مؤتمر عجمان الدولي الخامس للبيئة

Ajman 5th International Environment Conference

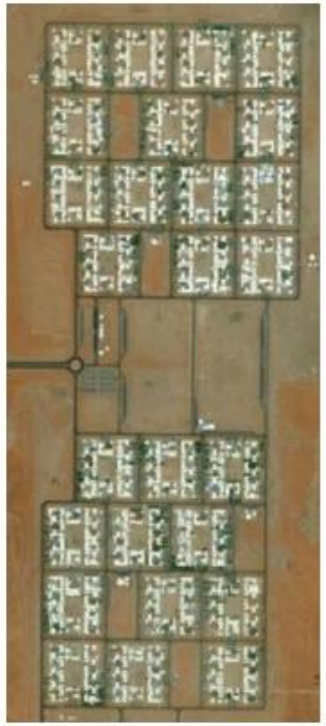
Constructability of an *Estidama* and Building Codes Compliant SIP System for Adaptive Public Housing in UAE

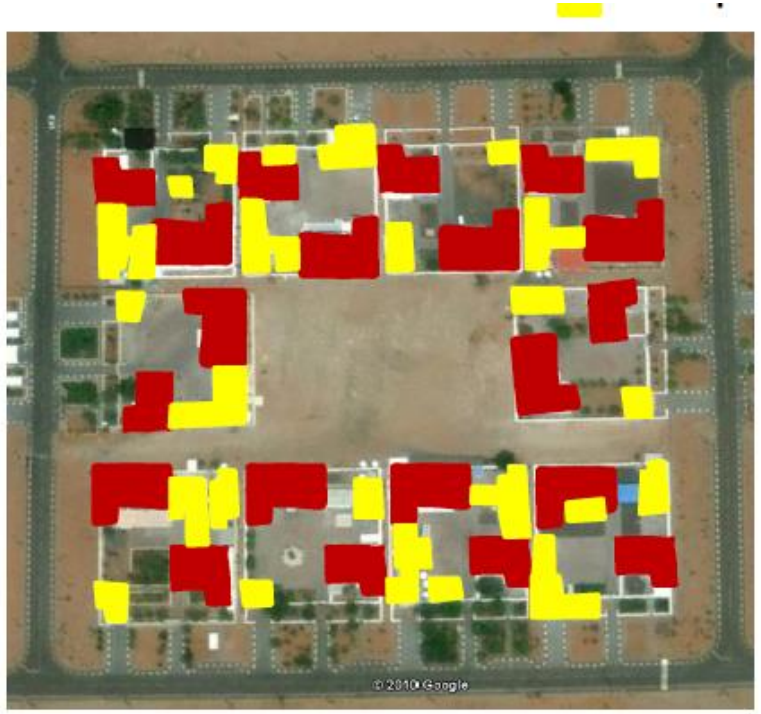
Dr. Khaled Galal Ahmed, Associate Professor, UAEU

Introduction

Housing ‘Rigidity’ as a Problem in Public Housing in UAE

- Abu Samra





Original
Adaptation

Research Objectives and Method

- Bridge the gap between the users' actual needs and the 'official' pre-designed public housing models to attain a '***resilient***' design ***controlled*** by the residents themselves.

- '***Relocatable***' self-build external/internal wall-floor-roof panel system replacing the currently used '***rigid***' masonry one.

- Structural Insulated Panel Systems (***SIPS***) are to be investigated for their compliance with the UAE locally applied building codes and regulations and, more importantly, for their applicability as '***self-build***' '***relocatable***' construction systems.

Four main objectives:

a) Comparing the different types of SIPS to define the most ***Estidama*** and Abu Dhabi ***Building Codes compliant*** one and the most suitable for ***self-build relocatability*** with as least required machinery as possible.

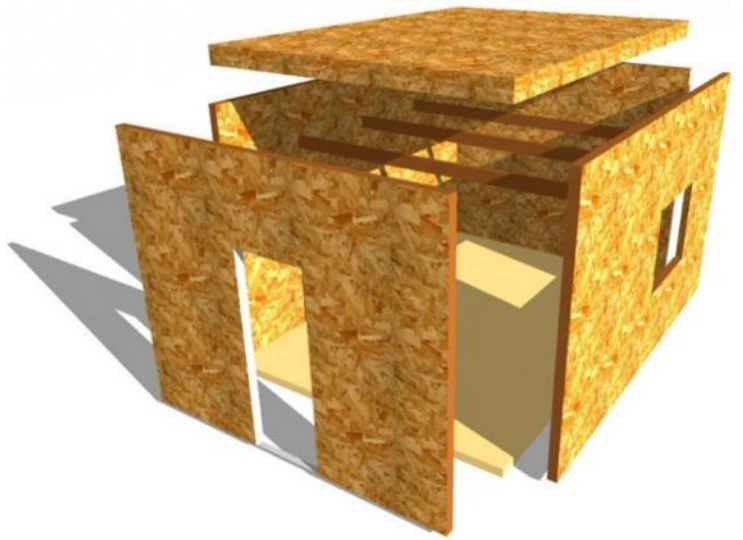
b) Developing an ***adaptive*** BIM ***modular house model*** that can be ***expanded/ retracted***, by residents, when needed.

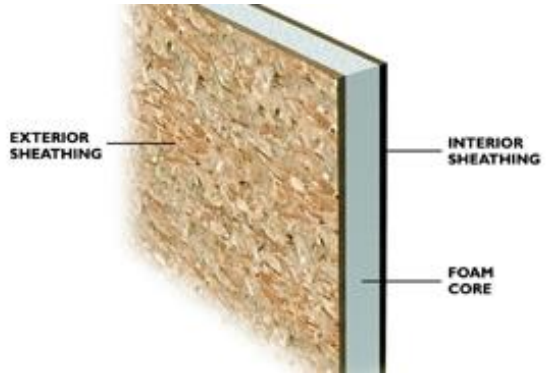
c) Checking ***energy consumption performance*** of the adaptive SIPS/Steel Structure housing model compared to the conventional CMU/RC Structure one.

d) Developing ***constructability mechanisms*** (fixation-relocation) of the selected SIPS to be compatible with the conventional post-and-beam steel structure skeleton system of the suggested adaptive house model.

Structured Insulated Panel System (SIPs) as a sustainable self-build construction material

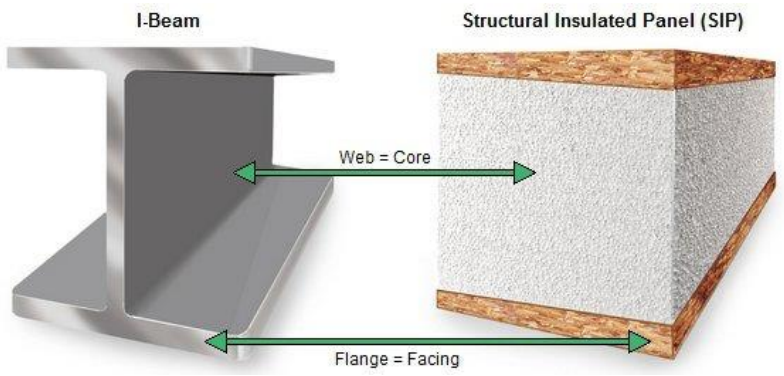
- High-performance composite building panels designed for all internal and external, wall, floor and roof applications.
- Made by sandwiching a core of rigid foam insulation between two structural skins.
- Variety of structural skin materials, including oriented strand board (OSB), treated plywood, fiber-cement board (cementitious), and metal.
- Core materials are typically expanded polystyrene (EPS), extruded polystyrene (XPS), or polyurethane (PU).
- Have high thermal performance, lightweight and environmentally friendly, resistance to damp, low build cost, massive reduction in build time and wet trades, and their single skin build enables finishes directly applied to the panel.

