Construction of the final evolutive shelter test prototypes – Farchana's refugee camp, Tchad – March 2025

Final Report
Evolutive Shelter Prototype – from Emergency to Development

31st July 2025

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Table of Contents

A. Introduction

1. General Information

1.1. Objectives

1.2. Attained Outcomes and Outputs

1.3. Revised Agenda

B. Final Reporting

2. Construction of the Final Prototypes

2.1. Technical Report on the Construction of the Final Test Prototypes

3. Evaluation of the Final Prototypes

3.1. Qualitative Monitoring & Evaluation (M&E) - Comparison with Baseline

3.2. Quantitative Monitoring & Evaluation (M&E) - Indoor Environmental Quality (IEQ) Metrics Final Evaluation

4. Evaluation of the Tested Innovative Solutions

4.1. Evaluation of the Different Earth Construction Techniques for Walls at the Transitional / Development Stage

4.2. Evaluation of SAM Panels as an Alternative for Roofing, Doors & Window Shutters

5. Communication of Results & Reporting

5.1. Listing and Reporting on Communication of Results Initiatives

5.2. Reporting on the Final Communication of Results' Event *(Luxembourg Red Cross, 17.07.2025)*

C. Lessons Learnt & Recommendations

6. End of Project Key Findings & Results

6.1. Key Lessons Learnt and Results Achieved

D. Annexes

1. Quantitative M&E – LogTag's Reports & Graphs

2. Donation Agreement – AICRL / MIC – SAM Panels

3. List of Participants of the Final Communication of Results' Event *(Luxembourg Red Cross, 17.07.2025)*

4. Final Financial Reporting

A. Introduction

1. General Information

1.1. Objectives

Report Title	Evolutive Shelter Prototype – from Emergency to Development	
Country	Luxembourg, Chad	
Location	Luxembourg (Luxembourg) N'Djamena (Chad) Ouaddaï Province (Adré, Farchana, Abéché) (Chad)	
Objectives	Contribute to the reduction of protracted crises' impact by applying the humanitarian-development nexus approach; built on the exchanges held during the "Innovation in Humanitarian Shelter" conference (Luxembourg, 2023) to develop an adaptable shelter model - evolving from emergency to development - tailored to the refugee crisis context in Chad and validated both technically and by the community *(according to Annex 3 of Convention de Donation "Innovation in Humanitarian Habitat", signed between FVEMT and AICRL)*	
Project	19LU29 – « Luxembourg Humanitarian Hub »	
Responsible	Aide Internationale de la Croix-Rouge luxembourgeoise (AICRL)	
Duration	2023 – July 2025	
Report Date	September 30th 2025	
Author	Ana Carolina Helena, Shelter Officer – Shelter Research Unit (SRU)	

The 19LU29 "Luxembourg Humanitarian Hub" project, implemented by the International Department of the Luxembourg Red Cross (AICRL), financed by the Veuve Emile Metz-Tesch Foundation (FVEMT), and developed in partnership with the Red Cross of Chad (CRT), had as its main objectives contributing to the reduction of protracted crises' impact by applying the humanitarian-development nexus approach and building on the exchanges held during the "Innovation in Humanitarian Shelter" conference (Luxembourg, 2023) to develop an adaptable shelter model - evolving from emergency to development - tailored to the refugee crisis context in Chad and validated both technically and by the community.

This final report, prepared upon the conclusion of the project, aims to compile all key information and results from the last construction phase - namely, the completion of the final 5 (five) test shelters - and to ensure proper reporting on the achievement of the project's overall expected outcomes and outputs *(see, as well, Annex 4. Final Financial Report)*.

1.2. Attained Outcomes and Outputs

According to “Annex 3 : Les critères d'évaluation du projet” of the Convention de Donation « Innovation in Humanitarian Habitat » entre la Fondation Veuve Emile Metz-Tesch & l'Aide Internationale de la Croix-Rouge luxembourgeoise, a.s.b.l, the expected results of this project were as listed below:

- **A prototype of an evolutionary shelter**, from emergency to development, adapted to the context of the refugee crisis in Chad;

A design of a prototype for an evolutionary shelter, based on the scientific conference held in October 2023, was adapted and drafted to the context of the crisis in eastern Chad, in early 2024 by the previous AICRL collaborator, Isabel de la Vega Meroño. This first design was implemented during the 1st phase of construction – the first three test shelter.

- **Plans and specifications** for the prototype have been developed;

All needed technical drawings for construction were developed by the previous AICRL collaborator, Isabel de la Vega Meroño, before the beginning of the 1st phase of construction.

- A **prototype has been built**, and a **report on the activity process** has been produced;
- **Lessons learned** from the implementation of the pilot prototype have been analyzed;
- **Modifications to the drawings, construction details, and quantitative specifications** have been introduced based on the lessons learned from the implementation of the first prototype;

Between September and December 2024, three first shelter prototypes were built, near Adré Red Cross sub-chapter office, at three different stages of development, to ensure the feasibility of the proposed design. After the monitoring mission, in November – December 2024, a technical evaluation of these three almost complete prototypes was made, and its main conclusions were incorporated in the respective mission report (“3. Evaluation of the Test Prototypes“, “3.1 Technical Evaluation of the Test Prototypes”).

Following the report, lessons learnt were drafted and technical drawings as well as the respective bills of quantities (BoQs), in preparation of the construction of the 5 contractualized final shelter prototypes.

- **At least 5 shelters** have been implemented in real-life contexts;

- **Monitoring, and technical and community validation** of the 5 constructed shelters.

Five (5) final shelter prototypes, based in the revised design, were built in Farchana's refugee camp, between January and March 2025.

Evaluation of the final five prototypes was conducted during April and May 2025, both through the collection of quantitative data – i.e. measurement of Indoor Environmental Quality (IEQ) indicators, like indoor temperature and relative humidity, for comparison with baseline – and qualitative data – i.e. evaluating the incorporation on key aspects raised by the community during the KII's (key informant interviews, realized during the monitoring field mission.

1.3. Revised Agenda

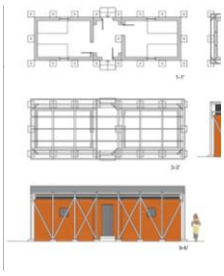
The following table presents the revised agenda of the project, marking its key milestones:

	2023	2024				2025		
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Design Competition / Scientific Conference	■							
Development of Contextualized Technical Design		■	■					
1st Test Prototypes - Procurement & Planning				■				
1st Test Prototypes - Construction					■			
1st Test Prototypes – Monitoring & Evaluation					■			
Support Field Mission (including M&E and Revised Design)					■			
Final Prototypes – Procurement & Planning					■	■		
Final Prototypes – Construction						■		
Final Prototypes – Monitoring & Evaluation							■	
Communication of Results							■	■
Reporting								■

Fig 1 – Revised agenda of the project, marking the implementation of its key phases.

Some delays were encountered, particularly at the start of the two construction phases. These were primarily due to logistical and transportation constraints, especially between late June and early September, a period during which procurement at both the regional and national levels is highly limited. Additionally, local markets are increasingly impoverished and strained as a result of the continuous arrival of large numbers of Sudanese refugees. This influx has significantly increased the population in bordering Chadian villages, compounded by the ongoing conflict across the border.

As a result, a one-month amendment was signed between the parties, granting a no-cost extension to change the expected completion date from 30-06-2025 to 31-07-2025. This extension aims to ensure the completion of final monitoring and evaluation (M&E) activities, facilitate data compilation, complete reporting obligations, and organize a final results' communication event in Luxembourg with the presence of all key project stakeholders.



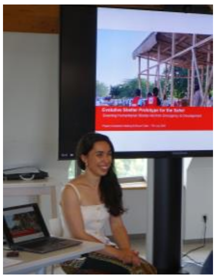



Fig 2, 3, 4, 5, 6, 7 and 8 – Photos of the main project milestones: (1) selection of the winning student design, during the international conference organized in October 2023; (2) development of the contextualized technical design, to ensure applicability in the eastern Chadian context; (3) construction of the first three shelter prototypes, in Adré, in November 2024; (4) support field mission, in November – December 2024, to ensure M&E of the first phase of construction as well as collect information for revising the technical drawings and BoQ's accordingly; (5) construction of the final five prototypes, in Farchana's refugee camp, between January and March 2025; (6) conduction of final M&E activities and (7) communication of results, in June – July 2025.

B. Final Reporting

2. Construction of the Final Prototypes

2.1. Technical Report on the Construction of the Final Test Prototypes

Informed by the revised technical drawings and BoQ's, developed during and subsequently to the support field mission (see "Mission Report – "Evolutive Shelter Prototype – from Emergency to Development"), between January and March 2025, five (5) final shelter prototypes were built in the extension of Farchana's refugee camp.

Fig 9, 10, 11, 12, 13, 14 and 15 – Photos that illustrate the construction of the last five (5) final shelter prototypes, at Frachana's refugee camp, between January and March 2025.

