TRIANGULAR PALLET HOUSE - TPH©

Elemental A-frame design applicable in emergency and recreational environments

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ABSTRACT: What does the 'cutting edge' of eco-dwelling mean today, by using low and light-tech applications? A sustainable approach towards potential housing design shows limitless possibilities by using manufacturing shipping pallet boards as A-framework.

The TPH© appears as a global response against over-packaged architecture, which explores unexpected trails of affordable housing production, providing new flexibility and interoperability by using timber shipping boards, bins and tensile straps. These components are massively manufactured by the packaging industry and each triangular chassis uses basic passive techniques such as orientation, building shape, and colours, local and recyclable materials as skin and insulation, and textile or timber shading devices that improve the indoor comfort.

In terms of structure, TPH© consists of an elemental triangular structure based on combinations of two Euro-pallets boards that are both connected by metal bins and embraced by packaging straps (metal or plastics) along the panels. Thus, TPH© performs as an easy-to-make, collapsible and tight panel that does not require complicated connectors. In terms of thermal insulation, the cavities between the top deck and the bottom deck of the PHS© A-FRAME is fully insulated with permanent or movable thermal layers -for instance, in cold lands-, depending on the climatic location and local supply's feasibility. In terms of installations, each cavity allows easily electric wiring, plumbing pipes and ventilating ducts. On short, TPH© displays new possibilities as flexible and adaptable housing frame, mainly in developing areas; easy to transport and assemble.

This research on experimental housing design is carried out both at the NTNU (Norway) and UPC (Spain). It also has been registered as patent design in the Swedish Patent and Registration Office. It constitutes a continuation of teaching experiences and previous studies on potential wooden architecture since 2001, by using shipping timber boards as wood-frame systems both in dwelling and mobile furniture.

Conference Topics: 5. Materials and building techniques / 9. Case studies
Keywords: Experimental dwellings; lightweight A-framing; low-tech solutions by using pallet boards.

WHAT DOES A-FRAME MEAN NOWADAYS?

Beyond a historical documentation of the post war American house as an icon of recreation, the A-frame represents a simple and affordable habitat to construct featured by a steeply sloping triangular shape which is easy to assemble and free of paint maintenance.

What should we design instead? First, TPH© emerges as a manifesto against over-packaged architecture, exploring the essential use of A-frame models as an unexpected design strategy of spatial outcome, for instance, applied mainly in emergency houses or vacation cottages [1].

But, does it need to be expensive? One field where expenses can be reduced and where affordable building solutions might experiment great innovation, lie in the use of packaging materials into domestic application under low-tech manufacturing (including the use and recycling of new or disused ones). The TPH© project performs as an affordable housing structure based on pallet units capable of becoming an elemental every-where dwelling. Also it can provide efficient thermal comfort by using passive techniques.

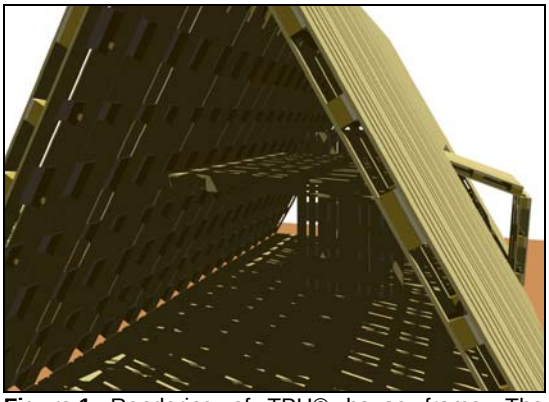

Figure 1: Rendering of TPH© house frame. The frame structure consists of Euro-pallet boards, applicable in several contexts as roof, floors and wall framing and embraced by plywood strips and tensile metal or plastic straps depending of the final skin. Source: Suau-Teixido.

TPH© house frame provides new flexibility and interoperability, by identifying potential occupants;

exploring climatic-adapted frameworks; inserting low-technologies and defining easy building guidelines. As result, it constitutes an open design system which involves several parameters such as programmatic layout, climates, location, flexible and lightweight structure and low-cost budget.

