LIVING SELF-UPGRADING SHELTER: A BIODESIGN APPROACH FOR FUTURE OF SUSTAINABLE DISASTER RELIEF

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Abstract

This research investigates the application of the proposed "Living Self-TransForming Disaster Relief shelter" (LTF DR-shelter) approach to provide sustainable self-upgrading post-disaster shelters. When disaster hits in countries where beneficiaries have limited access to resources, (i.e., construction material, labour, financial support) quickly, existing post-disaster shelter approaches frequently lead to economically and environmentally unsustainable implemented solutions that fail to meet the needs of those seeking shelter. Solutions are therefore needed to provide new and innovative approaches to providing disaster relief.

Intriguingly, looking forward, emerging Living Technology offers the potential for existing and future Engineered Living Materials to provide novel approaches to providing disaster relief. Such living materials, in which growth is incremental, self-upgrading and utilises living transformation mechanisms, whereby shelters could be grown on-site with living materials that offer features such as self-assembly, self-repair, resilience, etc. promising cost and energy-efficiency, and being environmentally friendly in the next 50 years. Through this future vision, the research explores the success factors of the conceptual approach of the self-upgrading LTF DR-shelter. The LTF DR-shelter concept proposed employs Biodesign and living technology potentials to envision integrating the separate emergency and temporary shelter into one initial ten-kit (living-textile). It self-transforms into a monolithic self-sustaining structure on-site while beneficiaries reside in it with disassembly and reassembly features for relocation.

Furthermore, contrary to conventional design approaches that use materials already developed, the emerging Biodesign methods initiate the material and shelter design simultaneously and even co-designing with microorganisms. Moreover, the applicable biocomposite for LTF DR-shelter is visioned to be designed in the future (next 10-50 years). Hence, while multiple studies are investigating Biodesign methods and DR-shelters separately, there is a dearth of research regarding applying living materials in DR-shelters through Biodesign. Therefore, to address this knowledge gap, this research aims to envision potential future alternative success factors, and challenges of LTF Dr-shelter Biodesign.

Keywords

Future, Shelter, Living material, Self-upgrade, Disaster-relief.

1 Introduction

Disasters occur frequently worldwide, causing significant damage to people's lives and displace millions of people every year, leaving them without adequate shelter, food, and basic necessities [1]. As sustainable architects, we are acutely aware of the urgent need for innovative and sustainable solutions for post-disaster shelter. The current approaches to post-disaster shelter solutions are often focused on providing quick, temporary shelter using conventional materials, such as plastic or metal. However, often, disaster-hit countries and communities have limited access to resources such as construction materials, labor, and financial support [2]. As a result, existing post-disaster shelter approaches frequently lead to economically and environmentally unsustainable solutions that fail to meet the needs of those seeking shelter [3]

Hence, there is a need for new, innovative approaches to provide sustainable, long-lasting satisfactory shelter solutions in disaster-stricken regions. Fortunately, emerging technologies such as living materials and biodesign offer the potential for novel approaches to disaster relief. One such approach is the Living Self-Transforming Disaster Relief Shelter (LTF DR-shelter) [4], which utilises biodesign and living technology to create a self-upgrading shelter that can be grown on-site with living materials. This innovative shelter has the potential to be cost and energy-efficient, environmentally friendly, and easily adaptable to the specific needs of disaster-stricken communities.

The application of living technology and biodesign in architecture provides a promising opportunity for the development of sustainable post-disaster shelters. Engineered living materials have potentials to be designed to have self-assembly, self-repair, and resilience features, which can provide a cost-effective, environmentally friendly, and self-upgrading alternative to conventional building materials [5]. The proposed LTF DR-shelter approach utilises the potential of biodesign and living technology to integrate emergency and temporary shelters into one initial ten-kit that self-transforms into a monolithic self-sustaining structure on-site with disassembly and reassembly features for relocation. This approach could potentially provide an effective and sustainable solution to disaster relief challenges.

While there is a growing body of research on biodesign and disaster relief shelters, there is a lack of research on the application of living materials to disaster relief shelter through biodesign. To address this knowledge gap, this paper explores the conceptual approach of the LTF DR-shelter, which envisions the potential of living materials in the next 50 years. The research aims to envision potential future alternative success factors, challenges, and ethical concerns of LTF DR-shelter biodesign. This paper contributes to the understanding of the integration of living technology and biodesign in disaster relief, offering a new perspective on the sustainable development of post-disaster shelters. By exploring the potential of living materials and self-upgrading technology, this research offers a promising vision for the future of disaster relief shelters. This future vision is a proactive approach fascilitating co-biodesign between interdisciplinary experts, hence, accelerating the successful living technologies application in disaster relief.