The final shelter prototypes, completed resourcing to local manpower – including workers from the local community and refugees -, were built at the latter stage of development (Phase 5 "Development"), incorporating changes according to the solutions proposed to answer the technical challenges and weaknesses identified during the support field mission conducted in November – December 2024. However, different earth construction techniques were used for the completion of the transitional walls as well as different materials for the roofing, to allow for the evaluation of the best combinations regarding not only price and structural resistance, but also environmental indoor quality metrics.

The five final shelters were built as follows:

- **final shelter 1** – Fired bricks (walls); CGI's (roofing, doors and window shutters);
- **final shelter 2** – Adobe (walls); CGI's (roofing, doors and window shutters);
- **final shelter 3** - Adobe (walls); CGI's (roofing, doors and window shutters);
- **final shelter 4** - Adobe (walls); SAM panels (roofing, doors and window shutters);
- **final shelter 5** – Compressed Earth Blocks (CEB's) (walls); CGI's (roofing, doors and window shutters);

Design and construction-wise, the following alterations were successfully included:

- **the height of the shelter prototype was slightly reduced** – to a maximum of 2,90m on the highest point to 2,70 on the opposite side; this slight reduction that, nonetheless, keep total height slightly above comparable models, allows for the safeguarding of the ventilation grid between the walls and the roofing structure, without compromising its structural resilience in case of strong winds or heavy rains;

- **a dry foundation solution was implemented** – as planned, substituting the concrete poured ones used during the first phase of construction; these showed to be appropriate (as they proved structurally sound), as still allowing for the re-use of the wood framing in case of need – one of the scarcest materials in the region;

- **the reduction of the cement and wood usage** – the changes made regarding the materiality solution used for the foundations (substituting concrete by sand and pebbles) and walls (prioritizing adobes and CEB's, instead of fired bricks, that relies on the use of big quantities of wood during their firing process), ensured significant reductions in the use of cement and wood, reducing overall cost as well as the negative environmental impact of operations;

- **the predicted reinforcements to the roofing were made** – as suggested after the evaluation of the first built test prototypes, the roofing structure's wood columns were embedded into the bearing walls of the final ones and the connection between the roof and the walls by looping flat iron wire around some of the upper brick rows was reinforced; this ensure the structural stability of the roofing structure without compromising the strategy to reuse materials needed during emergency.

- **the usable area was slightly increased** – by reconsidering the positioning of the bearing walls during the final stages of development, as anticipated, it was possible to increase the usable surface area by 2.3 m² per shelter—without increasing costs or the amount of material used.

- **the roof overhang was also augmented** – the initially planned 30 cm overhang was extended to 50 cm to better protect the earth walls from direct sun exposure and heavy rainfall; this adjustment is expected to enhance the durability of the earth plasters used on the adobe units, while also providing a larger shaded area for the households.

The final shelters were completed in roughly 4-5 weeks, including all phases of construction and the production of CEB's on-site (for the shelter that incorporated those). The plastering of the three done using locally produced and procured adobes was also planned subsequently, to ensure their resistance to the rainy season; an activity that took 2-3 extra working days.

Upon completion and as agreed previously, the final shelter prototypes were donated to CNARR, the camp management team, for non-residential use as predicted (they are expected to fulfil other needs such as stockage).

3. Evaluation of the Final Prototypes

3.1. Qualitative Monitoring & Evaluation (M&E) – Comparison with Baseline

To ensure the proper evaluation of the final solution, a table comparing the in-use models and this new prototype was made, considering their positive and negative externalities as well the variables pointed as key concerns during the KIIs done during the support field mission *(see 4.6. Questionnaire / Key Informant Interviews (KIIs) with Refugees and Local Community, "Mission Report – Evolutive Shelter Prototype – from Emergency to Development")*.

The following table presents the general information collected on the models already present in Farchana's refugee camp (UNHCR Emergency Shelter and Better Shelter), as well as the new evolutive model developed. It also compares how the different models answer to the self-reported preferences of the target population, in line with the information provided during the community consultations and key informant interviews (KIIs) done in November-December 2024, during the field support mission.

Emergency Shelter Models in Use at Farchana's Refugee Camp			
	UNHCR Emergency Shelter	Better Shelter	New Evolutive Model
			
	GENERAL DESCRIPTION		
Description	Rectangular shelter, single room, with gable roof, and a single entrance on one of the longer façades and a single window on the opposite one	Rectangular shelter, single room, with gable roof, and a single entrance on one of the longer façades and four windows (two on each of the longer façades)	Rectangular shelter, two rooms, with a pitched roof, and two separate entrances on the two longer façades and four windows (two on each of the longer façades)
Dimensions (Covered Surface) (Maximum Height)	*~4 x 6m* *(24m2)* (2,40/2,50m)	*~3,5 x 5,5m* *(19,25m2)* *(2,50m)*	*~3,5 x 5,5m* *(19,25m2)* *(2,90m)*
Maximum Capacity (m2 / person)	5 (~4,8m2/ person)	5 (~3,85m2/ person)	5 (~3,85m2/ person)
Price	*~800 - 1000$* ***(~685,54 - 856,92€)*** *	*~1250$* ***(~1 071,08€)****	***~1 153€*** *(Emergency)* + *~661 - 843€ (Transition / Development)***
Materials	(Foundations) Concrete (Structure) Wood (Walls) Plastic Tarpaulin (Windows / Doors) Corrugated Iron Sheets (CGIs) (Roofing) Corrugated Iron Sheets (CGIs)	(Foundations) Concrete (Structure) Metallic (Walls) PVC (Windows / Doors) PVC (Roofing) PVC	(Foundations) Sand / Pebbles (Structure) Wood (Walls) Plastic Tarpaulin, Adobes, CEB's (Windows / Doors) CGI's, SAM panels (Roofing) CGI's, SAM panels
Ventilation (Windows) (Doors) (Other Openings)	(1 medium-sized window) (1 door) (no other openings)	(4 small-sized windows) (1 door) (no other openings)	(4 medium-sized windows) (2 door) (ventilation opening, between walls and roof)
Temperature (Indoor vs. Outdoor)	(40,5C indoors, with 37,5C outdoors) (~ + 3C indoors) *(measured at 12:00, in December 2024)*	(42,5C indoors, with 37,5C outdoors) (~ + 5C indoors) *(measured at 12:00, in December 2024)*	(37,3C indoors, 41,5C outdoors) (~ - 4C indoors) *(measured at 12:00, in May 2025; shelter with walls in adobe and roof in CGIs)* ***
	DESIGN / MATERIAL / SOCIO-CULTURAL PREFERENCES *(according to community consultation / KIIs)*		
Bigger covered surface *(more space for a household of 5)*	~4,8m2/ person *(above minimum Sphere Standards, for hot, arid climates (3,5m2))*	~3,85m2/ person *(slightly above minimum Sphere Standards, for hot, arid climates (3,5m2))*	~3,85m2/ person *(slightly above minimum Sphere Standards, for hot, arid climates (3,5m2))*

Bigger shaded area *(protection from the sun)*	Slight roof overhang (~15cm)	No roof overhang	Large roof overhang (~50cm)
Possibility to divide the space *(ensure male-female separation for sleeping)*	Limited *(no hinges in the wood structure, no material provided for internal partitions)*	Very limited *(pre-fabricated model, no hinges or material provided for internal partitions, and lack of structural soundness to do it)*	Yes *(two separate rooms, with a common wall and independent entrances)*
More than one independent entrance *(to ensure autonomy to multigenerational or polygamous families)*	No	No	Yes *(two separate entrances – doors –, in two opposite façades)*
Building materials with higher thermal inertia *(passive temperature control)*	No *(walls made of plastic tarpaulins and roof of CGIs)*	No *(walls and roof panels, made out of PVC)*	Yes, at transitional / development stage *(walls are made out of earth (substituting the plastic tarpaulins) and roof of CGIs or SAM panels (compressed natural fibers))*
Building materials that are more soundproof	No	No	Yes, at transitional / development stage *(earth construction provides passively sound insulation / in the shelter using SAM panels, noise indoors from heavy rain hitting the* roof is also reduced when compared to CGIs)
More structurally-sound walls and roofing structure *(resistance to heavy rains and strong winds)*	Partially	Limited *(with many complaining about roofing panels frequently being dislodged in strong winds)*	Yes, especially at transitional / development stage *(the embedded roofing structure in the bearing earth construction walls and the reinforcements using flat iron wire ensure improved structural soundness)*
More resistance to flooding	Limited *(sandbags have been previously distributed to protect foundations and tarpaulins, according to need)*	Limited *(sandbags have been previously distributed to protect foundations and tarpaulins, according to need)*	Yes, especially at transitional / development stage *(the 50 cm-high fired brick subbasement ensures watertightness and prevents contact between the soil and the earth bricks)*
More windows, fairly sized, placed high enough *(to preserve privacy, but ensure proper ventilation)*	Very limited *(a single medium-sized window is installed below eye level on the wall opposite the door, with no additional openings)*	Limited *(4 small-sized windows, slightly below eye level, in opposite façades)*	Yes *(4 medium-sized windows, slightly below eye level, in opposite façades, plus a ventilation grid between the walls and the roofing structure)*
Possibility to lock doors and windows *(to ensure security)*	Yes, partially *(lockers were provided for doors, but not always for windows and plastic tarpaulins can easily cut)*	Yes *(lockers were provided for doors, but not always for windows and plastic tarpaulins can easily cut)*	Yes, especially at transitional / development stage
More low-cost, easiest, independent	Limited *(maintenance can be done partially by beneficiaries, that are however dependant on the*	Very limited *(maintenance cannot be done by beneficiaries, as it is a modular solution / model not*	Yes *(maintenance be done by beneficiaries, with cheap materials that are easy to find /*

maintenance / Easy to "transition"	*distribution of needed materials / model not designed to consider reuse of materials for transitional / development stage)*	*designed to consider reuse of materials for transitional / development stage)*	*model designed to consider for transitional to reuse materials / at transitional / development stage)*

Fig 16 – Summary table comparing the existing models in-use and the final developed prototype, regarding qualitative indicators.