Inevitable, we find prefabricating spatial features in the TPH© case studies: *A. Flexible rectangular ground plan (variable interior divisions) and collapsible walls; B. Service buffer (kitchenette and lavatory); and C. Sleeping loft.*

The case studies are focused on both a constructive design based on simple triangular frame solutions and also a climatic design which improves the indoor thermal comfort by using passive energy systems in cold, arid and tropical lands [2].

2. ASSUMPTIONS

I. Use and recycling of packaging materials as building and structural components formulate a pioneering design process for triangular low-budget houses and explores straightforward techniques and uses of timber framework in emergency and recreational environments.

II. Simple passive techniques such as orientation, building shape, colours, low-value materials, and shading devices can improve housing indoor comfort. Nevertheless, the impact of these factors can vary according to specific climatic parameters and the occupancy.

3. DESIGN AND BUILDING DEVELOPMENT OF TPH© COMPONENTS

PALLET DESIGN SYSTEM Version 3.0
Pallet Structural Analysis

Pallet ID: EuroPallet-Type Design
Classification: 800 x 1200, Block-Class, Double-Face Non-Reversible, Full 4-Way, Multiple-Use
Unit Load Type: Uniformly Distributed - Full Pallet Coverage
Unit Load Weight Variability: User-Specified
Weight Coefficient of Variation: 49.5 % Maximum to Average Weight Ratio: 2.15
Service Environment: Dry Service Environment (EMC <= 10%)

Support Condition	Safe Maximum Load	Deflection at Maximum Load	User Specified Deflection Limit	Maximum Load for Deflection Limit	Critical Member
Racked Across Length (Span = 610)	1042 kg	8 mm	—	—	Top Stringerboard
Racked Across Width (Span = 1099)	1566 kg	12 mm	—	—	Bottom Deckboard
Stacked 1 Unit Load High	5756 kg	4 mm	—	—	Top Deckboard
Stacked 4 Unit Loads High	1853 kg (each pallet)	6 mm	—	—	Center Bottom Deckbd

Pallet Durability Analysis

Low | Medium | Good | Excellent
Durability Rating = 101

Table I: Pallet structural analysis. There are different kinds of pallets: heavy pallets, mid-heavy pallets, and light pallets. They are distinguished by the thickness of the decks and load capacity. The TPH© utilises mid-heavy and light pallets boards. Source: Suau.

The TPH© system is a based-panel construction of two Euro-pallets [3] sizing 80cm x 120mm each.

Floor and roof framing are connected mainly by internal bins and aside straps and both deck sides are covered with panel-type sheathing (mainly plywood boards or strips, using 2400mm x 1200mm x 6mm panel). Wall framing has the same modulation and side sheathing.

After arise the whole frame, the final embracing and also exterior cladding is carried out by overlapping a structural sheathing, consisting of mainly plywood board or strips with waterproof adhesive. Diagonal rafters can also be applied inside pallets instead of outer sheathing. If climatically the dwelling frame is not entirely covered by sheathing but should perform as shading device (i.e.: TPH© roofs in the Coastal Desert or Tropical lands); the bare pallets must be embraced by standard metal connections and tensile bracing such as metal or plastic strapping.