2 Literature review

2.1 Biodesign in architecture

Biodesign in architecture is a rapidly growing area of research that combines biology, design, and engineering principles to create sustainable and innovative solutions in the built environment. One of the key focuses of biodesign in architecture is the development of living materials and textiles that are capable of self-regeneration, growth, and adaptation to their environment [6]. These materials have the potential to transform the way buildings are constructed, offering greater sustainability, efficiency, and resilience to natural disasters. The goal of the living construction vision, according to Hub for Biotechnology and the Built Environment (HBBE) [7], is "to develop a new generation of living structures that are sensitive to their surroundings, grown with living engineered materials to replace inefficient industrial construction methods, metabolise their own waste to reduce pollution, produce high-value products and energy, and control their microbiomes to promote the health and wellbeing of both people and the environment".

Such future visions and the consequent architectural speculations offer the What and sometimes Why, but the How lies within the field of synthetic biology fascilitating creating engineering living materials that has gained significant attention in recent years. By thinking of materials not as matter to be harvested after the death of the organism which created them but by controlling the process of material creation while the organism is alive, synthetic biology offers an opportunity in which we might begin to harness a much greater range of biological materials, many of which do not yet exist [8]. Such living materials can be engineered to gain the ability to self-heal, respond to changes in the environment, and regenerate damaged parts [9]. One example of engineered living materials applied in living construction is self-healing concrete, which is embedded with bacteria that produce calcium carbonate when activated by moisture. This process helps to repair cracks in the concrete, extending its lifespan and reducing the need for maintenance [10]. Some examples of recent non-engineered living materials already applied in architecture already are shown in Figure 1 including Mycelium (the vegetative part of fungi) and Bacterial Cellulose. Overall, Biodesign application in architecture has initiated, representing a promising avenue for future emerging sustainable and innovative design solutions.

Figure 1. Hy-Fi Tower- Mycelium-bricks (left), Growing Pavilion Mycelium-panels (middle), Aguahoja Biopolymer Pavilion- Bacterial cellulose (right)

Some novel Biodesign solutions are the development of living textiles incorporated with mycelium and engineered living materials, with the potential to revolutionise how buildings are constructed and maintained, offering greater sustainability and resilience to natural disasters and beneficial in such contexts. Living textile architecture is a field of Biodesign that explores the use of living materials and textiles in architecture. These materials are typically made from living organisms such as bacteria and fungi and are designed to perform specific functions within the built environment [11]. One example of living textile architecture is using mycelium, the vegetative part of a fungus, as a building material. Mycelium can be grown into various shapes and sizes and has been used to create everything from furniture to building panels.

One of the most recent novel examples of living textile architecture is BioKnit Prototype. BioKnit is a project by a team of designers and scientists from the HBBE that explores using 3D knitted fabric structurally at the architectural scale. The prototype is a monolithic, free-standing biohybrid structure made of mycelium, bacterial cellulose, and 3D knitting (knitted from wool and linen) and was not grown in the lab but in "The OME," an experimental test bed in Newcastle. The materials used have a lower environmental impact than conventional construction materials, making it a sustainable and innovative approach to building with living textiles (Figure 2) [12].

Figure 2. BioKnit Prototype, biofabrication and construction process [12].

Recent research in Biodesign in architecture has shown promising results for developing sustainable and innovative building materials. Living materials and textiles have the potential to transform the way buildings are designed, constructed, and maintained, offering greater sustainability, efficiency, and resilience to natural disasters and the design of emergency shelters (tents-kits). However, further research is needed to fully understand the properties and limitations of these materials through experiments and prototyping and to develop scalable and cost-effective production methods.

2.2 Disaster-relief shelters

In the aftermath of natural disasters, providing shelter is a critical aspect of emergency response efforts. Affected populations in post-disaster contexts tend to move between different settlement options [13]. However, in this research target population is nonlocally displaced affected populations after a natural hazard-induced disaster living in a grouped settlement in tents (planned camp). The provision of shelter has traditionally been divided into three main phases: relief, rehabilitation, and reconstruction [14]. During the relief phase, emergency shelters such as tents are typically provided to those affected by the disaster to provide immediate and temporary accommodation until more durable solutions can be found. The rehabilitation phase involves the provision of more durable temporary shelters that can last for several months up to two years, while the reconstruction phase involves rebuilding permanent housing for those affected by the disaster.