** We could not find any recent document with an updated BoQ to confirm the exact unit cost of these shelter models based on 2024 prices in Ouddai province, particularly in Farchana. The presented estimates are based on information gathered through discussions with fellow humanitarian professionals working in the region, so variations from the exact costs should be expected (specially increases linked to rampant inflation).*

*** All prices were calculated based on a market study conducted in Farchana in November/December 2024; variations are possible depending on the availability of materials throughout the year and transportation constraints.*

**** Direct comparisons between thermal comfort indicators cannot be directly make between the three models, as measures were taken during different times of the year and using different tools.*

Overall, the developed evolutive model demonstrates a significantly better response to a wider range of design, material, and socio-cultural concerns expressed by the affected population, especially when compared to existing solutions. However, further improvements remain necessary - particularly during the emergency phase - in areas such as thermal comfort, sound insulation, and security. This pilot and its accomplishments are, in any case, a great example of the practical approach to research led by AICRL, sparked by true challenges faced on our zones of intervention.

3.2. Quantitative Monitoring & Evaluation (M&E) – Indoor Environmental Quality (IEQ) Metrics Final

Simultaneously to the qualitative evaluation of the final prototypes, sensors – LogTag TRIX-8[1] and HAXO-8[2] - to measure outdoor, indoor temperature and indoor relative humidity were installed (as it can be seen in the table below), to best understand how such metrics would vary according to the materials used for wall and roofing.

LogTags were installed accordingly to what was planned for, during the support field mission *(see 5.3. Organizing the (Indoor Environmental Quality) IEQ Metrics Final Evaluation, "Mission Report – Evolutive Shelter Prototype – from Emergency to Development")*:

- **LogTag TRIX-8**, to measure the variation in outdoor temperature, installed outside the shelters, hanging from the roof overhang border, in the middle of one of the longest façade, at circa 2,20m from the ground.

[1] LogTag Recorders. *LogTag TRIX-8* [Product sheet]. https://www.logtag-recorders.com/fr/hardware/trix-8/
[2] LogTag Recorders. *LogTag HAXO-8* [Fiche produit]. https://www.logtag-recorders.com/en/hardware/haxo-8/

- **LogTag HAXO-8**, to measure the variation in indoor temperature and relative humidity, installed inside the shelters, hanging from the horizontal beams composing the roofing structure, at circa 1,70m from the ground.

The sensors were installed upon the completion of the five (5) final shelters and activated in early May. Programmed to measure these three metrics each hour during a week (7 days, from May 7th to May 14th).

The following table presents key data recorded by the sensors—including maximum, average, and minimum values for the three measured variables: outdoor temperature, indoor temperature, and indoor relative humidity. This data provides valuable insights into which material combinations contribute to improved Indoor Environmental Quality (IEQ).

Lower indoor temperatures, particularly during outdoor temperature peaks, along with indoor relative humidity levels within recommended standards, are closely linked to better health and comfort. These factors should be carefully considered when selecting material combinations for future implementations and for the potential large-scale replication of this evolutive shelter model.

Assemblage Matrix for Final Test Shelters' IEQ Evaluation					
	Final Shelter 1 **Walls** Fired Bricks **Roofing / Doors / Window Shutters** CGI's	Final Shelter 2 **Walls** Adobes (*Banco*) **Roofing / Doors / Window Shutters** CGI's	Final Shelter 3 **Walls** Adobes (*Banco*) **Roofing / Doors / Window Shutters** CGI's	Final Shelter 4 **Walls** Adobes (*Banco*) **Roofing / Doors / Window Shutters** SAM Panels	Final Shelter 5 **Walls** CEB's **Roofing / Doors / Window Shutters** CGI's
	Int – HAXO-8 (1) Ext – TRIX-8 (1)	Int – HAXO-8 (2) Ext - TRIX-8 (2)	x	Int – HAXO-8 (3) Ext - TRIX-8 (3)	Int – TRIX-8 (4) Ext - TRIX-8 (5)
Temperature (°C)					
Outdoor	(Maximum) 43,3C (Average) 33,9C (Minimum) 24,8C	(Maximum) 42,7C (Average) 33,8C (Minimum) 24,8C		(Maximum) 43,7C (Average) 33,7C (Minimum) 24,8C	(Maximum) 47C (Average) 34,7C (Minimum) 24,6c
Indoor	(Maximum) 40,9C (Average) 34,2C (Minimum) 26,8C	(Maximum) 39,7C (Average) 33,9C (Minimum) 26,3C		(Maximum) 39,8C (Average) 33,3C (Minimum) 25,6C	(Maximum) 40,1C (Average) 33,6C (Minimum) 25,9C
Relative Humidity (%)					
Indoor	(Maximum) 20,5% (Average) 7,6% (Minimum) 2%	(Maximum) 14,6% (Average) 11% (Minimum) 5,7%		(Maximum) 22,6% (Average) 8,1% (Minimum) 2,6%	(Maximum) x (Average) x (Minimum) x

Fig 17 – Final test shelters' IEQ evaluation matrix, compiling collected data on outdoor, indoor temperature and indoor relative humidity, in May 2025

Even though measurements were taken at a very small scale, without taking into consideration, for instance, placement or sun exposure, some tendencies can be observed:

- **By using earth construction techniques, for the walls, at transitional / development stage, it is possible to significantly reduce passively the temperature inside the shelters** – on average, considering the maximum temperatures recorded both indoors and outdoors, this approach results in a reduction of approximately 4°C compared to existing shelter models - where indoor temperatures (during December 2024, measured at 12:00) were found to be 3 to 5°C higher than outdoor temperatures.

- **By using SAM panels for the roofing, instead of corrugated iron sheets (CGIs), a further slight decrease of indoor temperature should be observed** – a comparison between final shelters 2 and 4 - both featuring adobe walls, but with shelter 2 using a conventional CGI roof and shelter 4 equipped with SAM panels - indicates that, based on the maximum indoor and outdoor temperatures recorded, an additional reduction of approximately 1°C in indoor temperature can be expected with the use of SAM panels.

- **In all models, indoor relative humidity showed to be very low** – probably mirroring outdoor conditions; such low levels of indoor relative humidity are nonetheless concerning as they are linked to many preventable health issues, namely drying of mucous membranes (eg. nose, throat, and lungs), irritation of the airways (eg. asthma, allergies), increased risk of respiratory infections (eg. cold, flu, bronchitis), of viral transmission (eg. SARS-CoV-2 (COVID-19)) and irritation of the eyes and skin (eg. dry, itchy skin (xerosis), cracked lips, and dry, irritated eyes). According to WHO[3], indoor humidity levels should range ideally between 30 to 60%.

4. Evaluation of the Tested Innovative Solutions

4.1. Evaluation of the Different Earth Construction Techniques for Walls at the Transitional / Development Stage

For the construction of the five (5) final test shelters, three (3) different earth construction techniques were used for the walls:

  - **adobes** (raw earth bricks), bought as is to local producers, in three (3) of them;

[3] World Health Organization. (n.d.). *Moisture control and ventilation*. In *WHO Guidelines for Indoor Air Quality*. NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK143947.

- co**mpressed earth blocks (CEB)**, produced previous to construction by our locally hired masons and volunteers, in one (1) of them;
- **fired bricks**, bought as is to local producers, in one (1) of them;

These different earth construction techniques were employed to enable further testing, with the goal of identifying the most suitable option for the specific context of this camp and region. The evaluation considered multiple factors, including environmental impact, indoor environmental quality (IEQ) performance, socio-cultural acceptance, and cost.