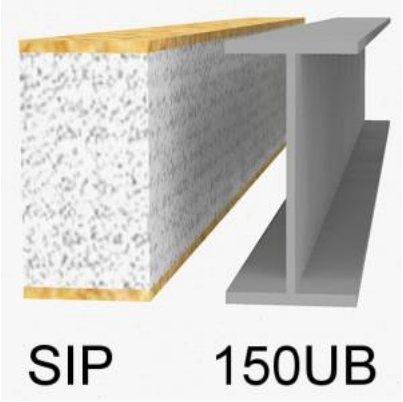




Structural Properties:

- Behave similarly to a wide flange steel column, the foam core acts as the web and the sheathing responds as the flanges.
- Under axial loads, the sheathing responds similarly to a slender column, and the foam core acts as continuous bracing preventing the panels from buckling.
- Just as wide flange sections increase in strength with increased depth, thicker cores result in stronger panels in compression and bending.
- Ability to resist bi-axial bending and lateral shear allow them to be used as roofs and floors.
- Large SIPs structures rely on a secondary framing system of steel or timber to satisfy requirements for unobstructed spaces.
- Unique screw connections are available to attach SIPs to wood, light gage steel, and structural steel up to 1/4 inch thick.





Sound Attenuation and insulation:

- SIPs insulate against high frequency noise better than low frequency noise.
- As monolithic wall units with continuous insulation and fewer gaps to seal than stick-built framing, SIPs are airtight and effective at stopping airborne ambient noise.

Durability

- SIPs proper lamination and smooth surfaces and edges will ensure that the SIPs can endure long-term use as long as the structural skins are properly protected from degradation.

Ease of Construction & Lower Cost:

- Contractors can quickly install up to 7.30 m sections of SIP wall panels. The panels of floor-to-ceiling height can simply be dropped into place for a very fast assembly process.
- Construction costs are comparable to more conventional building methods when savings associated with labor costs, material waste, and energy efficiency are considered.

a) Applicability of SIPs as a code-compliant relocatable wall-floor-roof material

Relevant Building Codes Requirements

Topic	Code Requirement	Source
Thermal Insulation	Non-Government Projects 1- Fenestration U-Factor 2.2 2- Roof U-Facto 0.31 3- Mass Wall U-Facto 0.57 4- Floor U-Facto 0.36	ADIBC - Section 2602- Page 487
Sound Insulation	Sound transmission class (STC) of not less 50 and 45 if field tested.	ADIBC - Section 719 - Page 170
Water Insulation	1404.2 Water-resistive barrier: A minimum of one layer of No.15 asphalt felt.	ADIBC – Chapter 14
Fire resistance	Fire resistance rating of not less than 1 hour.	ADIBC - Section 709
	Building should be class A or B	UAE Fire and Life Safety Code of Practice

Relevant *Estidama* Regulations

Regulation	Description
U-value	External Wall: 0.57 W/m^2.K Roof: 0.31 W/m^2.K
LBi-9: Indoor Noise Pollution	Demonstrate that internal ambient noise levels do not exceed 35 dB(A) Leq (8 hour) and 45 dB(A) Lmax, fast in bedrooms (night-time, 23:00 – 07:00 hours) and do not exceed 40 dB(A) Leq in other areas.
SM-R1 Hazardous Materials Elimination	Requires an undertaking letter stating that Asbestos Containing Materials (ACMs) and Chromated Copper Arsenate (CCA) - treated timber shall not be used within the project.
SM-3: Design for Flexibility and Adaptability	To lengthen the useful life of buildings through designs that are easily adaptable for other program uses, floor-to-floor heights of at least 3.60 m.

Comparing and selecting an appropriate SIP System

- Besides its compliance with relevant sustainability regulations and building codes requirements, selected SIP system should allow inhabitants to fix/relocate it either to increase (or even decrease) house spaces easily and safely with minimal time and effort.

The Core Material:

- Polyurethane (PU) is selected for its best R-value/in @ 75° F of 6.54 compared to 5 for extruded polystyrene (XPS) and only 3.6 for the expanded polystyrene (EPS type).
- PU has the highest strength and water resistance among the other two commonly used XPS and EPS types.
- XPS and EPS types are produced with hexabromocyclododecane (HBCD) a brominated fire retardant material classified by the European Union (REACH program) as persistant, bioaccumulative, and toxic (PBT), while the PU is produced with chlorinated phosphate flame retardants which is not as hazardous as most brominated flame retardants.
- As for compressive strength @ 10% deformation (psi) PU gives the highest value of 35 compared to only 20 and 10 for XPS and EPS types respectively.
- Common Fire Rating Class is 1 for all the three types.

Comparing and selecting an appropriate SIP System

The structural skins:

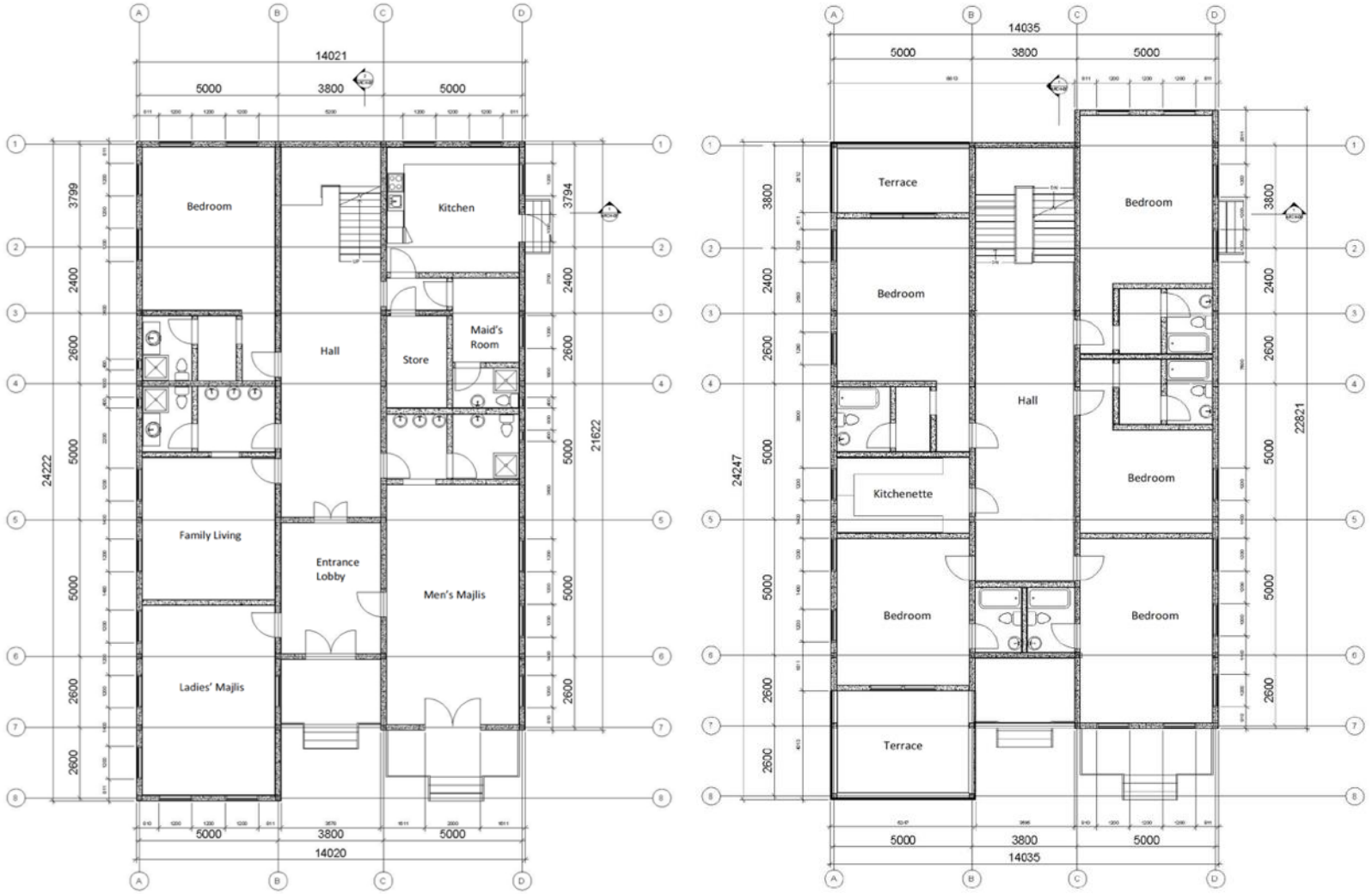
- Oriented Strand Board (OSB): load bearing, availability in large panel size, needs treatments against mold and termites while Fiber Cement Siding and Magnesium Board: resistant to mold, termites, and fire but disadvantaged for their weight and limited panel size.
- Availability in appropriate modular sizes. One SIP type has an ideal overall modular thickness of 200mm with a width of 1200mm and standard lengths ranges between 2400, 3000, 3500, 4000, 5000 and 6000mm. Limited availability of similar modular sizes in Cement Fiber Skin type was noticed (the best available cement fiber skin panel has an overall thickness of 275mm, with width of 1100mm and standard length of 2650mm), which would not easily be configured with the modular structure framing system of the house.
- The panel weight is about 22 kg/m^2 which is much less than its Cement fiber skin counterpart (40kg per m^2).
- As moisture protection is a concern for OSB sheathing but it is evident that when it comes into contact with water, the structural integrity of the panels can be saved if the OSB is quickly exposed to allow to dry.
- Although SIP Systems are originally designed and used as a fixed wall-floor-roof panels, but in this research their suitability of being developed into relocatable demountable external/internal wall, floor and roof units was considered.

The selected SIP System: OSB Faces and PU Core

Compliance of the OSB-PUR SIP System with Estidama Requirements and Local Building Codes and Regulations.

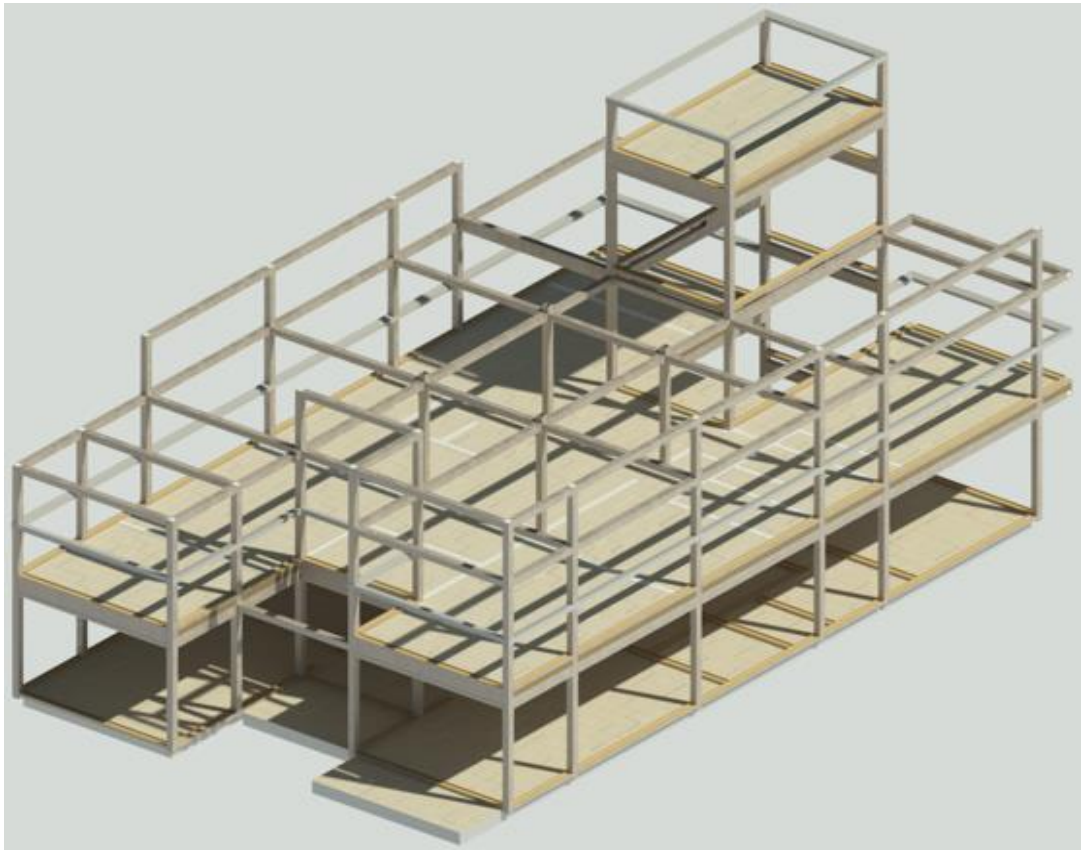
Estidama Req. & Building Codes and Regulations	OSB-PUR SIP System
Estidama, Thermal Insulation (U-value) requirements: • **For mass walls: 0.57 W/m^2.K.** • **For roofs: 0.31 W/m^2.K.**	200 mm//0.15 W/m^2.K
Abu Dhabi Building Codes, sound insulation requirements: • **For mass walls: 50 STC.**	Separating walls: 50 STC Internal walls: 40 STC
Abu Dhabi Building Codes, fire resistance requirements: • **For mass walls: 60 minutes.**	External walls: 60 minutes (from inside) Separating walls/60 minutes (from either side)
Abu Dhabi Building Codes, water proofing requirements: • **For mass walls, a minimum of one layer of No.15 Asphalt Felt.**	Completely watertight and weather resistant
Abu Dhabi Building Codes, impact & loads resistance requirements: • **Uniform load 1.9 KPa for Roof Panels.**	Pass
Design for flexibility & adaptability for the SIP panels: **Floor -to-floor heights of at least 3.6 m.**	Width 1200 (mm), Lengths 2400, 3000, 3500, 4000, 5000, 6000 (mm)
Weight of SIP panels per square meter.	For 200 mm: 21.99 kg/m^2
Volatile organic compounds (VOCs) and other Health hazards prevention requirements.	No known toxic health hazards