One approach to sustainable post-disaster sheltering is transitional shelter (TS) approach, which involve incrementally upgrading existing emergency shelters to more durable temporary shelters by reusing materials or incremental external resource allocation. However, the rush to provide shelter and the subsequent delays in the process have often led to low-quality shelter and reconstruction efforts. Furthermore, the reuse of materials for the next phase is often done with inevitable degraded quality, leading to additional costs and a lack of sustainability in the long run [15]. (Figure 3).

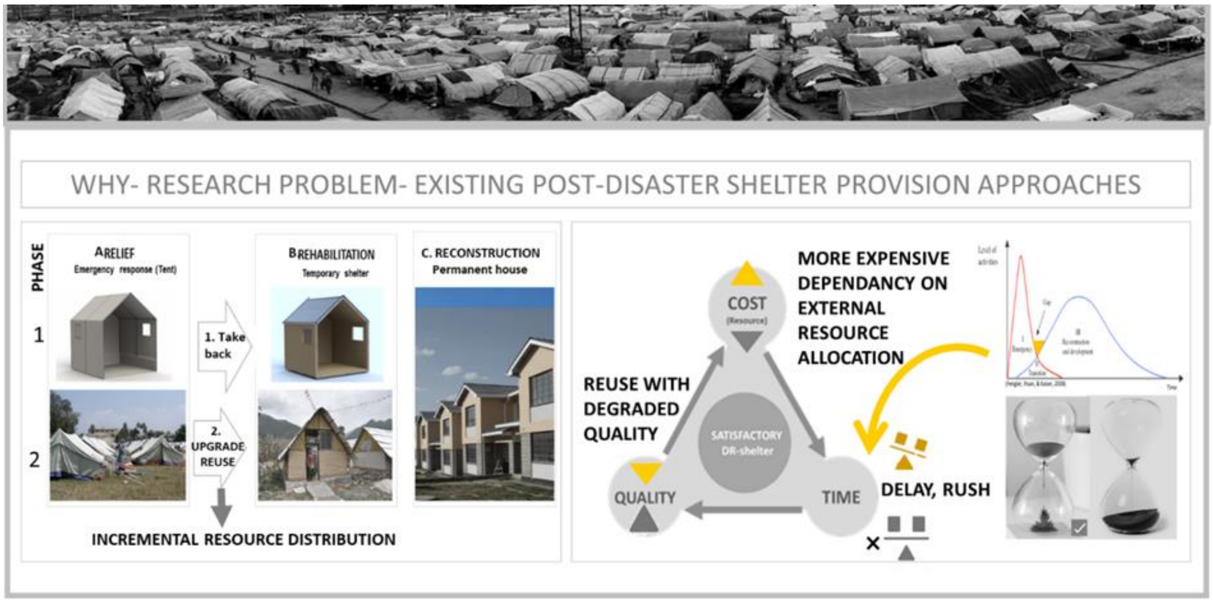

Figure 3. Research Problem in existing post-disaster shelter approaches

Dependency on external resources is another major challenge in sustainable post-disaster sheltering. External cash and material allocations are often required to provide adequate shelter upgrades. Various factors can affect this dependency, including difficulty in accessing the location, limited budgets and resources, and pre-existing or disaster-related lack of infrastructure [13]. In some cases, the cost of providing Transitional shelter can be up to three times more than that of permanent housing reconstruction, highlighting the need for more sustainable and cost-effective solutions [16].

Furthermore, according to [17], supporting shelter self-recovery is encouraged to promote equitable support for all affected populations and facilitate participation; the survivor-led process of recovering adequate living conditions and re-establishing a sense of home is what [17] refers to as self-recovery. Using living materials and technologies is one innovative approach to facilitate self-recovery through sustainable post-disaster sheltering. For example, living textiles are incorporated with engineered living organisms, such as bacteria or fungi, to create on-demand functional living materials that adapt to changing environmental conditions [18].

