Living-Transforming Disaster Relief Shelter: A Conceptual Approach for Sustainable Post-Disaster Housing

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Abstract

Purpose – The purpose of this paper is to investigate the performance of post-disaster housing reconstruction projects, propose the conceptual Living-transforming disaster relief shelter (LTFDR-shelter) approach where temporary shelter is incrementally transformed into a more permanent dwelling by using living technologies, and investigate its applicability to provide sustainable post-disaster housing following natural-hazard-induced disasters.

Design/methodology/approach – A questionnaire survey with 120 household recipients of three Sri Lankan post-disaster housing projects was employed to explore how the post-disaster housing projects have performed against the occupants' expectations. Furthermore, the new proposed LTFDR-shelter conceptual approach's applicability to address the existing issues found in the study was investigated.

Findings – The paper evaluates and identifies the physical and technical, and socio-economic performance issues of post-disaster housing and discusses the applicability of the proposed LTFDR-shelter conceptual approach as an efficient tool to adequately improve the identified factors integrating three phases of relief, rehabilitation, and reconstruction employing living technology.

Research limitations/implications – Although the study's scope was limited to the occupant view of the performance of post-disaster housing in Sri Lanka, the findings and conceptual LTFDR-shelter approach could be of particular relevance to other developing countries affected by similar disasters. Further research is recommended to investigate and develop this concept in depth.

Originality/value – This study lays the conceptual foundation for a new theoretical approach in post-disaster housing, which encourages more interdisciplinary collaborations and empirical investigations that potentially enhance post-disaster housing performance and facilitates the application of living technology in the built environment.

Keywords– Housing, Performance, Post-disaster, Transform, Living technology

Paper type – Research paper

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1. Introduction

Housing reconstruction following a disaster situation is often inefficiently managed, uncoordinated, slowly initiated, and tends to overlook the affected community's long-term requirements (Lloyd-Jones, 2006). Since natural-hazard-induced disaster events often cause widespread property destruction, extensive reconstruction initiatives are required. Notably, throughout rapid-onset events, housing is usually the most extensively damaged or lost element and often represents the highest share of loss in the total impact on the national economy (Ahmed, 2011). For example, the Boxing Day tsunami in 2004 that affected many Asian countries wiped out more than 100,000 houses in Sri Lanka alone, requiring new houses to be built to accommodate those affected. In 2013, typhoon Haiyan destroyed 550,000 houses and an additional 580,000 houses were severely damaged in the Philippines (DEC, 2013). For housing providers, including local and central government, post-disaster housing is a politically sensitive subject requiring extensive funding. Under such extreme conditions, performance and occupants' satisfaction are often overlooked by policymakers, practitioners, funding bodies. For example, Ingirige, et al. (2008) discussed how the post-tsunami reconstruction work in Sri Lanka concentrated more on short-term solutions than on longer-term due to the various challenges. While multiple studies have investigated how post-disaster housing initiatives have performed during the planning, construction and initial occupation stages, there is a dearth of research investigating how these projects have performed in the long-term. Hence, the overall aim of the research was to investigate the performance of post-disaster housing reconstruction projects.

Addressing the above aim, the primary research objectives that form the background to this paper were: to investigate the requirements and expectations of the post-disaster housing projects' occupants, to explore how these projects have performed against the requirements of the occupants. Building on these, the remaining objectives of this paper were to review the living technology's applications in the built environment, to propose the conceptual LTFDR-shelter approach based on literature review, and ultimately to investigate the applicability of LTFDR-shelter concept to address the existing issues found in the primary research. The study focuses on post-disaster housing in Sri Lanka, a country frequently affected by natural hazard-induced disasters and requires post-disaster housing to be provided to those affected. Based on the research findings on post-disaster housing performance, limitations of current post-disaster housing are identified. These findings are then discussed concerning the new conceptual LTFDR-shelter approach proposed in section 2.4 to tackle the post-disaster housing issues found in the case study research, potentially enhancing post-disaster reconstruction performance and facilitating the application of living technology concept in the built environment. The study focuses on situations where the disaster-affected are provided with a new home, either via the donor-driven or owner-driven approach, within a post-disaster housing scheme. It is envisaged that this new conceptual approach will help deliver successful post-disaster housing by integrating recovery, rehabilitation, and reconstruction. In this integrated process, accommodations in each phase add value to the next phase and even transform into a more quality one deploying living material.