Adobes and fired bricks were sourced locally and used as supplied - purchased from local producers identified during the follow-up mission conducted in November/December 2024. In contrast, compressed earth blocks (CEBs) were produced on-site by locally hired technicians and volunteers, under the guidance of Chad Red Cross technicians (seconded to the Luxembourg Red Cross), who had received prior training in the technique. As there was no existing CEB's production capacity locally before, a new production line and a dedicated, adequate stockage space had to be put in place in Farchana's refugee camp, near to the construction site, in preparation for the construction of the final test shelters. Working teams, composed of local Red Cross volunteers and skilled refugees identified by their representants, were composed both to ensure the needed CEB production and later construction of the five (5) final test shelters. All the upfront investment made to enable local production of CEBs demonstrates AICRL's commitment to promoting sustainability in its operations, strengthening the partner Red Cross Society, and building local capacity.

Those working on the CEB production line started by sieving the supplied earth, mixing it with sand, concrete and water (in accordance to the earth construction test made beforehand) and to compress it using the two manual presses previously both and repaired (see chapter 5.1 Preparing for CEB Production for Walls at the Transitional / Development Stage, Mission Report "Evolutive Shelter Prototype – from Emergency to Development") . Two teams, each of four (4) elements, accomplished the task – producing circa 3 500 / 4 000 CEB needed for building one of the final test shelters using the technique - in circa two weeks and a half, working two (2) 4 hours daily shifts (totalling 8 hours / day).

The CEB were later dried during circa 21 days before use, in a warehouse built for the effect – over plastic tarpaulins to avoid direct contact with the soil and were sprinkled with water as needed to control drying speed (due to high temperatures) to prevent cracks, improve curing and strength and prevent surface dusting (tat might weaken the bricks outer layer and compromise mortar and plaster adherence).

Fig 18, 19, 20, 21, 22, 23 and 24 – Several photos showing the on-site CEB production line using two manual presses and stockage for drying before assemblage (18 to 23) and the final shelter prototypes, built using the different earth construction techniques mentioned above (24).

The later assemblage of the different bricks sourced and produced was done similarly – using a locally-used mortar mix, relying on earth and sand. Upon completion and evaluation of the shelters, at this stage, we may conclude the following:

- **Even though CEBs show undeniable advantages – structural strength, increased resistance to the rainy season, no plastering needed, and overall low-maintenance requirements – they still remain, for the moment, substantially more expensive than fired bricks, and especially adobes.** While it is possible to envision achieving similar unitary costs, this highly depends on upfront investments in more productive press machines and other relevant tools and infrastructure needed for CEB production.

- **Regarding Indoor Environmental Quality (IEQ), the different earth techniques perform comparably** – no significant advantage was identified between the three (3) earth construction methods used. All showed consistent passive thermal control capacity, with a rough reduction of indoor temperatures by 4°C compared to outdoor levels.

- **For the moment, the best option remains locally produced adobes, as they are significantly more cost-effective and already produced in large quantities locally.** However, to ensure resilience, it is necessary to raise awareness on the importance of properly testing, sieving, and mixing the earth before use; regular plastering (yearly, after each rainy season); avoiding direct contact with soil; and refraining from using cement-based mortar or plasters, which react with and degrade the blocks over time.

4.2. Evaluation of SAM Panels as an Alternative for Roofing, Doors & Window Shutters

Upon arrival to N'Djamena in December 2024 (see 5.2 Testing SAM Panels as an Alternative for Roofing, Doors & Window Shutters, "Mission Report – Evolutive Shelter Prototype – from Emergency to Development), the panels, a test resulting from a pioneering agreement between the humanitarian and private sector, were later shipped internally, by truck, to Farchana's refugee camp. The shipment arrived in January 2025 and contained, as agreed *(see Annex 2 – Donation Agreement – AICRL / MIC – SAM Panels)*:

- **175 SAM Pure Bovine Processed Fiber panels (120 cm x 80 cm x 2.5 mm)** – for the roof of one of the final test shelters, composed of two layers (assembled horizontally and vertically, respectively), pre-cut and ready for assembly;

- **15 SAM Solid 5 BPF SAM Pure Bovine Processed Fiber panels (120 cm x 80 cm x 5 mm**) – for the doors and windows shutters of the same shelter, to be cut to size on-site prior to assembly.

The construction teams reported that both cutting the panels (using a standard saw) and assembling them onto the roofing structure (with regular nails, similar to those used for corrugated iron sheets) were fairly straightforward and required no special considerations or precautions. In terms of time, the assembly of SAM panels was reported to be comparable to the standard roofing solution.

Regarding potential positive externalities related to public health, the IEQ evaluation (see Section 3.1: Quantitative Monitoring & Evaluation (M&E) – Indoor Environmental Quality (IEQ) Metrics Final) strongly indicates that SAM panels—made from bio-sourced raw materials—work synergistically with the earth construction walls and can contribute, on average, to an additional indoor temperature reduction of approximately 1°C.

Fig 25 and 26 – The pre-cut SAM panels upon arrival to the construction site (25) and its assemblage, using a double-layer strategy to avoid water leakage, over the roofing structure (26).

Fig 27, 28 and 29 – The SAM panels applied as roofing solution to one of the final test shelters (27 and 28) and as doors and window shutters, contrasting to the conventional corrugated iron sheets (CGI) (29).

Concerning waterproofing resistance, the panels demonstrated overall durability against rain, as evidenced by their condition at the end of the rainy season. Although some temporary shrinkage and slight deformation were observed for a few days, no leakage occurred. Additionally, selected members of the refugee community who visited the shelters after construction noted informally that the SAM panels contributed to indoor spaces that were more comfortable temperature-wise, aesthetically pleasing and inviting, and quieter during heavy rainfall.

Fig 30 and 31 – The SAM panels after a couple days of heavy rain, during which they have shown some temporary change in shape but no leakage, in late July 2025.

We might conclude that SAM panels show strong potential to become a more sustainable alterative to corrugated iron sheets (CGI) in transitional / permanent shelter response in humanitarian contexts in the Sahel. However, the following improvements or adjustments should be considered

- **Develop an undulated version of the panel for roofing**, in order to eliminate the need for a double layer to prevent leakage, reduce material consumption, and improve local acceptance by aligning more closely with the shape of standard roofing solutions already in use;

- **Improve waterproofing capacity**, potentially through the application of a non-toxic, bio-based coating. The tested panels, made from cow manure, already demonstrated natural waterproof and water-repellent properties; however, to match the level of resistance offered by corrugated galvanized iron sheets (CGIs), the use of an additional additive should be considered;

- **Assess the feasibility of local or at least regional production**, given the energy access constraints in this geographical context and the significant upfront investment required to establish a production line. Without this, international shipping would hinder the scalability of the solution in the region, due to increased costs, higher carbon emissions (particularly if partially reliant on air freight), and inevitable customs-related delays in material procurement and supply.

In parallel to the on-site testing of the panels, AICRL and MIC also developed a Digital Product Passport (DPP) for the SAM panels tested in this project, in eastern Chad.

A DPP is not a fixed document or certificate, but a flexible, evolving data system that collects, stores, and shares detailed, product-specific information across its entire lifecycle - from production, through use, to potential reuse or recycling. Unlike static documents such as Environmental Product Declaration (EPDs), Safety Data Sheet (SDSs), or Health Product Declaration (HPDs), DPPs allow real-time updates, multi-stakeholder input, and customizable fields tailored to specific regulatory, logistical, or operational needs.

In humanitarian settings, DPPs can significantly enhance material traceability, enabling organizations to track flows, assess quality and potential health risks, and plan for reuse or responsible disposal – which is particularly key in contexts where there are no-centralized waste management infrastructures. When implemented on secure digital platforms (e.g. blockchain), DPPs provide tamper-proof, auditable records, increasing transparency, ensuring data protection and reducing greenwashing, which is especially relevant for donor accountability.

Most importantly, DPPs lay the groundwork for evidence-based material choices in future projects. By making data on emissions, toxicity, and circularity visible and comparable, they empower decision-makers to choose safer, more sustainable, and context-appropriate materials.

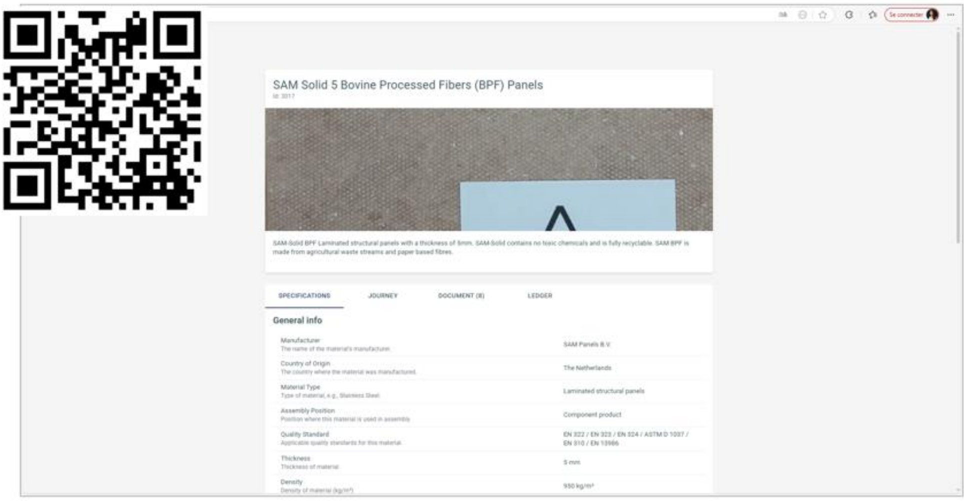


Fig 32 and 33 – Overview of the developed DPP for the SAM panels tested in this project, in eastern Chad, as well as its respective QR code.