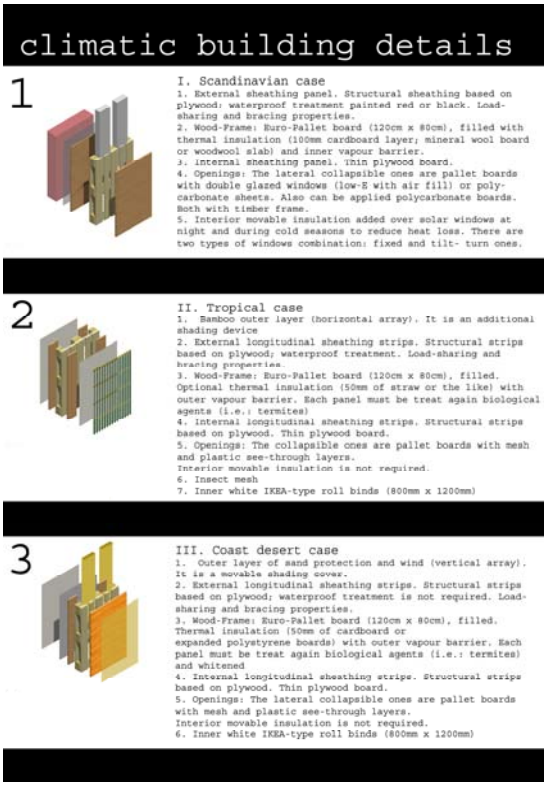

Figure 2: Three constructive details of **TPH© roof** applied in the Scandinavian, tropical and semi-arid cases. In the case of the flooring, we must exclude the outer layers of the TPH© roof's solutions. Source: Suau & Teixido.

Depending on the climatic context and local feasibility, its cavity between top and bottom decks can be partial or fully insulated with or local or disused packaging materials (i.e.: cardboards or expanded polystyrene).

In terms of installations, the cavity between deck-sides allows easily electric wiring, plumbing pipes and ventilating ducts.

Summarizing, fundaments of consists of:

1.Self-bracing by structural sheathing boards or strips

2.Simple triangular geometry for fitting-out and façade
3.Standard mechanical galvanised connectors (floor suspended and floor laid on top) and metal strapping

Figure 3: Structural test of PHS-F1© developed in my studio in 2004. The whole structure consisted of simulate the collapsible way to assemble a triangular chassis by using Euro-pallet boards. The TPH© roof is supported by a tensile V-bracing using two metal straps. Afterwards, the panels are reinforced by plywood boards on each deck. The unions of floor desk with lateral pitched roofs are executed with metal bins and joints. Source: Suau.

Due to its building features, the TPH© constitutes a semi-finished product consisting of a twin-board system, a wood-based board [4]. The principal components applied in TPH© are the following:

A. TPH© RF It is a prefabricated twin board system based on ribbed slabs with structural plywood in both deck-sides used in roof and floor. They perform as bracing elements. It is filled in with several insulation materials, depending on the climatic parameters.

B. TPH© shading devices. This is a bare framing board based on pallets distributed along aside facades, painted according to the location and connected with metal bins, plates and standard connections as bracing elements. There are also textile or paper manual blinds.

C. Standard strapping, connections and joints (Metal or plastic straps / Gang-nail punched metal plate fastener / Wood screws in floors, walls and roof / Ordinary round wire nails in floors and roof). Also perforated sheet metal plates (rafter-purl in anchor / joist hanger for web beam); prefabricated bases (cast in / height-adjustable dowelled) and special connectors (wires and turnbuckles for V-tensile bracing).