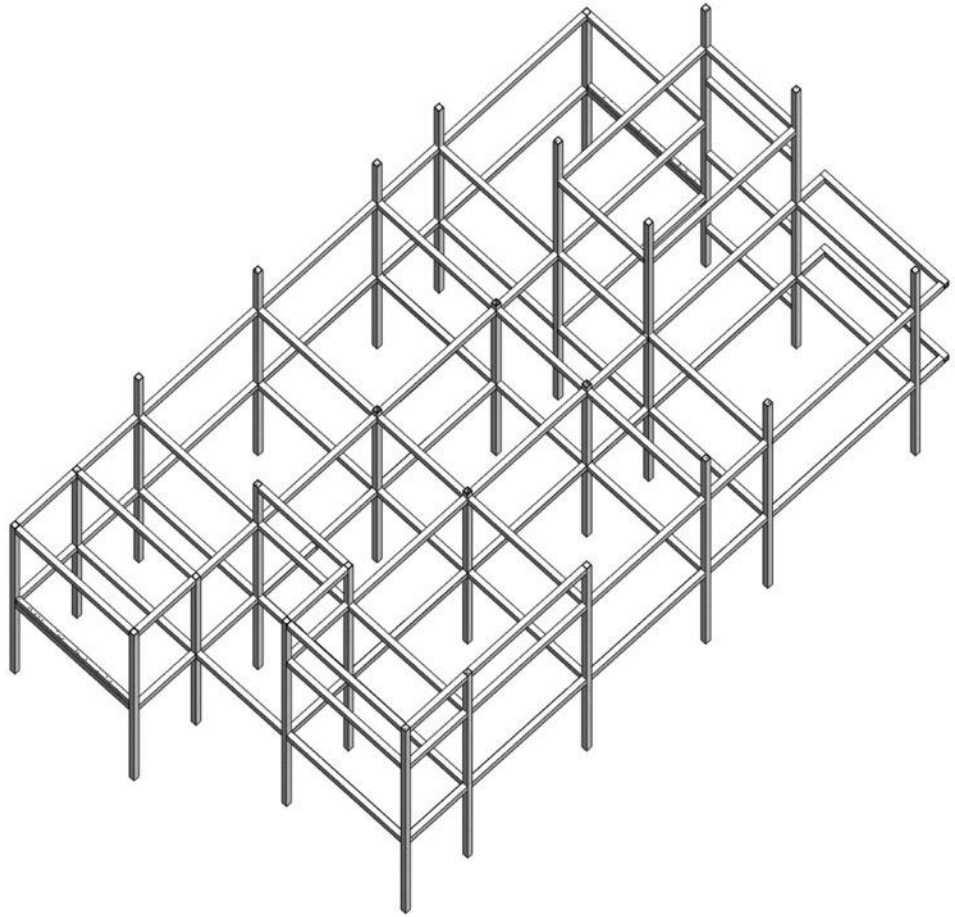
b) Developing A BIM Modularly-Coordinated Resilient House Model



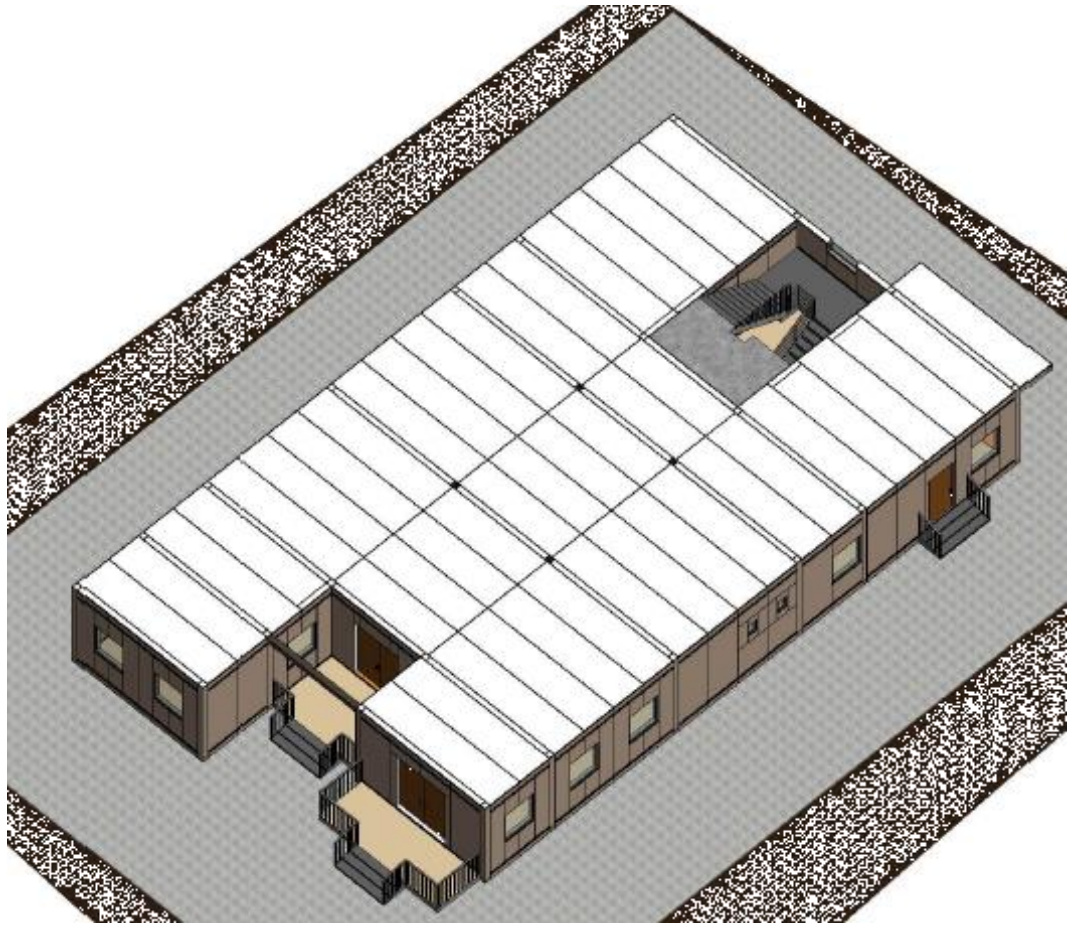
Adjusting modularity of the 5 bedroom 'complete' house to conform with the dimensions of the selected SIP System: a) GF Plan, b)1st F Plan.