As this is a pioneering initiative - the first known test of Digital Product Passports (DPPs) in humanitarian shelter operations - and early results have clearly demonstrated the tool's potential to support "greener," healthier, and more informed material choices across the sector, the AICRL and the Material Innovation Center (MIC) are currently developing a white paper on the topic and this specific case study. The objective is to further evaluate the potential benefits and challenges of standardizing DPP use in humanitarian contexts and to help raise awareness toward future large-scale adoption.

5. Communication of Results & Reporting

5.1. Listing and Reporting on Communication of Results Initiatives

During and upon completion of the final shelter prototypes (April to July 2025), AICRL collected data related to the project's final outcomes and shared its conclusions and lessons learned through various communication initiatives.

Luxembourg

At the Luxembourgish level, two main communication initiatives were led:

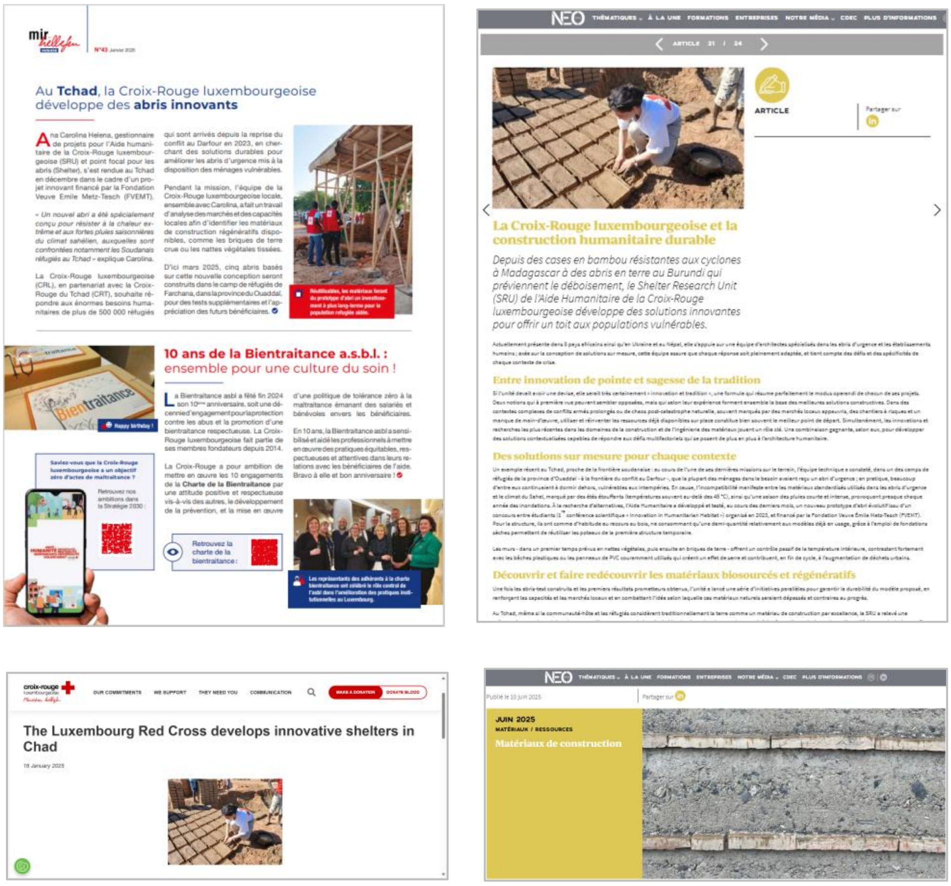


Fig 34 – Communication of results initiatives in Luxembourg – Luxembourg Red Cross website, "mir helefen" (Luxembourg Red Cross newsletter) and article on Neomag, in June 2025 (Neomag #71).

- **one, using the Luxembourg Red Cross communication channels** – namely through a two-part article in its website – "The Luxembourg Red Cross develops innovative shelters in Chad" – and a short version of the same text in its newsletter "mir helefen", reporting on the first results inferred from the first three prototypes, after the support field mission in late 2024 (in English) (01-2025)

- **another, through an invitation to write an article for Neomag** – upon the conclusion of the final test shelters' construction – "La Croix-Rouge luxembourgeoise et la construction humanitaire durable"; Neomag is a luxembourgish magazine, dedicated to innovation and sustainable construction, published monthly online and physically. The article focused on the innovative partnerships made amongst stakeholders to develop a more context-specific solution, that best responds when it comes to sustainability and public health promotion concerns (Neomag #71) (in French) (06-2025)

<u>Chad</u>

In Chad, the intervention country, several communication initiatives were implemented both at the national level - in the capital, N'Djamena - targeting key representatives of relevant government bodies and humanitarian organizations, and in the eastern region - Abeché, Adré, and Farchana - closer to the affected communities and local partners.

In addition to multiple community consultations conducted during the field support mission, where the new shelter model was presented and discussed to better understand potential improvements based on the reported needs and preferences of the target populations, the developed prototype was also shared with other humanitarian organizations present locally, such as UNHCR, ECHO, and Help Tchad. These sessions were held in French, with simultaneous translation into the local Arabic dialect when necessary.

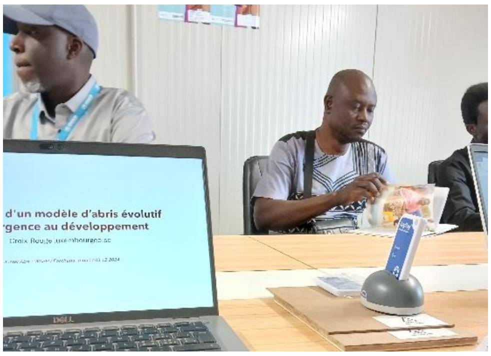


Fig 35, 36 and 37 – Photos of the communication initiatives led in Chad, in the country of intervention: (1) meeting and consultation with the community representatives, in Adré, in November 2024; (2) presentation of the new evolutive shelter design and first results at one of the regional Shelter Cluster meetings (Adré – Farchana), in December 2024; (3) meeting with the representatives of UNHCR (another key entity providing shelter aid in the region) to discuss eventual future synergies.

Red Cross Red Crescent (RCRC) Movement and the Humanitarian Sector (Global Shelter Cluster

To promote the positive results of the evolutive strategy tested and the encouraging data on reduced environmental impact of the model, as well as its public health promotion advantages, two main presentations of its final lessons learnt were also done, during two main events / forums of the sector:

Fig 38 and 39 – Sharing of the lessons learnt with other RCRC entities and other humanitarian actors: (38) presentation of the project at the RC3 Long Night of Research 2025 – "Evolutive Shelter Prototype for the Sahel – Greening Humanitarian Shelter Aid from Emergency to Development"; (39) presentation of the research initiative's results at the 1er Forum du Réseau Habitat d'Urgence Francophone".

- **RC3 Long Night of Research 2025** – the most important annual event on the innovative and research initiatives led by the different RCRC entities; a 15-minute presentation was made, in hybrid mode, showcasing the main steps of the project and showcasing its main advantages for the Sahelian context (in English) (16-05-2025)

- **1er Forum du Réseau Habitat d'Urgence Francophone** – the first of its kind, organized by the French-speaking working group of the Global Shelter Cluster (Réseau Habitat d'Urgence Francophone); a 10-minute presentation was made, and several questions were posed by different participants on particularities of the model during the Q&A (in French) (01-07-2025)

5.2. Reporting on the Final Communication of Results' Event *(Luxembourg Red Cross, 17.07.2025)*

By the end of the project, in July 2025, AICRL organized a final communication of results' event, in Luxembourg, aiming to gather all Luxembourgish and European partners and stakeholders, to present first-hand the achievements made by the end of construction, discuss lessons learnt and collectively brainstorm on next steps – on how we can continue collaboration to bring innovation to humanitarian construction and support the development of more context-specific, adequate shelter models for the different on-going humanitarian crisis where AICRL is present.

The event took place in Luxembourg Red Cross installations in Bertrange, on the 17th of July 2025, at 18:30, counting with the participation of:

- **humanitarians** (several country coordinators and technical profiles from AICRL);
- **innovators and specialists from the private sector** (Material Innovation Center (MIC), Geobloc, OLYX);
- **researchers and academicians** (University of Luxembourg);
- **donors and non-for-profit sector in Luxembourg** (ArcelorMittal, FVEMT).