In summary, sustainable post-disaster sheltering requires a holistic and innovative approach considering the unique challenges of providing shelter in emergencies and post-disaster contexts. Through the use of transitional shelters, sustainable characteristics, living materials and technologies, and a focus on cost-effective and sustainable solutions, it may be possible to improve the quality and long-term sustainability and, accordingly user satisfaction rate of post-disaster sheltering efforts.

3 Methodology

The LTF DR-shelter concept relies on the Technology Readiness Level (TRL) of ELMs (Figure 4). Overall, living materials' TRL is now at level one, two, or three [10], with the anticipation of the next 20-50 years improving to higher levels. Hence methodology adopted for this study involves future forecasting and strategic foresight combined with the Biodesign approach to design. The design process was divided into *Ideation, Validation,* and *Application*.

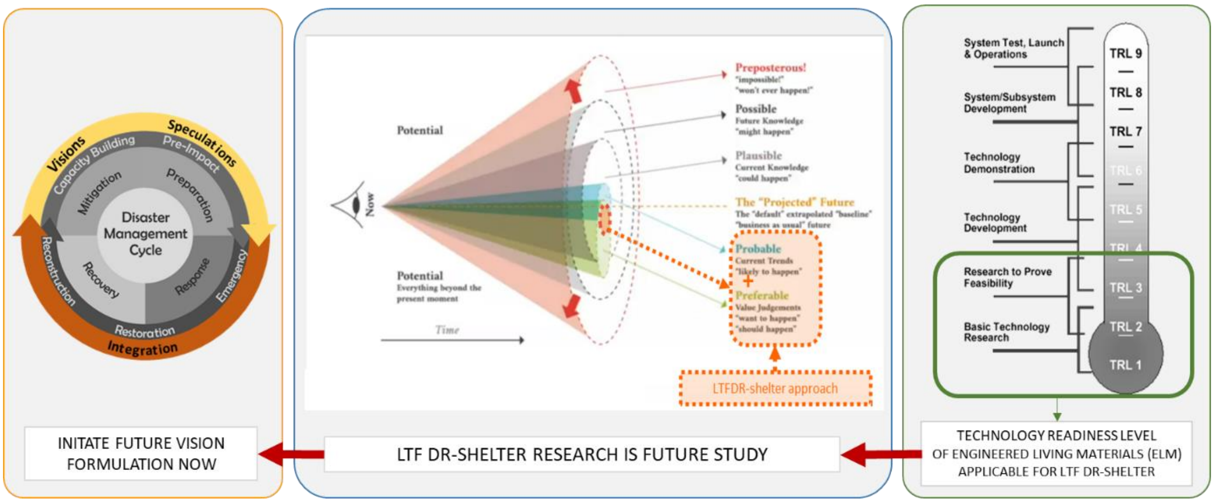

Figure 4. Research Design based on TRL of ELMs

The Ideation phase involved formulating alternative future preferred visions of LTF DR-shelter success factors based on the findings of a SWOT analysis of the literature for existing post-disaster shelters and the opportunities presented by living technology, Biodesign, and living textiles. This phase resulted in developing a framework for the future preferred success factors of LTF DR-shelters.

The Validation phase involved conducting a workshop with eight interdisciplinary experts, including two participants from each expertise, including post-disaster shelter, industrial, living material, and living architecture Biodesign. The purpose of this phase was to validate the framework developed in the Ideation phase and make necessary modifications. In addition, visual speculations of the future LTF DR-shelters were developed using AI tools such as Midjourney.

This methodology aligns with the current trend in architecture and Biodesign, which emphasises the need for sustainable and innovative solutions to address societal challenges such as natural disasters and climate change. Adopting a Biodesign approach in this study provides a new perspective on the design of disaster relief shelters, emphasising the use of living materials and technology to create sustainable and self-adaptable solutions.

4 Results and Discussion

This section presents the research findings, categorised into three themes: *Time, Quality*, and *Cost* related Success Factors. Based on these themes, the user and technology success factor visions are formulated and further divided into two sub-categories: project and product-level visions. The product level visions are categorised into Shelter, Material, and Microorganism Biodesign, with LTF DR-Shelter focusing on Architectural Biodesign, living material Biodesign, and Microbial Biodesign. This approach enables a comprehensive understanding of the various factors contributing to the success of LTF DR-project, including innovative materials, organism design, and engineered living materials with programmable functions.