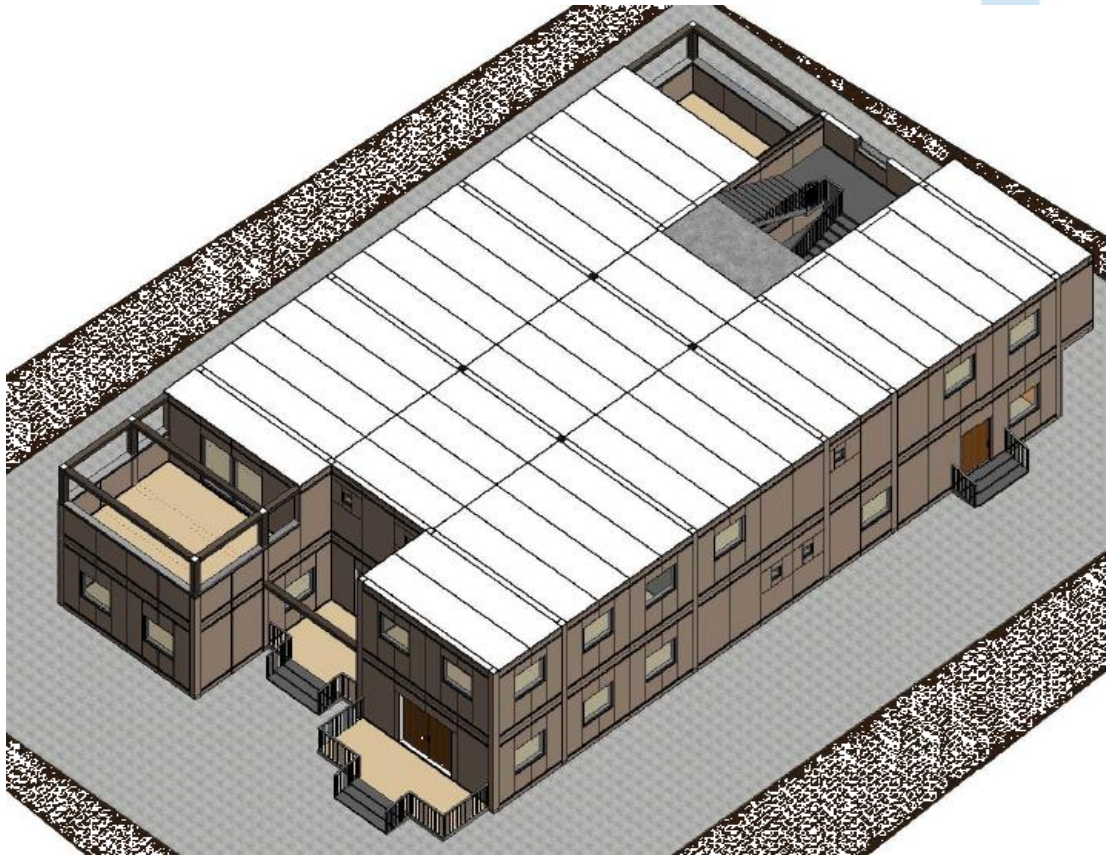
The ‘fixed’ Steel skeleton structural system composed of 20x20 cm tubular section columns and beams.



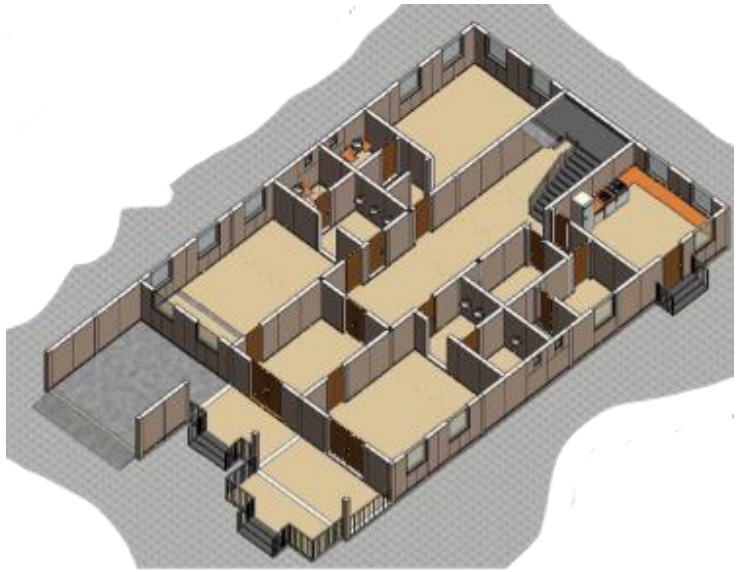


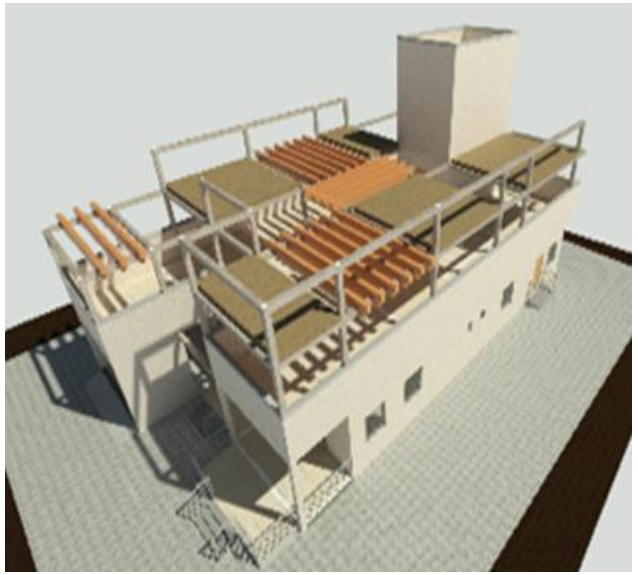
Study of the SIPs as modular movable Roof, Floor and Wall panels supported within the Steel Framing of 20x20cm tubular sections: a) GF, b) 1st F.