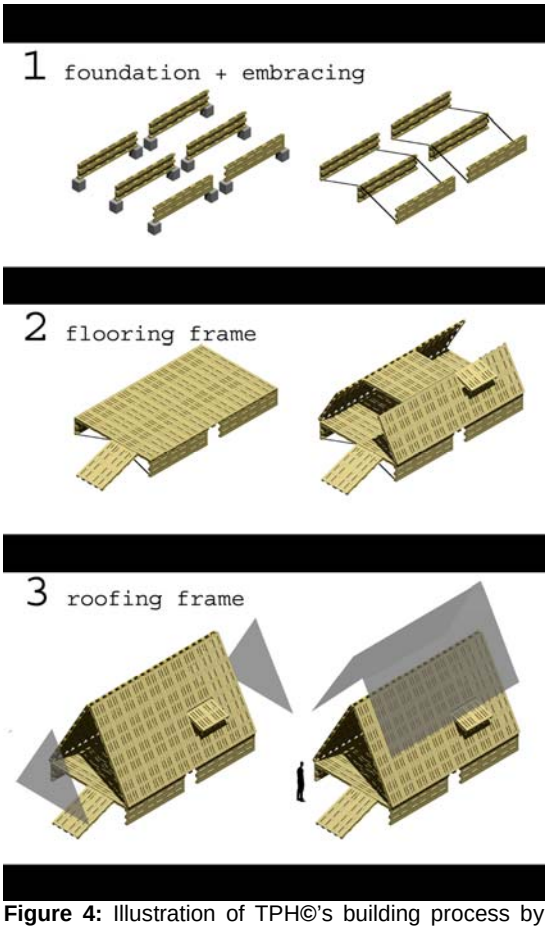

Figure 4: Illustration of TPH©'s building process by using based-panels consisting of twin-pallets module. It is applied in floor and equilateral pitched roofs. Source: Suau - Teixido.

4. METHOD

This study has been oriented towards a research by design:

On one hand, structural and building solutions have initially been experimented on site (models 1:1 scale) in order to demonstrate the feasibility and flexibility of TPH© modules. TPH© modules of 800mm width have been tested (See figure 3). The first triangular experiment has used 6 pallets by recycling the same materials of the previous operative working cabin presented in PLEA 2004. By assuming the recycling of existing pallet boards, some joints and wheels; I estimate that the TPH©'s construction budget was around € 85 (item called 'strapping, connections and joints'). Handwork hours and tools have been not calculated. The countable items were standard connections and joints, paint, blinds and wheels.

On another hand, it is about how to improve indoor climate in this triangular dwelling, the preliminary designs has been first compared with traditional analytical tools (i.e.: Givoni's bio-climatic chart and Mahoney tables) and solar diagrams. Computer simulation -DEROB-LTH [5]- indicates that indoor comfort conditions improve by using simple

passive technique: use of low-value materials; appropriate insulation; shading devices; climatic-adapted colours in roofs and orientation of openings as solar collectors or cooling flows.

The house prototype has not been built yet.

5. DESIGN GUIDELINE FOR TPH© MODELS

The Triangular Pallet House© (TPH**)** formulates an entire life cycle model by recycling timber shipping boards with lightweight insulation materials in 3 different climatic contexts: Scandinavian woodland: summer shed outside Gothenburg city; Atacama coast desert: temporary immigrant refugee outside Iquique city and Colombo city in Sri Lanka: emergency house sited along the shoreline.

5.1. PHS© Scandinavian woodland case

Sweden, Västra Götaland, Gothenburg
Geographic location: 57° 42´N - 11° 58´E
Bioclimatic chart of Gothenburg city may be found by reviewing *"Pallet Housing System"* paper, PLEA 2004)

1. Form. The dwelling is a triangular shape with plan layout based on 4 pallets (480cm) times 10 pallets (800cm) and facing South. It has a sleeping loft naturally well-lit. Its envelope is fully well-insulated with a permanent and movable insulation in roofs and floor (see figure 2). The main floor contains sanitary services facing north and a flexible multifunctional area. The pitched roofs are 60 degrees inclined and covered by plywood boards.

Figure 5: Rendering of TPH© Scandinavian case. It includes location, across section and climatic detail. The roofs contain both full and movable insulation (winter-autumn). Plot is situated in woodland nearby Möndal. Source: Suau - Teixido.

The Direct Gain Systems (DGS) is located in the south-glazed façade. In winter, it admits extra-direct sunlight and co-operate when there is a solar blockage of the south wall by nearby trees.

2. Solar orientation. It is the main factor during winter. Large or medium-size plus double-glazed openings facing south are the most suitable. During wintertime, mobile indoor insulation is recommended to reduce night-time heat losses.

3. Ventilation. Prevailing southern winds along the year keep an average speed of 4.2 m/sec. Low rate of ventilation is required.

4. Materials. According to the climatic chart, the dwelling mostly requires heating and internal gain. Thermal insulation and exterior dark colours (high absorptance and high emittance, over 80%) must be utilized in order to gain a comfortable indoor climate.

5.2. TPH© Tropical case

Sri Lanka, Colombo
Geographic location: 6° 55'N - 79° 50'E

In this case study, a passive cooling system is required along the year. Unfortunately, we cannot find an important comfort zone. So, a lot with surrounding vegetation offers additional shading and wind shield.