The rest of the paper is organised as follows. First, it includes a review of current post-disaster housing knowledge, particularly the key performance indicators used to assess post-disaster housing performance and the Sri Lankan context. Then a literature review of living technology in the built environment is presented. Subsequently, section 2.4 proposes the new LTFDR-shelter conceptual approach based on the literature review to employ living technology in the post-disaster context. Next, the primary research method is detailed. The research findings and analysis are then described, followed by a discussion that indicates how the proposed LTFDR-shelter could address issues found in research findings and, ultimately, the conclusion.

2. Literature review

2.1 Post-disaster shelter/housing categories

There are various post-disaster shelter solutions available. Individuals tend to move between them before going back to their previous permanent residencies, upgrading shelters to permanent houses, or building new houses. They can be divided into four categories: emergency shelters, temporary shelters, temporary housing, and permanent housing (Félix et al., 2013, Johnson, 2007a, Johnson, 2007b, Johnson et al., 2006, Quarantelli, 1995, Wu and Lindell, 2004). However, the International Federation of the Red Cross and Red Crescent Societies (2013) have included transitional shelter (abbreviated as T-shelter), progressive shelters, and core shelters/one-room shelters.

While the emergency shelter is intended to be used for a single night to a few days to deliver life-saving support and is the most basic kind of shelter support (IFRC/RCS, 2013), a temporary shelter is a simple tent or a public mass shelter used for a longer time up to a few weeks following a disaster. Temporary housing, on the other hand, such as rental houses and prefabricated units, are often distributed for a long-term duration such as six months to three years (Félix et al., 2013, Johnson, 2007a, Johnson, 2007b, Johnson et al., 2006, Quarantelli, 1995, Wu and Lindell, 2004). International Federation of the Red Cross and Red Crescent Societies (2013) indicates that progressive shelter is designed and built to be more permanent and upgradeable in the future through alterable structural components (IFRC/RCS, 2013). Similarly, core shelters/one-room shelter is intended to be permanent housing in the future, including a foundation and all or some of the key services, such as plumbing and various utilities (Corsellis, 2012). This shelter aims to build at least one or two rooms to meet permanent housing standards and facilitate improvement. However, these shelters are not intended to be a full permanent house (IFRC/RCS, 2013). The most recent type of shelter is the T-shelter which Yoshimitsu et al. (2013) pointed out to be expected to serve for months or years. T-shelter is commonly relocated from a temporary site to a permanent location, upgraded into part of a permanent house, resold to generate income to aid with recovery, recycled for reconstruction, and reused for other purposes. As (IFRC/RCS, 2013) argued, the displaced population usually develop T-shelter following a disaster. Such resourcefulness and self-management should be supported. Ultimately, the permanent housing may be upgraded from a T-shelter, a progressive shelter, a core shelter, or be even a new-reconstructed house (Johnson et al., 2006, Félix et al., 2013, Johnson, 2007a, Johnson, 2007b).