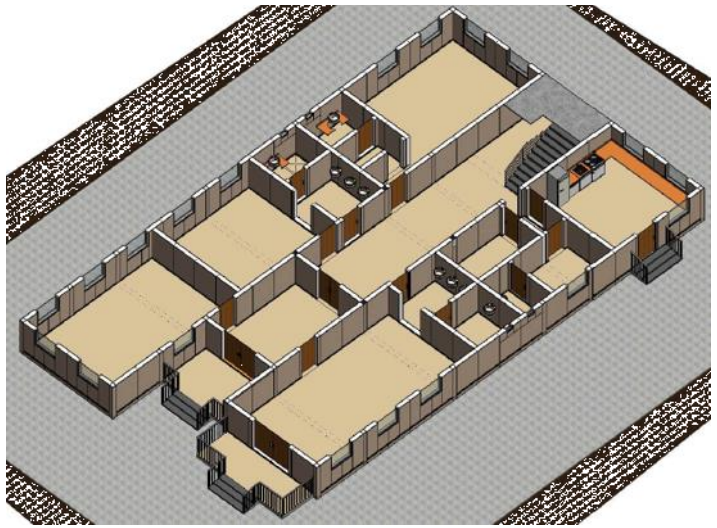


From ‘Core’ to ‘Complete’:
Examples for the house’s adaptability scenarios

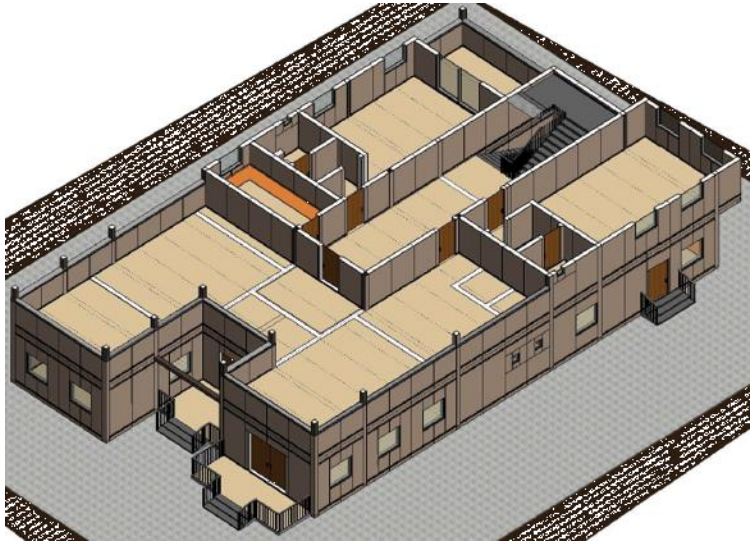




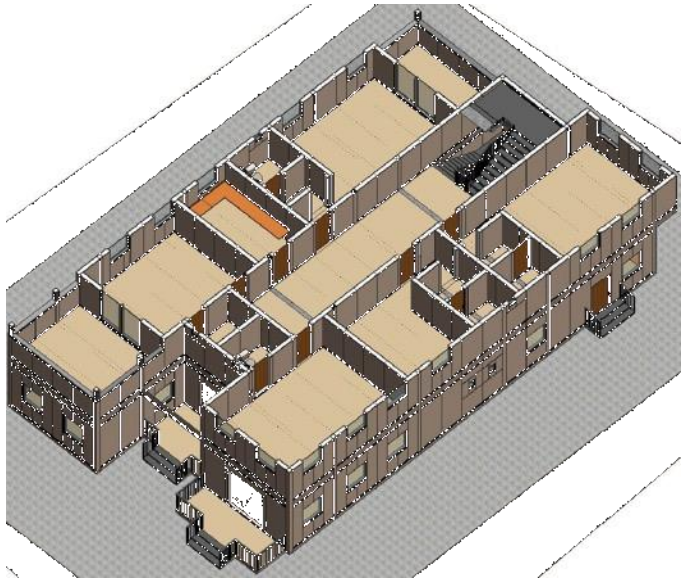
The Core House – Men’s Majlis (Saloon) + Dining + 1 Bedroom in GF and a roof garden.

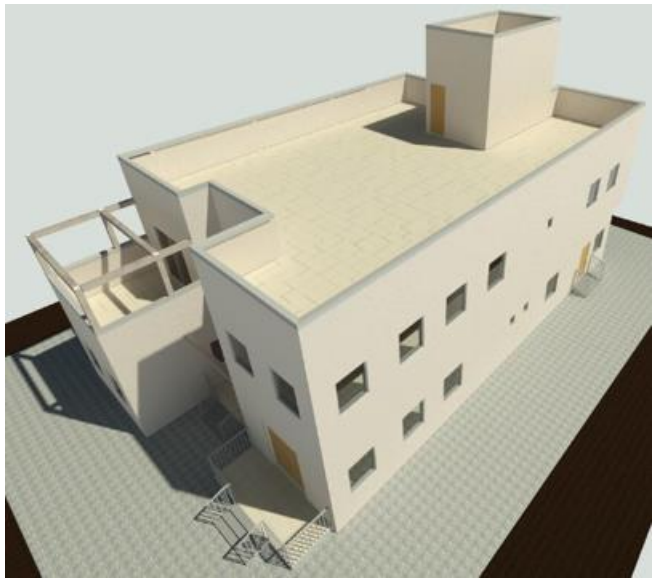


Expansion Scenario 1– Similar to the core with added ladies’ Majlis and enlarging Men’s Majlis.



Expansion Scenario 2 - Similar to Scenario 1 with two more bedrooms added to the 1st Floor.





Completed House – Similar to expansion Scenario 2 with two more bedrooms added to the 1st Floor. Total number of bedrooms is 5 with allocated toilet and dressing in each room.

c) Energy performance for the selected SIPs Vs. CMU for the completed house

Calculated Results	
Peak Cooling Total Load (W)	5,394
Peak Cooling Month and Hour	August 8:00 AM
Peak Cooling Sensible Load (W)	5,300
Peak Cooling Latent Load (W)	94
Maximum Cooling Capacity (W)	5,394
Peak Cooling Airflow (L/s)	296.3
Peak Heating Load (W)	33
Peak Heating Airflow (L/s)	2.1
Checksums	
Cooling Load Density (W/m²)	10.11
Cooling Flow Density (L/(s·m²))	0.56
Cooling Flow / Load (L/(s·kW))	54.92
Cooling Area / Load (m²/kW)	98.92
Heating Load Density (W/m²)	0.06
Heating Flow Density (L/(s·m²))	0.00

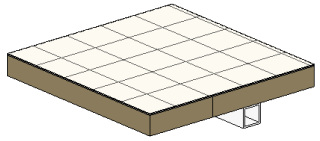
SIPs house energy simulation

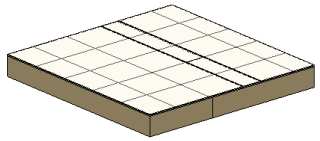
Calculated Results	
Peak Cooling Total Load (W)	8,768
Peak Cooling Month and Hour	August 5:00 PM
Peak Cooling Sensible Load (W)	8,751
Peak Cooling Latent Load (W)	17
Maximum Cooling Capacity (W)	9,397
Peak Cooling Airflow (L/s)	529.0
Peak Heating Load (W)	2,087
Peak Heating Airflow (L/s)	133.8
Checksums	
Cooling Load Density (W/m²)	16.66
Cooling Flow Density (L/(s·m²))	1.01
Cooling Flow / Load (L/(s·kW))	60.34
Cooling Area / Load (m²/kW)	60.02
Heating Load Density (W/m²)	3.97
Heating Flow Density (L/(s·m²))	0.25

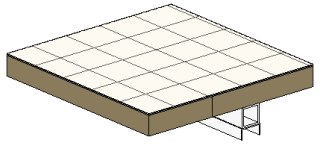
CMU house energy simulation

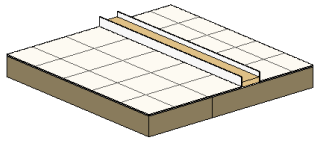
d) Developing a self-build fixation and relocatability construction mechanism for the SIPs

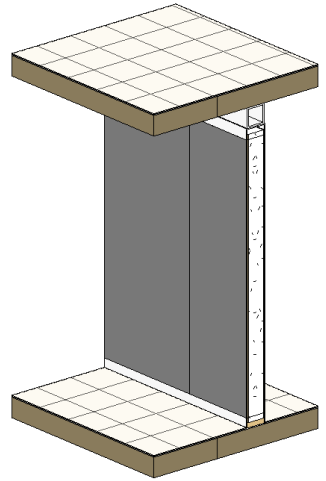
- First, upper and lower tracks of galvanized LGS channels are to be used for fixing the 20cm thick x120cm width OSB-PUR SIPs.
- On the ground floor, the non-movable SIPs (the core case) are to be supported over LGS channels fixed over the lightly reinforced slab-on-grade.
- For the relocatable SIPs, the LGS channels can be fixed directly over the finishing material, ceramic tiles for exampe.
- In the first floor, SIPs are used as structure flooring panels supported over the tubular steel structure framing and finished with ceramic tiles that exactly have the same modular size.
- The LGS channels for SIP walls will be fixed directly with screws to the skin and PUR core of SIPs flooring panels.