The full list of participants, including their contact details, might be consulted in the annexes of this report *(see Annex 3 – List of Participants for the Final Communication of Results' Event)*. The session, that lasted for circa two (2) hours, counted with two parts:

1. ***Ouverture* "Luxembourg Humanitarian Hub" and *Presentation* "An Evolutive Shelter Design for the Crisis in the Sahel"** – an introductory speech, providing context on the beginning and initial objectives of this research project, done by Daniel Ledesma (AICRL), followed by a presentation of the conduction of works and results of the project, done by Ana Carolina Helena (AICRL);

2. ***Table Ronde* "Bringing Innovation to Humanitarian Habitat"** – an informal exchange on potential next steps and synergies amongst those present to keep promoting such type of research; the moderation of the session was made by Ana Carolina Helena (AICRL);

During the second part, all the participants answered proposed questions, aimed to spark the brainstorm and exchange between all the stakeholders present. Below, some key notes of some of the key ideas discussed and potential next steps to promote similar research initiatives:

- **research continues to be needed and is more important than ever, even with all the challenges and constraints faced by the humanitarian sector** and contexts supported currently (worldwide financial cuts to humanitarian aid, increase in the number of protracted crisis and its complexity, etc.);

- **partnerships amongst stakeholders coming from different sectors (public, private, non-for-profit) are key to keep fostering innovation and work synergistically to cover technical gaps identified in humanitarian construction projects.** Each sector can best contribute in different domains and at different stages of the research project's implementation (e.g. while academia can best produce models to be tested and help compile, analyse and infer conclusion from large sorts of data, the humanitarian sector can offer access to testing developed solutions in concrete humanitarian contexts and private actors often can ensure the facilities and specialized HR for development and controlled testing);

- **practical research, through the setting of pilot projects, should be privileged, over theoretical and procedural changes**, as they will have a greater chance of being implemented, entail less entropy on regular operations and simultaneously work as awareness / sensibilisation mechanisms to later foster systemic change;

- **research and innovation should always be also discussed with "those in the ground" from day one**, to ensure feasibility of what is being proposed and an implementable calendar of activities, informed by local experience of the context and socio-economic ecosystem as well as resources available (HR, tools, materials available in the local markets, skilled manpower, etc.);

- **communication of such research efforts is often weak, and fostering it not only within organisations but among potential counterparts in other sector is essential to break the "silo effect" in which we often work and increase capacity to keep doing research** and improve the solutions available to best respond the technical challenges we are faced with daily in the domain of humanitarian construction;

- **Research is not exclusive to the development of new building materials nor construction techniques; it also can be linked to new aways to reinforce local capacity, strengthen awareness and promotion of best practices** (e.g. development of guidelines on how to best use a newly developed, more sustainable material; the development of a more interactive training on a more adequate construction technique to the needs identified, the adaptation of a methodology or tools to (eg. promotion of modularity, simpler assemblage, local production capacity, the use of tools such as DPPs to take better material decisions and ensure its traceability, etc.);

- **Research needs proper planning and to account monitoring and evaluation both in its budgets and calendar of activities**, to ensure a more seamless implementation, avoid overburdening teams and make sure promising findings are properly communicated and shared as best practices with those involved and wide sector, aiming at the biggest positive impact of the resources allocated to those efforts.

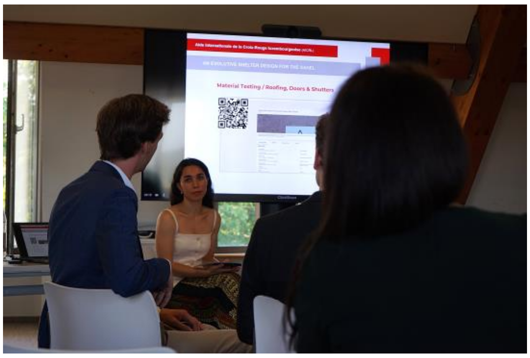


Fig 40, 41, 42, 43, 44, 45 and 46 – Several photos of the final communication of results' events, in Luxembourg, July 2025.

C. Lessons Learnt & Recommendations

6. End of Project Key Findings & Results

6.1. Key Lessons Learnt and Results Achieved

Upon conclusion of this project and having analysed its achievements, the main lessons learnt can be summed up in the following points:

- **The evolutive prototype designed and tested within the framework of this project proved to be a model that adapts well to the climatic and socio-economic context and population it was aimed at, and could potentially be promoted as a solution to implement on a larger scale.** After analysing the data collected during the various monitoring and evaluation activities conducted throughout the entire project lifecycle, it is possible to conclude that the prototype outperforms existing models *(see 3.1 – Qualitative Monitoring & Evaluation (M&E): Comparison with Baseline)* and best addresses the self-reported needs and preferences expressed by the targeted population *(see 4.6 – Questionnaire / Key Informant Interviews (KIIs) with Refugees and the Local Community, Mission Report – "Evolutive Shelter Prototype: From Emergency to Development")*. Its implementation at a larger scale, as a context-sensitive shelter model for the crisis in the Sahelian region, could be confidently considered.

- **The evolutive prototype designed and tested within the framework of this project proved to perform better in terms of environmental impact and public health co-benefits than models already in use, while matching them cost-wise.** In addition to the advantages mentioned above, the tested model also proved to have a lower environmental impact. While a thorough Life Cycle Assessment (LCA) was not conducted, preliminary observations—such as the substantial reduction in wood use (approximately 50%), decreased concrete consumption, and the prioritization of bio-sourced materials over petroleum-based or high embodied carbon alternatives—clearly indicate its environmental superiority over standard models. Regarding public health, we can also infer clear benefits. Special attention was given to passive temperature control, resulting in a substantial reduction in indoor temperatures—a rough initial estimate suggests a decrease of 4°C compared to the outdoor temperature, whereas in standard models, an increase of 3–5°C was recorded *(see 3.2 – Quantitative Monitoring & Evaluation (M&E): Indoor Environmental Quality (IEQ) Metrics – Final)*. All these positive externalities and co-benefits come at no additional cost, as they primarily stem from strategic material and design choices. Moreover, the evolutive nature of the model allows for phased investment, enabling alignment with funding availability without value loss—an important feature in chronically underfunded crises such as those in the Sahel.

- **The engagement of other relevant private sector actors and academic partners, both in Luxembourg and neighbouring European countries, and their specialized contributions brought quality to the achieved outcomes and outputs and leveraged the impact of the**

mentioned research efforts. The engagement of partners from the private sector and academia - who are not often involved in humanitarian projects - was key to ensuring the quality of the results achieved and initiating discussion around key concerns related to the environmental and public health impacts of solutions currently in use in the Sahelian context. For example, the involvement of the Material Innovation Centre (MIC) enabled the testing of a bio-based, more sustainable alternative to corrugated iron sheets (CGIs), as well as the piloting of Digital Product Passports (DPPs) to better assess their potential positive impact in "greening" shelter operations globally. The innovative partnering agreements established during this project also provide a solid foundation for similar collaborations in the future, as they have proven to foster positive synergies and create win-win outcomes for all stakeholders involved.

- **The innovative building materials tested during this pilot have shown promising results and applicability to the technical challenges faced.** Both the earth techniques used for walls—as a replacement for plastic tarpaulins or partitions—and the tested SAM panels as an alternative to corrugated iron sheets for roofs, doors, and window shutters proved to be promising choices in addressing the technical challenges identified from the outset and targeted by the project. These challenges included extreme heat, flooding, and constraints linked to impoverished local markets, which guided the project to prioritize locally-sourceable, bio-based materials whenever possible. Furthermore, the various earth construction techniques tested in the final shelters—adobe, compressed earth bricks (CEBs), and fired bricks - provided additional insight into which option might be the most appropriate for the specific context of eastern Chad. This assessment considered factors such as overall cost, availability of raw materials, and the level of skilled labour required for production and assembly. Larger-scale use of earth construction techniques in shelter response in the Sahel should be envisioned to "transition" emergency solutions into more dignified ones during protractedness, as they are easy to develop locally, can foster the creation of livelihoods and collaterally present co-benefits linked to reduced environmental impact and public health prevention.

- **Digital Product Passports (DPPs) and other material disclosure / transparency documents, also tested during this pilot in a humanitarian context, might help foster better and more informed material choices, traceability, and circularity in the sector if widely adopted, at a low upfront investment.** The development of a pioneering Digital Product Passport (DPP) for the SAM panels tested in one of the final prototype shelters built in Farchana refugee camp (SAM Solid 5 – Bovine Processed Fibers (BPF) Panels) *(see 4.1 – Evaluation of SAM Panels as an Alternative for Roofing, Doors & Window Shutters)* was initially intended to support internal reflection on how we might improve our practices to foster circularity. However, it has also shown strong potential for large-scale adoption across the sector. As a tool, the DPP can support both technical and non-technical stakeholders in decision-making processes and raise awareness about the true overall impact of shelter responses.