2.2 Performance of post-disaster housing

The Sendai Framework of Action 2015-2030 aims to prioritise "Build Back Better" in recovery, rehabilitation and reconstruction and motivates national and local governments to consider post-disaster reconstruction strategies with performance concerns (UNISDR, 2015). However, it is usually undermined, especially in developing countries, mainly due to the yawning gap between the emergency and reconstruction phase by either the late initiation of the permanent reconstruction or, on the other hand, the too-quick transition from disaster relief shelter (hereafter DR-shelter) to it. Losing a house is more than physical deprivation; it is losing dignity, identity and privacy (Barakat, 2003). Moreover, the time leading up to receiving a permanent housing solution is subject to extreme trauma and stress for disaster victims. Therefore, post-disaster re-housing must be quick; however, urgent solutions has not led to effective options. Consequently, even T-shelter solutions have significantly been criticised for being unsustainable and culturally and locally inadequate (Félix et al., 2013). Correspondingly, both delay and rush could fail to address occupants' short-term and long-term satisfaction. Delays lead to prolonged use of DR-shelters and affect short-term satisfaction. On the other hand, any rush also leads to long-term dissatisfaction due to poor reconstruction quality attributed to a lack of adequate knowledge of occupants' long-term satisfactory requirements. Ophiyandri (2013) identified delays, cost overruns, poor quality and poor satisfaction as some of the significant problems associated with post-disaster housing projects.

Recently, there have been attempts to tackle the aforementioned issue by integrating three phases of relief, rehabilitation, and reconstruction employing some new approaches, namely progressive shelters, core shelters/one-room shelters and T-shelter, with sustainability concerns. For instance, in T-shelter provision, the material is incrementally added to the shelter through the whole three phases of rehabilitation; while, reuse, recycle, resell, relocation and upgrade, as the five major contributors to this approach, are employed as shown in figure 1 (Corsellis, 2012). However, none of the current approaches has comprehensively addressed the problem and lacks innovative and efficient tools to adequately fulfil long-term sustainable performance (Félix et al., 2013). Moreover, these approaches have frequently led to unsuccessful and undesirable outcomes and economically and environmentally unsustainable implemented solutions (Félix et al., 2013). Take, for example, T-shelter, a costly option compared to its lifespan, can cost the same as a permanent house (UNDRO, 1982) or, in some cases, three times more (Hadafi and Fallahi, 2010). Similarly, T-shelter has also been criticised for taking away resources from the reconstruction (Johnson, 2007a). Even the cost of T-shelter intended to serve as a sustainable step between emergency shelters, and permanent housing is still higher than intended in many cases (Abrahams, 2014). Consequently, economic incentives indicate the paramount importance of a new sustainable incremental process-oriented approach with a sustained pace of resource provision employing new methods to facilitate more sustainable integration of shelters incorporating long-term requirements while mitigating rush or delay.

Moreover, resource management issues are one of the significant factors contributing to such problems. For example, Ingirige, et al. (2008) discussed how post-tsunami reconstruction in Sri Lanka ran into difficulties due to the extreme shortages of materials and labour for construction that fueled inflationary increases in the construction sector. Therefore, in addition to addressing the delay or rush in post-disaster housing provision by considering the potential of DR-shelters phase to contribute to reconstruction, which is the foundation of the LTFDR-shelter concept (explained more in detail in section 2.4); according to Wijegunarathna et al. (2017), a clear understanding of occupants' requirements and satisfaction indicators is of paramount importance for enhancing the housing performance. Hence, in this paper, primary research was conducted to investigate those factors. The findings are used to explore the applicability of LTFDR-shelter concept, which is developed based on a literature review, to address those problems encountered in current post-disaster reconstruction. Since upgrading and improving shelters is cheaper than moving i.e., from an emergency response to a temporary shelter and then to a permanent house (Corsellis, 2012), an incremental process-oriented interconnection of accommodations during all these phases could be considered as an opportunity to enhance the permanent reconstruction; in terms of additional time, construction material, financial and social aspects, which have the potential to foster its long-term sustainability by bridging the aforementioned gap.