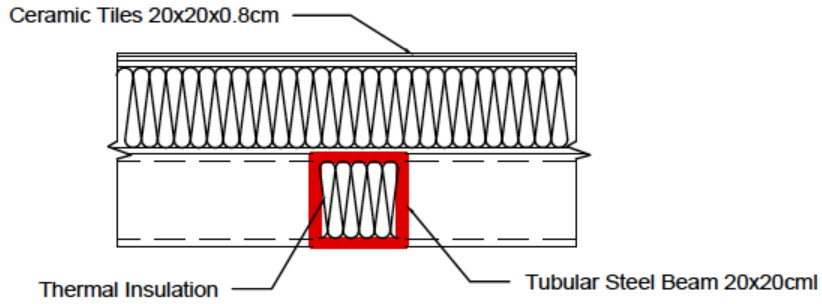




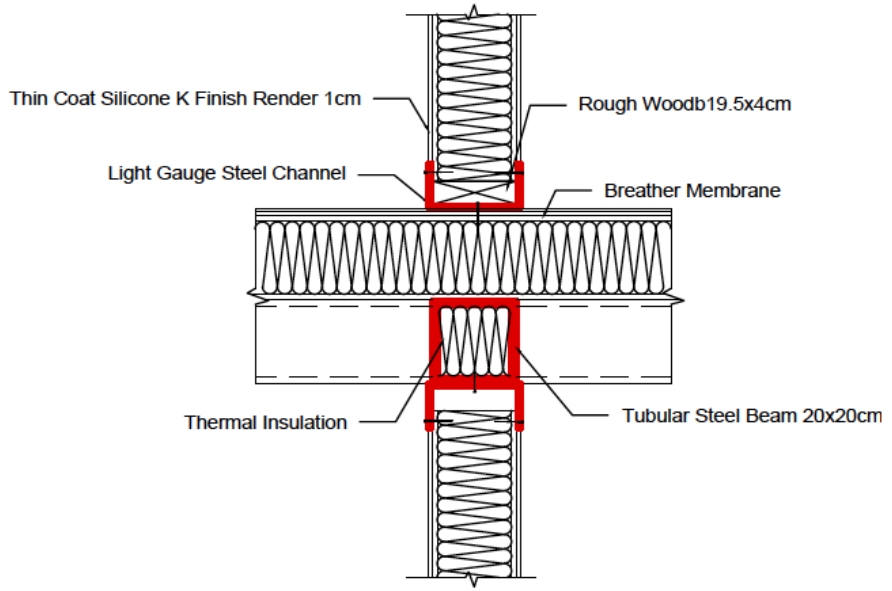




- For relocating the SIPs, the LGS channels can be easily removed.
- A space is to be left inside the upper LGS track for raising and tilting the panel to be positioned correctly in its upper track space.
- Then it can be easily pushed to be vertically aligned with the lower track and be subsequently released to rest over a rough wood piece measuring put inside the LGS lower track.
- Afterwards, panels can be screwed with the upper and lower tracks from both sides.