4.1 Time-related Success Factor visions

The findings from the workshop discussion revealed that time is a crucial factor for the success of LTF DR-shelter implementation. The time-related success factors were classified into two main categories, namely, user and technology. For user-related success, the workshop participants highlighted the importance of cohabiting with the living shelter throughout its growth process. This factor is critical in facilitating the desired integration of relief, rehabilitation, and reconstruction phases in a new way that decreases the workload required for material fabrication and shelter upgrade compared to existing approaches due to shelter and material's natural growth over time (Figure 5). It was also noted that trauma and the need for resilience building should be considered, and the acceptance of the shelter solution and its benefits in relation to other alternatives are key factors for success.

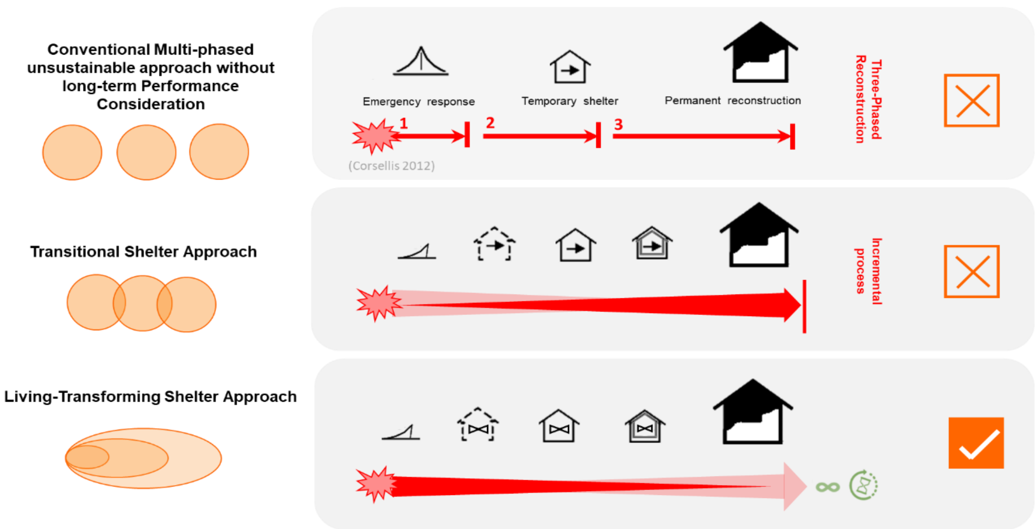

Figure 5. *Integration* of post-disaster shelter phases; A comparison of between LTF DR-shelter vision and existing approaches

The literature supports the importance of time in post-disaster sheltering. Studies have shown that providing temporary shelter in a timely and efficient manner can help alleviate displacement's negative impacts on affected populations [19]. Additionally, the literature emphasises the importance of user-centred approaches in post-disaster sheltering to ensure that the needs and preferences of affected populations are considered [20].

Regarding technology-related success factors, the workshop participants highlighted the importance of biofabrication and architectural Biodesign, living material Biodesign, and microbial Biodesign. These factors are critical in facilitating the self-upgrading of the living shelter and making it more sustainable and acceptable as a new space by the occupants. However, the challenge here is the time that this requires, and the nature of the self-upgrading living shelter will mean that ideally, over time, the shelters will get more durable and more suitable for the occupants growing needs through post-disaster phases.

The challenges identified by the workshop participants were mainly related to the length of stay, person-to-person variation, and the resources required for care activities. These challenges should be considered in designing and implementing LTF DR-shelter to ensure they are user-centred and meet the growing needs of affected populations at all stages.

In conclusion, time is a crucial factor for the success of LTF DR-shelter implementation. The workshop findings highlighted the importance of user-centered approaches and innovative technologies such as biofabrication and biodesign in ensuring the shelter's success. The challenges identified should be considered in the design and implementation of LTF DR-shelter to ensure that they are user-centred and meet the needs of affected populations.