2.3 Living Technology in the built environment

In this section, reviewing the living technology's applications in the built environment objective is presented. The LTFDR-shelter concept deploys the living technology as a tool to deliver living construction that means growing construction materials in the built environment employing living microorganisms, namely, microbes and fungus, which involves research into microbially synthesised mineral crystals to replace cement, bacterial production of cellulose fibres and bioplastics, and bacterial spore-based materials which change shape in response to water (Bridgens, 2020). According to Escamilla and Hebert (2015), the proper strategy to make post-disaster housing a success is by appropriate design and material selection and; intriguingly, as Imhof and Gruber (2016) indicated, nature's designs have stood the test of time and could provide us with the proper tools which are genuinely sustainable. Besides, the material is cheap in nature because it is effectively shaped, efficiently structured, and heterogeneously distributed. On the contrary, since the industrial revolution, the world of construction has been dominated by mass production and homogenous material assemblies in which designers' products are assemblies of discrete parts with distinct functions (Oxman et al., 2015). Besides, compared to human-made materials, they mechanically outperform some of the most common materials used by engineers and architects (Oxman, 2011). Furthermore, the bottom-up design manner of living systems, growth, is also an incremental transforming mechanism that signifies the revolutionising power of living technology in the first half of this century (Bedau et al., 2010).

Recently, academics have developed an interest in the idea of combining living technologies and architecture on account of nature's genius for overcoming any hurdle. So far, five ways are assumed for future buildings to become living, breathing ones. Firstly, buildings that grow, such as "Hy-Fi" installation in New York, consisting of a 13-metre-tall tower, constructed of mycelium bricks. Likewise, the "Myco-architecture" project, led by Lynn Rothschild at NASA, investigates the possibility of keeping mycelium partially alive and capable of growing and adapting. Besides, mycelial materials, already commercially produced, are fire retardant, insulators with no toxic gas production (Rothschild, 2018). To design "Healing Concretes" in a building, Henk Jonkers at the Delft University of Technology has embedded bacterial spores in the concrete mix (Jonkers, 2007). Similar to the material that Hironshi Ishii's group at MIT developed, which can alter their shape in response to water and clothing designed with the ability to respond to human perspiration (Yao, 2017); moreover, the Hub for Biotechnology in the Built Environment (HBBE) is extending this method to enable whole building membranes "sweat" as indoor humidity increases to develop breathing buildings by employing latex membranes coated with bacteria spores – like sweat glands – allowing air to flow through the walls like when steam builds from a kettle or a shower. HBBE's initial work is broader, focusing on the use of microorganisms across three main areas: living construction, microbial environment, and building metabolisms (Bridgens, 2020). The latter is where the E.U. project called "Living Architecture" explores the processing power of microbes in buildings and develops a type of microbial fuel cell that generates small amounts of energy from domestic waste. The fuel cells integrated into the bricks are like buildings stomach that takes in wastewater while the waste is broken down and bacteria convert chemical energy into electrical energy (Jiseon You, 2019). To design a building with immune systems, researchers at University College London have begun designing bio-receptive probiotic kitchens by promoting growing bacteria known to offer resistance against disease-causing bugs (Dade-Robertson, 2019). Furthermore, "zero-energy living buildings could feature bioluminescent lighting, walls and furniture with engineered living material" (Bridgens, 2020).

2.4 Introduction to LTFDR-shelter conceptual approach

This paper proposes the LTFDR-shelter concept (figure 1) to address some of the post-disaster housing issues found in the literature review by suggesting a new method for integrating emergency shelter, T-shelter and permanent housing through a novel in-situ incremental process-oriented transformation of shelter's material and design employing living technology. The possibility of programming living microorganisms to fabricate construction material with on-demand properties in the next 10-20 years (Michael Chui et al., 2020) offers appealing advantages for this concept. Namely, more sustainable cleaner production and optimisation of construction material properties to accommodate post-disaster shelters' transformations towards a more satisfactory permanent situation, resourcefulness, and self-management; Particularly, facilitating meeting the need of user for alternations, the extension of space, and more comfortable interior environment towards a normal life after a disaster. Therefore, novel process-oriented methods of material design and biofabrication, shelter design and construction, and co-creation and collaborations must be developed for this new proposed form of transformation in further research.