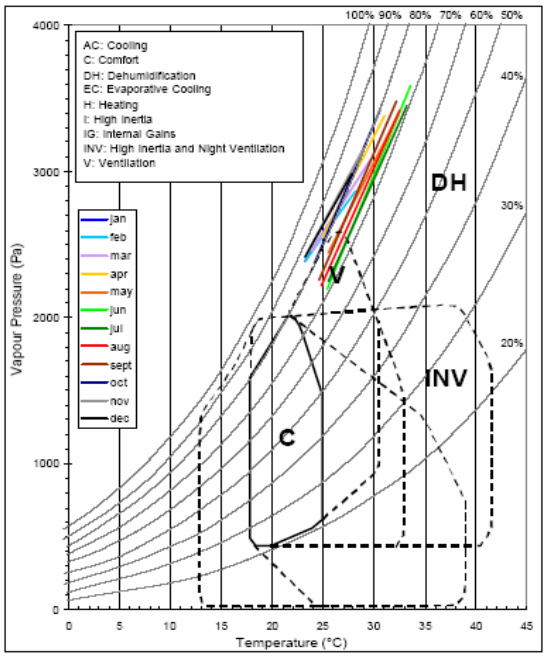

Table II: Bioclimatic data of Colombo city, according to Givoni's diagram. Source: M. Müller [6]

1. Form. The dwelling is facing prevailing winds, based on permanent and mobile shading devices. Its triangular shape performs structurally against strong winds. Layout plan is based on 4 times 10 Euro-pallets as well. Its array contains kitchenette and bathroom buffer plus a multifunctional social area.

The roof is a sloping pitched type, light-insulated and has an exterior waterproof and sand layer (low-absorption properties).

According to Mahoney table, large openings with high vents are required.

2. Wind orientation and ventilation.
Cooling is the main factor to take into account. During the year, the dwelling is cooled by natural cross ventilation through shading and mobile white panels made by bamboo or textile. To prevent moisture and rainfall, a waterproof membrane must be installed on cover

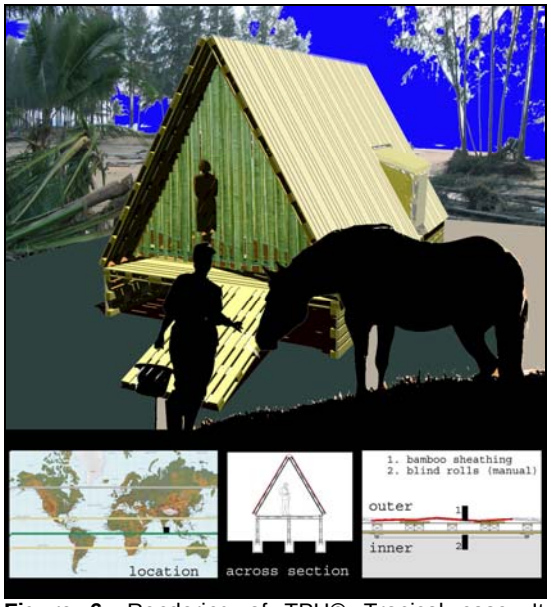

Figure 6: Rendering of TPH© Tropical case. It includes location, across section and climatic detail. The roofs and north-south façades contain both a movable shading device (bamboo logs) and internal roll blinds, which provide privacy. Source: Suau.

To maximise the passive cooling during hotter seasons, the house requires mobile shutters and blinds in main openings to provide good ventilation in the loft. Glazed layer are not used.

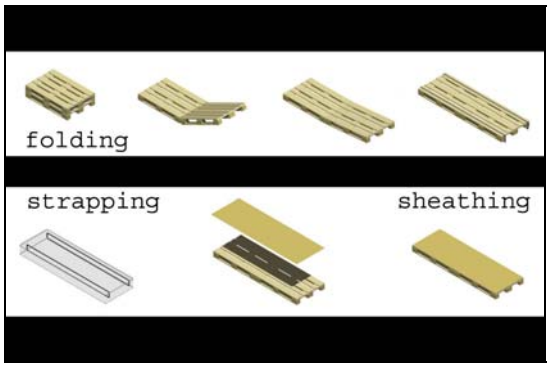

Figure 7: Rendering of TPH© panels by using based-panels. The structure consists of two Euro-pallets per frame, based on 240cm times 80cm each board. Source: Suau - Teixido.