4.2 Quality-related Success Factor visions

The workshop discussions revealed that quality is crucial in designing and implementing post-disaster shelters. The participants suggested that the success of the LTF DR-shelter would depend on the implementation of quality self-adaptation on-site, which includes self-management and self-recovery. User involvement and agency were emphasised as necessary for increasing the users' sense of belonging, satisfaction, and mental health. The findings suggest that user-centric approaches, such as participatory design and co-creation, should be considered to facilitate user involvement and ownership. The participants also highlighted the importance of technological aspects, such as structural stability, self-optimisation, and biotechnology solutions, in ensuring the quality of post-disaster shelters. The maintenance of LTFDR-shelters would be perceived in the middle of classical materials maintenance and gardening activities, suggesting that the shelter's design should consider the users' daily activities and lifestyles. The participants also identified some materials, such as bio-silicon, bacterial cellulose, and mycelium, which have potential for genetic manipulation and self-optimisation in terms of shelter properties. In conclusion, the thematic analysis of the workshop discussions suggests that the quality of post-disaster shelters depends on user involvement, agency, ownership, and technological aspects such as structural stability, self-optimisation, and biotechnology solutions.

4.3 Cost-related Success Factor visions

The thematic category of findings from the workshop discussion on the cost considerations for implementing the LTFDR-shelter concept revealed four key themes. The first theme, dependence on external support, emphasises the need to reduce reliance on external resources for successful implementation. This finding is consistent with the research problem that identified existing approaches as expensive and dependent on external resource allocation for upgrades. The second theme, efficiency and cost reduction, highlights the potential for LTFDR-shelters to eliminate inefficient shelter construction processes and associated costs. This finding aligns with the user cost-related preferred success factor vision related to cost, which emphasises less dependency on external resource allocation and less required incremental cash and material distribution for upgrades (Figure 6).

The third theme, circular economy and biomaterials, supports the formulated preferred and likely cost-related future success factor vision for the LTF DR-shelter, which includes using on-site local and grown materials. The use of biomaterials and a circular waste economy could contribute to reducing costs and improving sustainability [21]. However, it was noted that this would require significant pre-planning and setup and could potentially compete for resources in the local economy.

The fourth theme, DNA modification, aligns with the main success factor to contribute to the preferred success factor vision, which is material on-site biofabrication. DNA modification may become more accessible and cost-effective in the next 50 years and could lead to the development of new materials and building systems. However, it was noted that some level of expertise would still be required to fully utilise this technology, highlighting the significance of associated training provision.

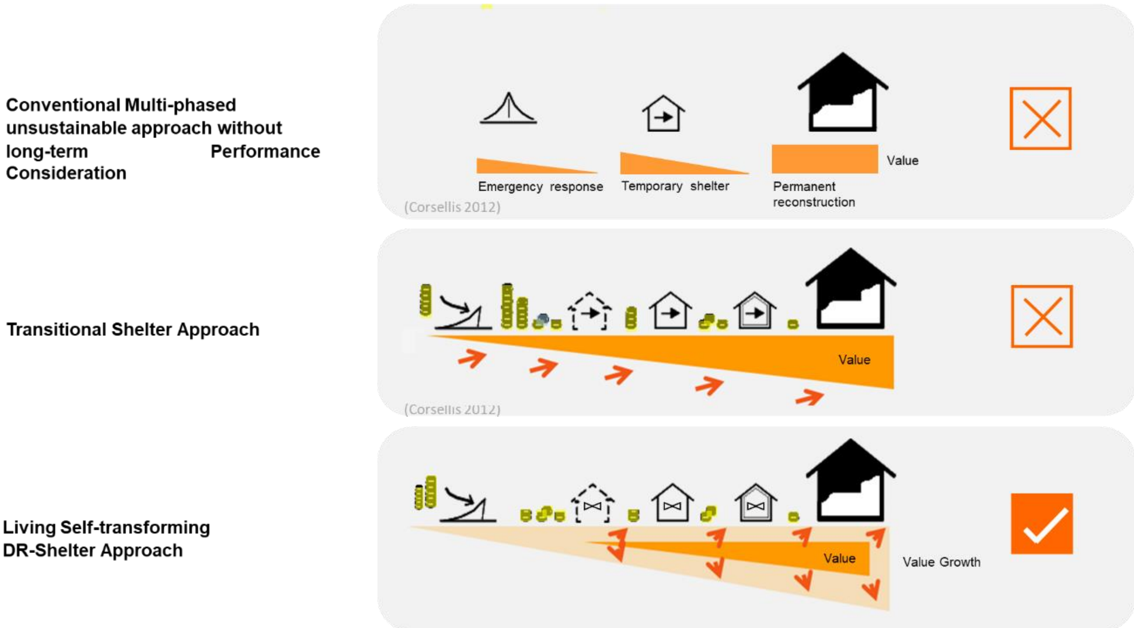

Figure 6. Shelter-related resource (Cash, Material) distribution strategies of existing post-disaster shelter approaches in comparison to LTF DR-shelter vision for values proposition and resource self-development with decrease in required distribution.