- **This research project, which also explored generic material and design choices that better address the challenges of extreme heat, flooding, and other extreme weather events linked to climate change, produced useful solutions that can also be adapted to other geographical contexts beyond the Sahel, including Europe.** The findings compiled in this project's final report, as well as in the intermediate and mission reports produced *(see Mission Report – "Evolutive Shelter Prototype – From Emergency to Development")*, contain many lessons learnt that are transferable to other geographical contexts, including the Luxembourgish and broader European ones. These findings present relevant responses to shared challenges - namely, the need to reduce the environmental impact of construction and to better prepare the built environment to mitigate and adapt to climate change and extreme weather events, showing how they are equally relevant for all the parties involved.

D. Annexes

1. Quantitative M&E – LogTag's Reports & Graphs

HAXO-8 (1)

LogTag

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Note: Toutes les dates et heures sont en UTC +01:00

Statut des alarmes

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Alerte	✓	OK
Alerte	✓	OK
Alerte	✓	OK

Information de l'enregistreur

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Description:

Configuration de l'enregistreur

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Retard au démarrage :	Aucune	Basse : -20,0 °C après 2 consécutif	Basse : 0,0 %RH après 2 consécutif
Intervalle :	1 Heure	Hautes : 70,0 °C après 2 consécutif	Hautes : 100,0 %RH après 2 consécutif
Indicateur d'alerte :	Inférieur et supérieur activé		
Indicateur OK :	Activé		

Données enregistrées

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Dernière mesure :	14-mai-25 09:46:46	La plus basse :	26,8 °C	La plus basse :	2,0 %RH
Temps écoulé :	7 Jours	@	08-mai-25 05:46:46	@	11-mai-25 14:46:46
Lecture totale :	168	La plus haute :	40,9 °C	La plus haute :	20,5 %RH
Première évaluation :	07-mai-25 10:46:46	@	12-mai-25 14:46:46	@	07-mai-25 10:46:46
Dernière évaluation :	14-mai-25 09:46:46	Valeur moyenne:	34,2 °C	Valeur moyenne:	7,6 %RH
Heure d'évaluation :	7 Jours	Ecart type:	3,7 °C(S)	Ecart type:	2,4 %RH(S)
Evaluation des données :	168	MKT(ΔH 83,144):	34,9 °C		

Alarme la plus basse

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Occurrences :	0

Alarme la plus haute

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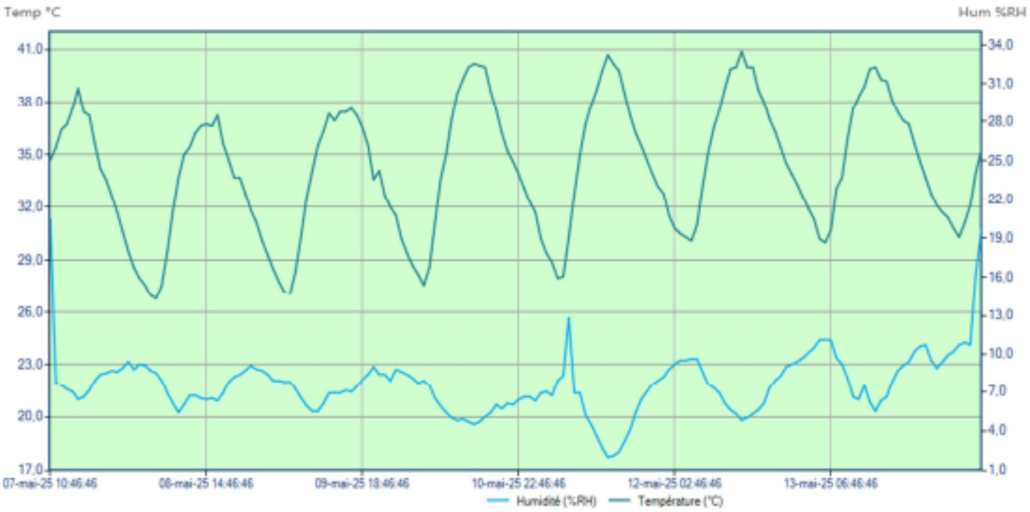

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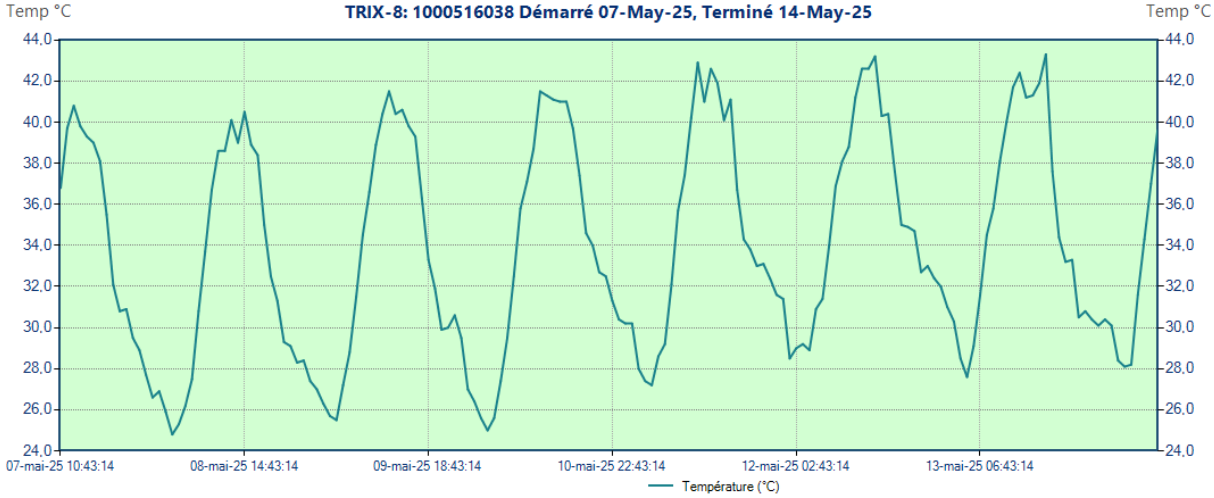

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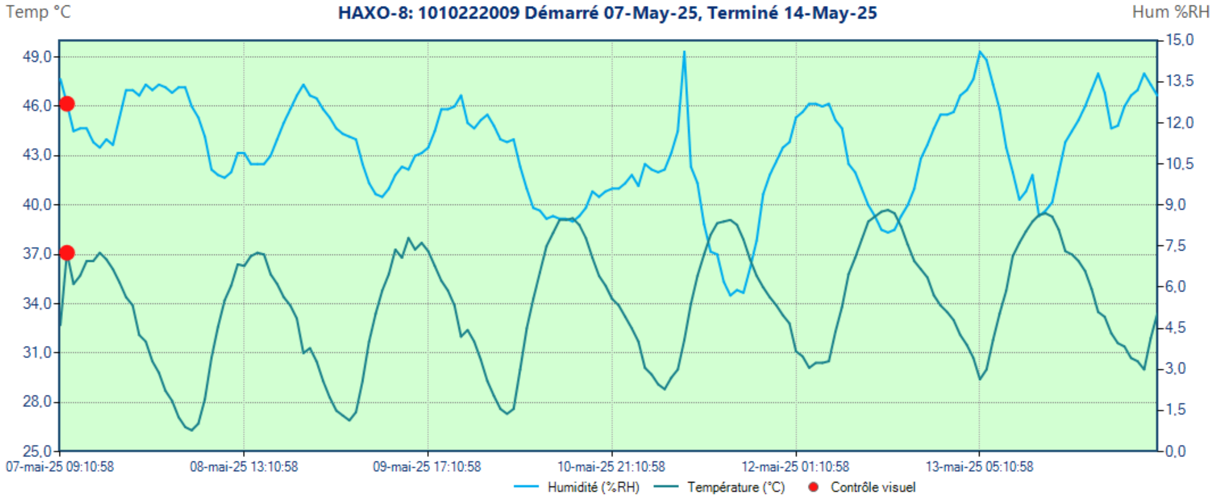