3. Materials. Basically in terms of insulation, the envelope needs lightweight materials due to there are small gap between day and night temperatures. A combined system of light thermal insulation based on straw is purposed in roof sections. Exterior light colours are highly recommended.

5.3. PHS© Atacama case
Chile, Tarapacá, Iquique
Geographic location: 20° 12' S - 70° 11' W
(The bioclimatic chart of Iquique city may be found by reviewing *"The Pallet House"* paper, PLEA 2003)

For dwellings establish in semi-arid coastal lands, cooling is the most important agent along the year, but in cool season certain heating is required for additional internal gains.
1. Form. In comparison to the previous pallet housing models developed between 2002 and 2004, this triangular shed has been reduced in size and the stringer pallet has been substituted by Euro-pallets as A-framing system and permanent shading device. The roofs are light-insulated. Mobile shading devices are set up, facing north and aside openings. Waterproof membrane is not necessary. The shed is cooled by cross ventilation. The main plan has an adjacent veranda facing north, performing as 'cooling buffer'. The loft contains the sleeping area and it also acts as a 'floating roof', reducing the overheating during daytime in summer. The roof has an exterior sand-proof layer with low-absorptance properties.

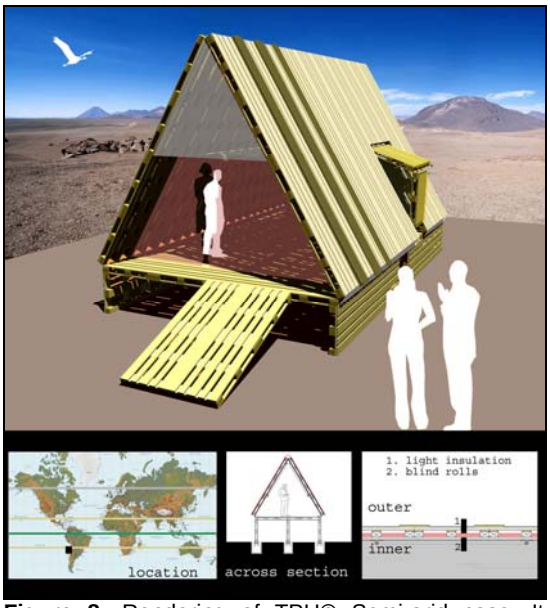

Figure 8: Rendering of TPH© Semi-arid case. It includes location, across section and climatic detail. The roofs and north-south façades contain both a movable shading device (canvas) and internal roll blinds. Also it is light –insulated. Plot: Coast of Iquique (nearby airport field), Chile. Source: Suau.

2. Solar orientation. Computer simulation indicates that solar orientation is the primal factor. Openings facing north-south are the most suitable arrangement. During wintertime, simple-glazed windows with movable inner insulation may minimize cooling. During summertime, the action of shading devices

made by bare pallet framing may reduce overheating specially during afternoon.

3. Ventilation. Prevailing southern winds (speed of 3.6 m/sec) are canalized and regulated throughout the veranda and loft. The shaded space under the floating roof is cooled through manual control of sliding shading devices and windows.

4. Materials. Due to the climate does not show extreme changes of temperature (short thermal variation between summer and winter), lightweight materials (i.e.: packaging ones) may be utilized in order to obtain a comfortable indoor climate. Nevertheless, light thermal insulation and light colour (high emittance, 85-95%) are recommended specially in the exterior roof because it avoids the most solar radiation during summer.

6. CONCLUSION

TPH© design is a research by design. It began as a playful combination and assemblage of residual shipping boards and ended in a wood-frame housing system, with a triangular shape. Here, THS© design proposes the development of variable and interchangeable elements of construction: exterior walls as roofing; interior movable buffers, panels and textile layers as furniture, capable to gather a temporary living by arranging well-adapted building components and parts, according to the type of occupancy and climatic variations.

