD adopts more mass timber projects, future research should undertake to evaluate not only costs but also the effect on occupant health and wellbeing through post-occupancy evaluations.



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APPENDIX: WADAJIR



The Wadajir housing project by Mithun and Forterra was developed as a volumetric modular concept but unfortunately was never realized. While the team did build a small prototype in Washington as a standalone apartment concept, the six-story building never broke ground. However, it was developed and thoroughly documented and served as inspiration for my design, especially being a project developed for the United States.

Every module has the same width, length, height, and window fenestrations, but interior configuration changes. With these specifications, the design team ended up with six distinct module types. Once different conditions were accounted for such as corners, roofs, podiums, and core, there were over 40 different modules with slight variations of the six types.

“When pre-fabrication standardization is mastered, design parameters have more flexibility to adapt more to site context, project, needs, and end users”

- Mithun