Overall, the primary data suggests that the successful implementation of LTF DR-shelters in the real world will depend on careful consideration of the costs and challenges related to both the user and technology aspects, along with a focus on reducing dependence on external support, increasing efficiency, and exploring innovative solutions such as circular waste economies and DNA modification of the microorganism that provides the on demand specification for the proper ELMs. The proposed preferred and likely cost-related future success factor vision for the LTF DR-shelter, which includes on-site local and grown materials, aligns with the third theme of circular economy and biomaterials [21]. To facilitate this, the shelter should generate free additional quantities of material to help with livelihood on-site. This approach's success depends on the level of DNA modification cost and accessibility, which aligns with the fourth theme of DNA modification. Future research could focus on developing sustainable and affordable building materials and exploring new technologies to reduce costs and improve the sustainability of LTF DR-shelters.

Overall, Biodesigning LTF DR-shelter while considering the significance and impact of the success factors mentioned above not only facilitates the balanced relationship between them to tackling the associated problems in the disaster relief shelter provision but also enables thriving through quality upgrade and transformation independent of external support towards more sustainability (Figure 7).

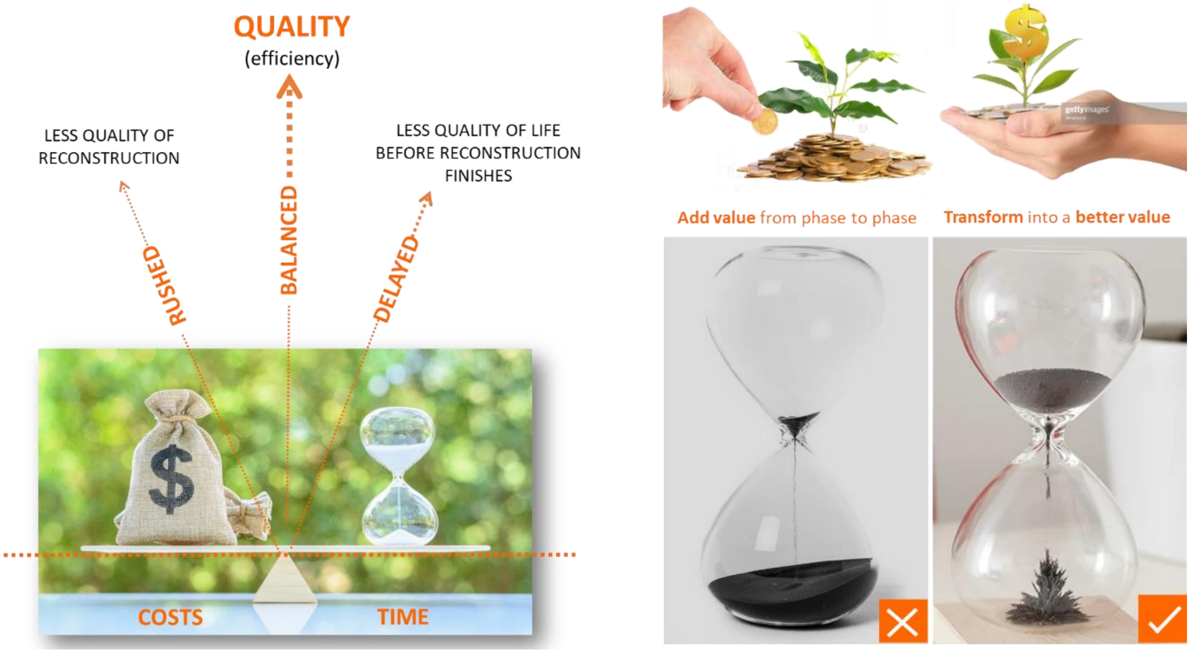

Figure 7. The significance of balance between LTF DR-shelter success factors *Time, Quality, Cost* to tackle existing problems through Biodesign and consequent LTF DR-shelter philosophy of thrive vs survive.