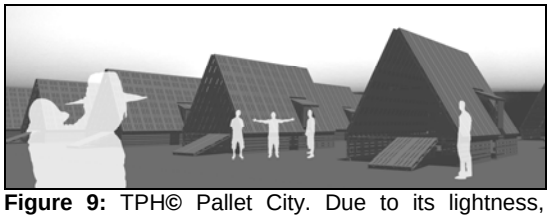

Figure 9: TPH© Pallet City. Due to its lightness, stiffness and versatility, these elemental dwellings can be built in any recreational or emergency plot no matter the climatic context. Source: Suau & Teixido.

Programmatically, TPH© design shows the possibilities for versatile layout applied in vacational or temporary dwellings, which can easily be assembled or disassembled, foldable, refillable and the like. It fosters the notion of TPH© as an inhabitable *eco- 'pack',* where its new applications achieve elemental building patterns and a radical appearance beyond the conventional realms of construction market or architectural style.

Finally, the TPH© demonstrates a deep and global adaptability, both in response to changing climatic conditions and also to simpler wood-framed dwellings, cheaper and greener.

7. ACKNOWLEDGEMENT

First, I express thanks to the permanent support of the NTNU, Department of History, Technology and Design; Design Department at Barcelona School of Architecture (ETSAB) and AGAUR, who have given me the possibility to carry out this case study and consequently enrich my academic experience in several research centers. This experience has not been only covered theoretically but also developed as a tactile and manufacturing exploration into new applications of wood.

Above all, I wish to highlight the critical and provocative reflections of my colleagues Anne Grete Hestnes, Finn Hakonen and Marcia Codinachs. Apart from them, I must express special thanks the collaboration of Alberto Teixido and his illustrative way to display TPH© framework in Barcelona.

I also wish to thank the fruitful debate on TPH© carried out on September 2005 at the Seminar on Sustainability in Architectural Design. It was organized by the Schools of Architecture of UPC, Politecnico di Milano and Hanoi University, and sponsored by ASIA LINK and University Network for Sustainable Architectural Design. Finally, I show gratitude to the doctoral students at ETSAB in the course titled *'Potential Architecture'* and also in the architectural workshop titled *'Bo Base'* carried out at NTNU during this year, where we have explored and learn limitless reflections on minimum dwelling.

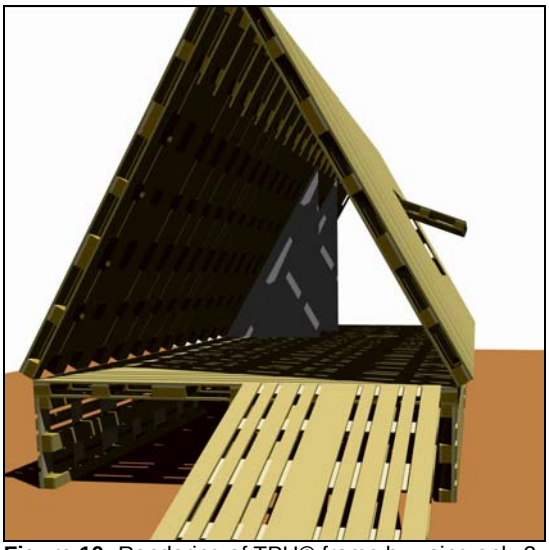

Figure 10: Rendering of TPH© frame by using only 3-based pallets. Loft is not required. Source: Suau.

8. REFERENCES

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[2] Suau, Cristian. *Pallet Housing System,* 2004, PLEA Congress, Holland. www.plea2004.nl

[3] Pallet is a rigid horizontal platform of minimum height compatible with handling by pallet trucks, and/or forklift trucks. The Pallet acts as a unit load base and is constructed primarily with wood. There are different types of pallets such as 4 way entries and 2 way entries, and various styles such as stringer and block pallets (Euro-pallet).

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