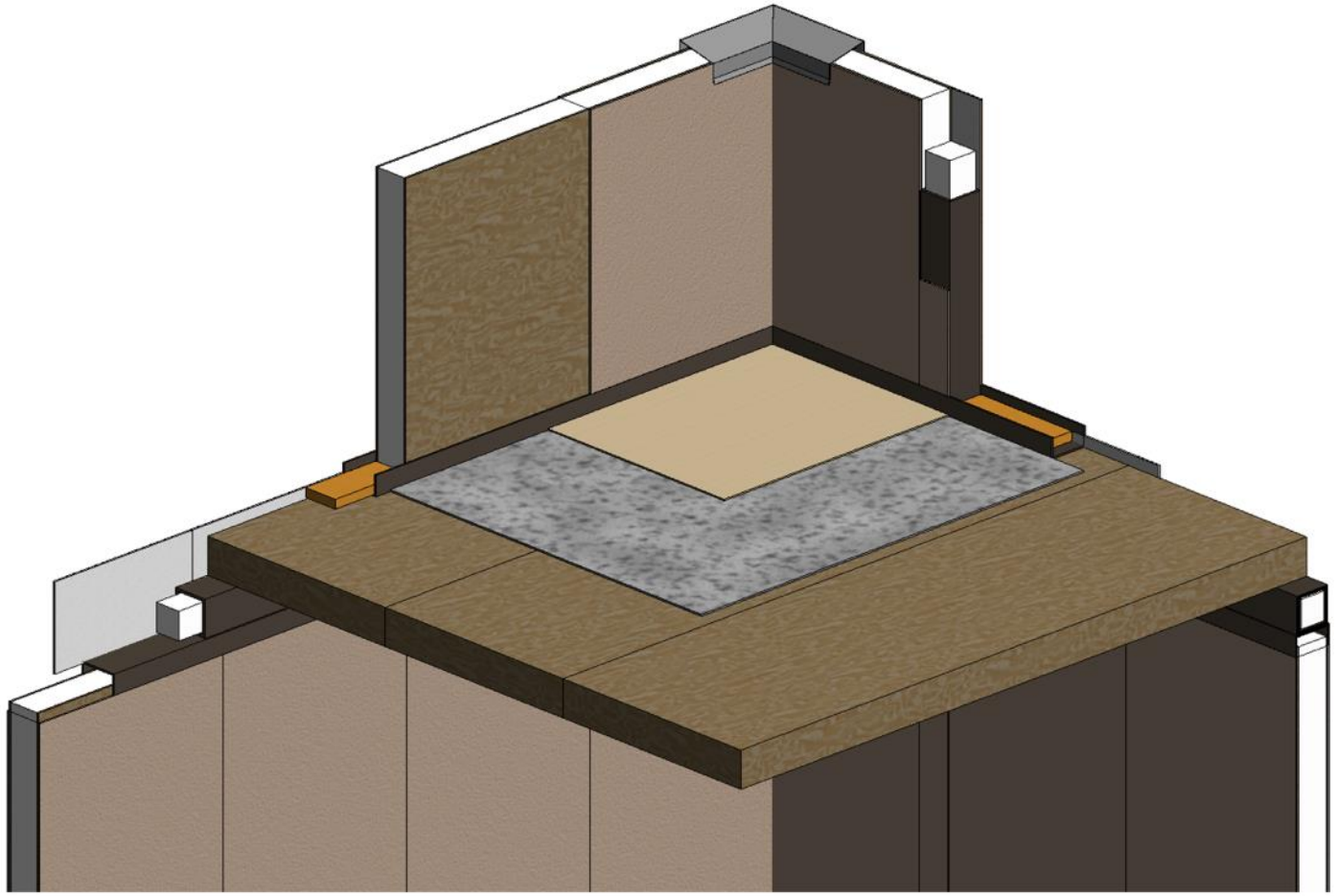


Before



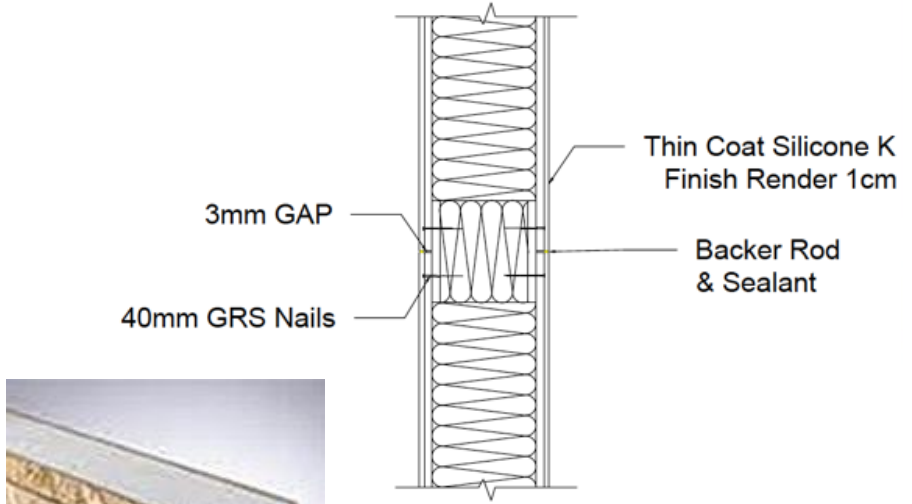
After

- Roof and floor panels can be fixed with the structure system using steel angles that allow them to be replaced if not needed.
- For dismantling the SIPs when not needed in their existing locations, the process can be merely reserved.
- This mechanism will allow residents to change, expand/contract the habitable spaces of their houses safely according to their own desired space dimensions.
- External tubular columns and beams can be finished with 1cm thick cement board around them and then painted with the desired color.
- External and internal wall partitioning panels can be finished by thin silicon coat mortar 1cm thick plus paint.

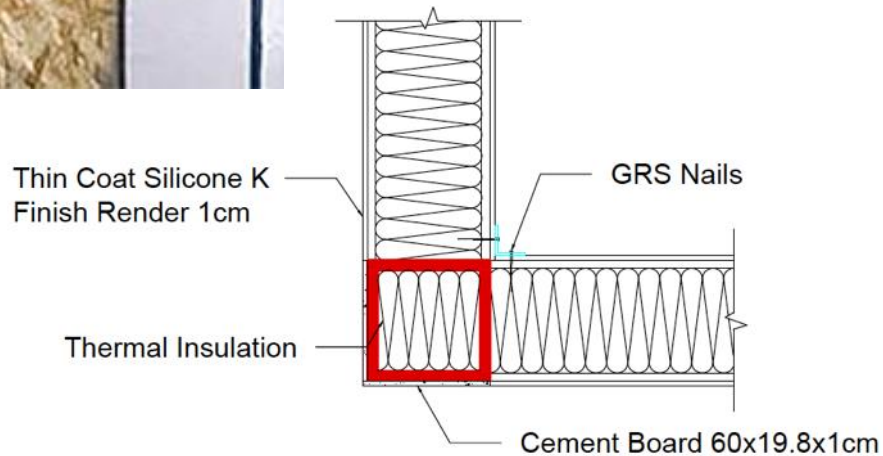


Joint design

- Joints between the floor panels are to be treated similar to that of the wall partitions.
- Properly sealed SIPs will provide for the air, vapor, and thermal barriers.
- Expanded foam, sealing tape, sealing mastic, and nails are also used for SIP connections.
- The block spline connection results in a continuous foam core across the panels, eliminating air infiltration at the joints.
- Water resistance barriers (WRB) should be provided for the exterior wall and roof. This WRB should be vapor permeable and must make all joints water and airtight.



Panels Joints - Plan



External Corner - Plan

Plumbing-Electrical and Mechanical works:

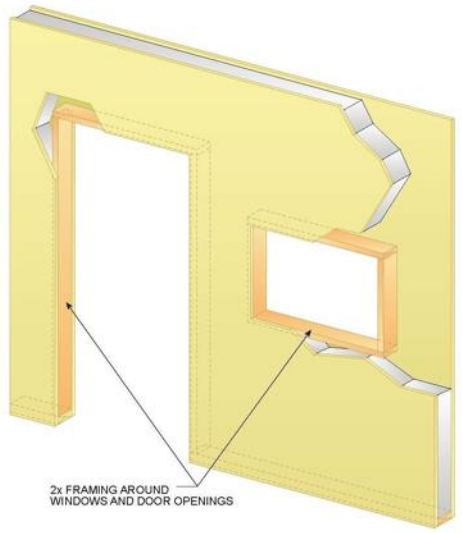
- The vertical stacks and water feeding tubes will go vertically through the floor SIPs and will travel horizontally, with appropriate slope, within the false ceiling's plenum space to eventually be connected to the man drainage or water feeding stacks and tubes collected.

- Electrical chases 1-inch to 1-1/2 inches in diameter can be incorporated into the SIPs during the manufacturing stage.

- Properly designed HVAC systems are required to address the air tightness and energy efficiency inherent with SIP designed buildings.

Window/door installation

- Is similar to that of wood frame construction.
- Openings around windows and doors, and other chases should be properly sealed and/or flashed to prevent moisture infiltration.
- Provide appropriate flashing systems at all exterior building envelope openings and penetrations.



DOOR AND WINDOW FRAMING

Conclusions

- Innovative construction system that aims at developing more adaptive public housing in Abu Dhabi and other UAE cities is desperately needed.
- The proposed SIP system can satisfy the genuine residents' needs for on-going expansions and adaptations in their houses and, thus, realizing more sustainable and resilient public housing.
- Through this mechanism, the house development is a ***process*** rather than a ***product***. This process reflects continuous changes and incremental additions (or subtractions, if needed, to reclaim open space rather than a closed one).
- In this process, local/federal authorities providing housing units will be only required to develop the steel structural skeleton and the core house SIPs while residents will be responsible for expanding their core houses, as and when needed.
- Residents can buy SIPs, channels and joint splines from the local authority to expand their houses and when they retract them, they simply sell back the dismantled SIPs, channels and joint splines to the local authority.
- Local authority should provide technical training for self-build processes to the residents and, if required, can provide some technical help in fixation and relocation of the panels.

Conclusions

- Real life validation of the proposed SIP System and its recommended construction mechanisms regarding the constructability, efficiency and usability considerations including: environmental limitations of this type of construction in UAE climate with its high diurnal ranges, energy consumption, cost, time of construction, availability of materials in the local market, ease of construction and quality.

- Testing constructability through building a 1:1 physical mock up model for a portion of the house to demonstrate and test the mechanism of installation and demountation of the external/internal walls, roof and floor panels.

Thank You! ☺