4.4 LTF DR-shelter Visions and Speculations

Finally, the LTF DR-shelters' vision was devised, signifying its main characteristics and alternative future visual speculations (Figure 8). This vision is based on five main characteristics of the Transitional-shelter (TS) approach: reuse, upgrade, relocate, recycle, and resell. The engineered living materials'(ELMs) existing and future potentials, on the other hand, provide the "How" to deliver TS characteristics in a novel way that would elevate the post-disaster philosophy from SURVIVE to THRIVE and encourage more self-recovery going beyond sustainability. Figure 9 is a conceptual illustration of how the Elms' potentials can be utilised to enhance one specification of shelter namely insulation. It signifies the importance of context-specific specifications, e.g., climate-related shelter Bidesign speculations and initiation with local experts that should take place in the preparation phase of the post-disaster management cycle.

Figure 8. LTF DR-shelters' vision, signifying its main characteristics and alternative future visual speculations.

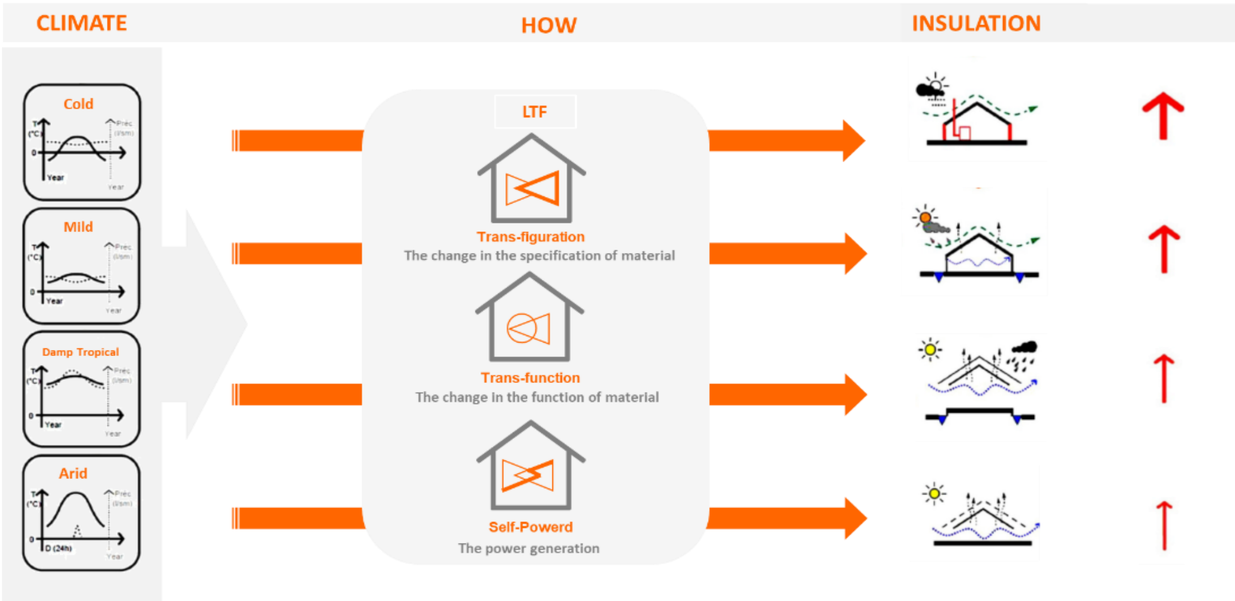

Figure 9. Conceptual illustration of how the Elms' potentials can be utilised to enhance one specification of shelter namely insulation.

5 Conclusion

In conclusion, disasters leave millions of people displaced and in need of adequate shelter, food, and basic necessities. However, the current approaches to post-disaster shelter design solutions often lead to economically and environmentally unsustainable solutions. This paper explores the conceptual approach of the Living Self-Transforming Disaster Relief Shelter (LTF DR-shelter) that utilises Biodesign and living technology to create a self-upgrading shelter that can be grown on-site with living materials. The methodology adopted for this study involved future forecasting and strategic foresight combined with the Biodesign approach to design. The results indicate that time, quality, and cost-related success factors are crucial for the success of LTF DR-shelter implementation. Future research in this field should focus on the development of living materials with self-assembly, self-repair, and resilience features, which can provide a cost-effective, environmentally friendly, and self-upgrading alternative to conventional building materials. The LTF DR-shelter approach offers a promising vision for the future of disaster relief shelters, and its successful implementation requires co-biodesign between interdisciplinary experts, accelerating the successful living technologies application in disaster relief.

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