Construction material in the LTFDR-shelter concept would constantly be transforming to optimise quality, quantity, and functionality, through an incremental in-situ process of low energy biofabrication while users are inhabiting the shelter. According to Chang et al. (2011), following a large-scale disaster, in the face of the quick, substantial amount of required construction material, most local production facilities and supply systems in manufacturing industries are likely to be damaged, and the construction market tends to be in chaos, contested and highly adversarial. If coupled with the disruption of energy supply and transportation and the local industry's pre-existing historical problems, it could exacerbate the challenge in procuring construction materials, leading to project failures such as project suspension, quality deficits, cost overruns, and delivery delay. Intriguingly, as Camere and Karana (2018) described, biofabrication as a process of producing complex materials by the growth of living microorganisms and cells is considered efficient compared to other material production technologies because of not requiring the extraction of natural resources from the earth's crust. Instead, it utilises local renewable resources for feeding living microorganisms. Therefore, the LTFDR-shelter concept is proposed to act as a micro in-situ bio-fabrication factory, owing to its living material that self-generates, self-organises, self-repairs, and operates at the molecular scale. This incremental procurement method of shelter supplies' provision diminishes the dependency on external support and dwindles quality material distribution demand for upgrading and reuse into more permanent shelters.

Beneficial applicable suggested living materials to fulfil LTFDR-shelter's objectives are found in secondary living technology category (Bedau et al., 2010), self-produced bio-composites, incorporated of engineered or non-engineered living materials existing or projected to exist in 10-20 years (Michael Chui et al., 2020); Such as bio-based composites, bacterial cellulose biofilms, or fungal materials (e.g. Mycelium composites). The potentially applicable features of the proposed LTFDR-material are self-assembly, self-repair, resilience, metabolism, intelligence, self-organisation, and regenerating at the molecular scale using, e.g., freely available soil, air or rainwater (Imhof and Gruber, 2016), leading to the robust macro-scale output to enhance quality, quantity, and function of the LTFDR-material. Moreover, as Imhof and Gruber (2016) described, it would be cost and energy-efficient, multi-functional, durable, bio-degradable, and sustainable.

Moreover, unlike existing post-disaster housing approaches, LTFDR-shelter concept goes beyond merely replacing existing construction materials with environmentally benign alternatives but outperforms them. Hence, the elevated durability of quality material with an extended lifespan reaches the desired level suitable for more permanent shelter in the next phases. Some existing examples of such living materials are self-repairing concretes, Jonker's (2007), and cheap, sustainable mycelium composites with low thermal conductivity, high acoustic absorption and fire safety properties outperforming traditional construction materials such as synthetic foams and engineered woods (Jones et al., 2020). The potential to grow the additional quantity of material would serve LTFDR-shelter transformation in different ways, take, for example, the living materials with the ability to self-bind and self-assembly aspect (Jones et al., 2017; Lee, 2011) or grow directly in the shape of a product (e.g. Benjamin, 2014, López Nava et al., 2016) could dwindle further associated material supply. Furthermore, Monolithic mycelium composite's self-supporting structure (Dessi-Olive, 2019) exemplifies a conceivable enhancement in biocomposite's structural load-bearing mechanical property. Moreover, recent attempts to introduce novel functionalities into living cells like generating auto bioluminescent plants (Kwak et al., 2017, Mishra, 2020) or moisture-responsive fabrics that dynamically modulates ventilation (Wang et al., 2017) demonstrate proof-of-concept, which adds validity to the LTFDR-material bio-composite as a concept with feasible, practical potentials in the foreseeable future.