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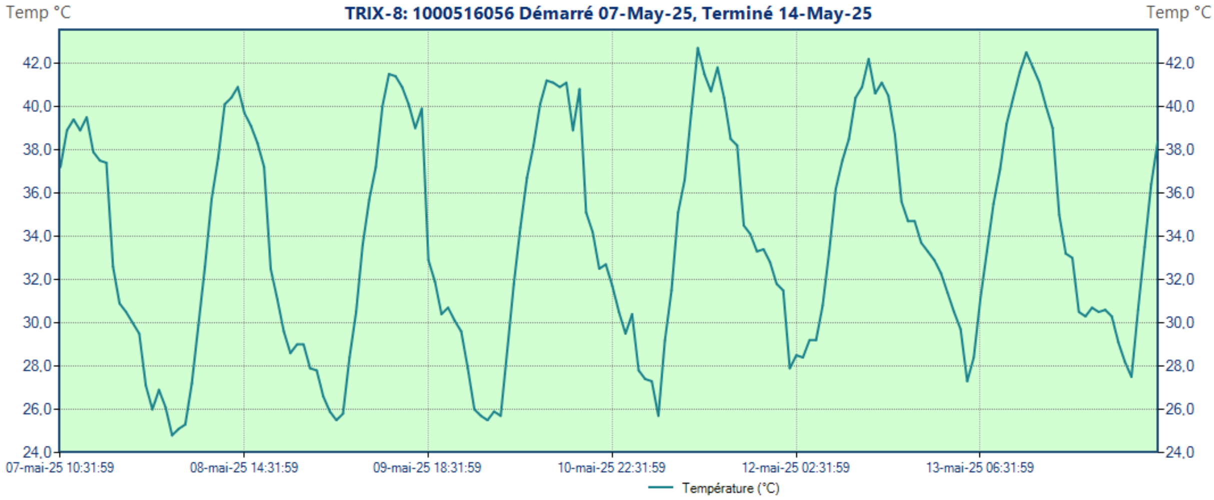

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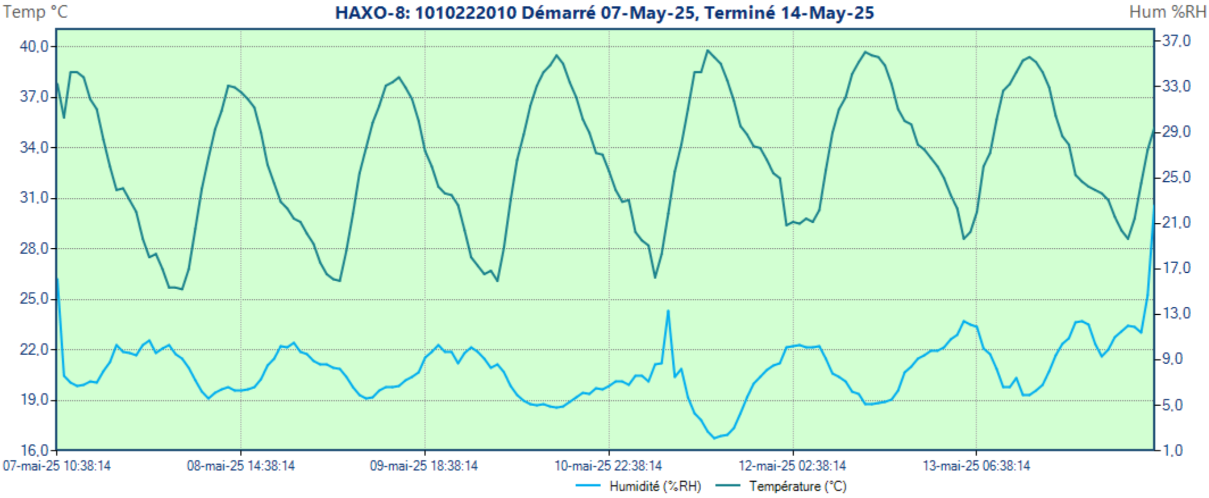

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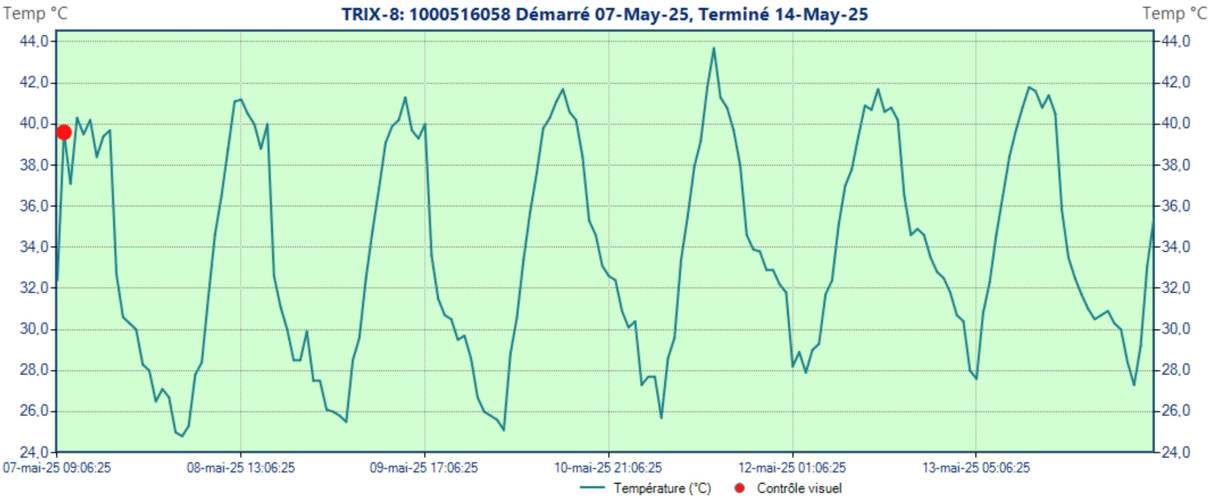

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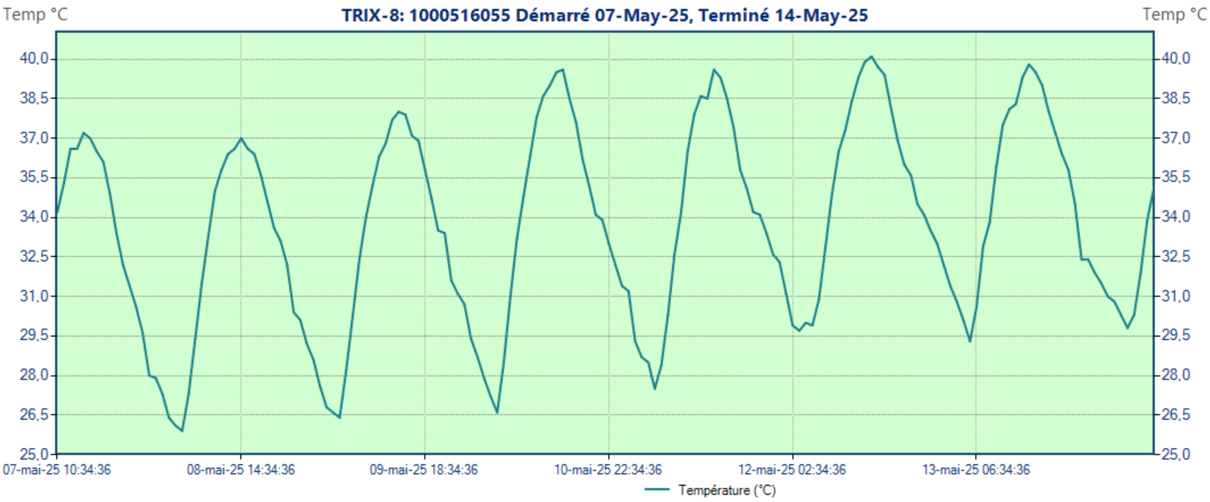

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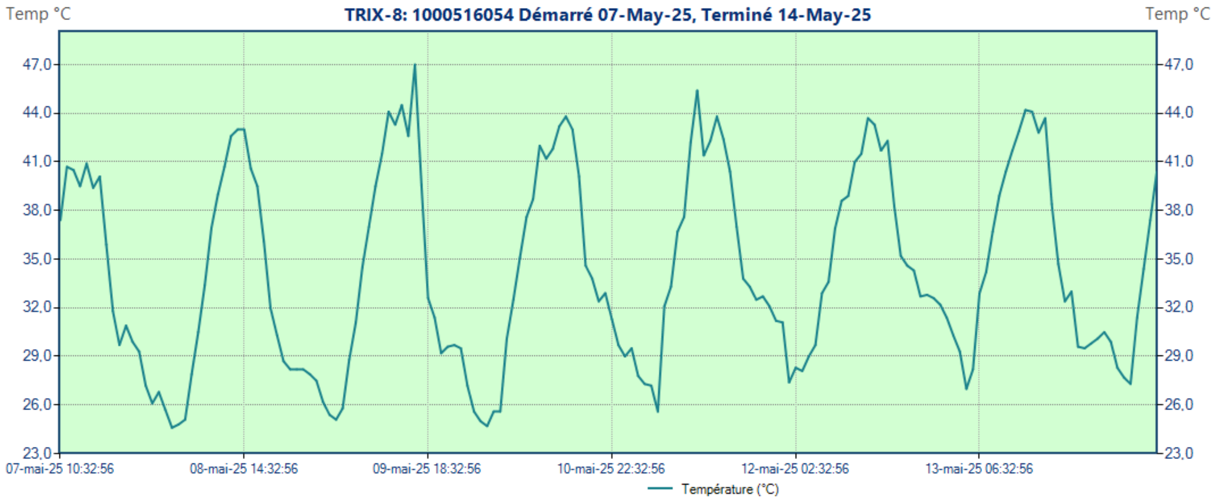
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