Correspondingly, such transformations of the bio-composite enable incremental in-situ process-oriented LTFDR-shelter transformations towards more permanency. This habitat is initially a light, rapidly built emergency shelter made of living growing bio-composite, enhancing on-site, allowing the shelter to transform into a more permanent one during relief, rehabilitation, and reconstruction phases. Consequently, unlike the transition of material with an inevitable decreased quality lifespan between the phases in existing approaches (Corsellis, 2012), the LTFDR-shelter concept ensures a semi self-sufficient process adding emergency shelter and T-shelters' quality resources and lifespan to the permanent reconstruction. LTFDR-shelter would be built, altered, upgraded, and maintained by the affected population themselves, leading to resourcefulness and supporting self-management. The transformation occurs on-site, providing the bio-composite adequate time to acquire the required specifications akin to more permanent conventional construction materials. The categories of the building envelope functions transforming in the LTFDR-shelter are support, control, and finish, representing structural integrity, the flow of matter and energy of all types, and aesthetic aspects, respectively. In the LTFDR-shelter concept, integrating future transformation and alteration possibilities in the design and construction process of support function plays a significant role in facilitating the transformation of some components' functions towards more permanency. For example, due to the bio-composite transformation, some emergency shelter components (e.g., textile) could transform into cladding panels or more rigid load-bearing structural components (Dessi-Olive, 2019) such as beams columns, enabling alternations and expansion of space into T-shelters. The control function is at the centre of good performance. Some of the future LTFDR-material's optimised features mentioned above could equip the shelter with enhanced thermal, acoustics, natural ventilation, lighting, and moisture protection to deliver a more comfortable interior living environment that replicates that of traditional, more permanent shelters over few weeks to months. Furthermore, it is essential to ensure an appealing cultural and traditional appropriate finish appearance in terms of colour and texture.

This conceptual approach is based on co-creation methods to involve the affected population, shelter designer, living material scientists and post-disaster stakeholders, governments and humanitarian agencies in the decision making, design and manufacture process. Its adoption level and timing are dependent on different variables, such as commercial availability, regulation, and public acceptance (Michael Chui et al., 2020). Ultimately, to accelerate this adoption pace, the LTFDR-shelter concept takes a proactive approach that paves the way for further research to mitigate potential ethical, economic, environmental, cultural, societal, and technical challenges regarding living technologies' application in a post-disaster context.

"Insert Figure 1 here."

3. Research Method

Primary research was undertaken to assess the long-term performance of post-disaster housing. Accordingly, three post-disaster housing projects in Sri Lanka were used as case studies. Sri Lanka is exposed to a range of hazards, such as floods, landslides, cyclones, droughts, high winds, lightning, thunderstorms, coastal erosion, subsidence, tidal waves, and infrequent seismic events. Many houses are either destroyed or significantly damaged due to various recurrent disaster events. For instance, nearly 45,000 houses were destroyed or substantially damaged due to disaster events in 2017 alone (Wedawatta et al., 2018). The findings from this primary research are then used in the discussion section to explore the applicability of the LTFDR-shelter conceptual approach, introduced in section 2.4, to address the key issues of current post-disaster reconstruction encountered in the findings of this primary research.

3.1 Data collection

Primary data was collected from post-disaster housing recipients via a questionnaire survey to achieve the research objectives. First, a desk-based literature review was conducted to assess the existing knowledge on the issues. Based on this understanding and the research objectives, a questionnaire survey template targeting the housing recipients was developed. The questionnaire survey sought to address the objectives including, investigating the occupants' requirements and expectations, and exploring how the post-disaster housing projects have performed against the requirements of the occupants. The questionnaire covered issues related to basic details about the property and occupants, satisfaction about various aspects of their property, any further work undertaken to the property, and their overall satisfaction. The questionnaire template was piloted among a panel of selected experts and practitioners to assess whether the structured questions and options provided reflected Sri Lanka's context. Several minor modifications were made to the questionnaire template following the pilot survey. These were to reword a question about educational facilities' satisfaction and provide suitable bands for questions on pre and post-disaster household income levels.

3.2 Case studies for questionnaire survey

To survey the views of the housing occupants, three permanent post-disaster housing projects (case studies) from Sri Lanka were randomly selected. The main consideration therein was that the houses have been handed over to and occupied by the recipients for what is considered beyond the short and medium terms (more than five years). Collis and Hussey (2009) define a case study as a methodology used to explore a single phenomenon in a natural setting to obtain in-depth knowledge. The research sought to obtain a detailed understanding of post-disaster housing provisions' performance, a contemporary phenomenon within a real-life context external to researchers' control. Yin (2003) identified a case study method as appropriate for studying contemporary phenomena within its real-life context.

The houses in the two case studies have been occupied for more than ten years, whereas they have been in use for more than eight years in the other case study. The selected case studies have been completed to house those affected by the 2004 Boxing Day tsunami, flooding in 2003 and landslides in 2006. The three case studies are located in the Galle, Nuwara Eliya and Rathnapura districts of Sri Lanka. In addition to the information collected from the survey recipients, further details about the case studies were obtained from the Divisional Secretariats (local administration offices), the Grama Niladhari (civil service administrative officer in each village), as required.

3.3 Questionnaire survey

In line with one of the major characteristics of questionnaire survey research, a questionnaire survey as a data collection technique allowed collecting information from a relatively sizeable number of respondents (Easterby-Smith *et al.*, 2008). This allows forming a clear picture of each project's situation as a substantial number of properties are represented within each case.

The research team administered the questionnaire survey, including researchers from the National Building Research Organization (NBRO) Sri Lanka, considering the socio-demographic profile of the occupants. A total of 120 permanent dwellings were involved in the survey: 41 from Case Study 1, 50 from Case Study 2, and 29 from Case Study 3. While the households were randomly selected, whether the current occupants were the original recipients were considered. Only the households in which the original recipients have remained in occupancy were selected for the survey.

The head of the household was the respondent in 71% of the sample, whereas it was either the spouse or descendants in the other instances. The average age of the respondents was 51 years, with a standard deviation of 15 years. Apart from 22.7%, the rest of the respondents were employed. However, many occupants were in low-paid manual labour or self-employment, earning below the average household income for their respective districts.

4. Findings and analysis

Based on the data collected from the relevant local authorities, the percentage of original housing recipients still occupying their dwellings is 79%, 56%, and 73% in Case Study projects 1, 2 and 3, respectively. Da Silva et al. (2010) noted that post-disaster housing projects' occupancy rate is a proxy for quality or acceptability to beneficiaries. While the percentage of original recipients remaining is acceptable in Case Studies 1 and 3, it is considerably low in Case Study 2, which is the oldest of the three projects surveyed and relates to the pre-tsunami period, that could be an indication of the level of dissatisfaction, or the property provided not meeting the requirements of the recipients.

4.1 Satisfaction of Occupants

The questionnaire survey gathered views of housing recipients on some aspects of their post-disaster houses; the discussion here focuses on two aspects of satisfaction physical and technical criteria; and socio-economic criteria (See Wedawatta et al. (2018) for a detailed account of the survey findings). The respondents' views on satisfaction were obtained on a 5-point Likert scale; (Highly satisfied (allocated score = 2), Satisfied (1), Neither satisfied nor dissatisfied (0), Dissatisfied (-1) and Highly dissatisfied (-2). Gianluca et al. (2020) identify Likert scales as a common methodological tool for data collection used in quantitative approaches in multiple domains, often employed in surveys or questionnaires, for benchmarking answers in the fields of disaster risk reduction. Mean Likert scale values (+ or -) were then converted to present the level of satisfaction or dissatisfaction as a percentage score (net + or – value as a percentage of maximum + or – value possible). Accordingly, in the discussion, the contribution of the LTFDR-shelter concept to each aspect is mentioned to clarify the implications of employing LTF for more sustainable post-disaster housing performance.

"Insert Figure 2 here."

4.1.1 The physical and technical performance of the houses

Although the average level of satisfaction relating to physical and technical issues was positive in many aspects, it was not strong in the majority. For example, the level of satisfaction was minor with building material quality, provision for alterations, size of the house, number of rooms when the Likert options were statistically analysed. Figure 2 represents the level of satisfaction when converted to a percentage. Although this should be treated with caution because they are based on converted Likert scale values, they still indicate the occupants' strength of satisfaction/dissatisfaction. While the occupants were quite satisfied with the city centre's location and proximity, satisfaction relating to other aspects was quite low. The major issue found was the recipients' dissatisfaction about the building material quality and the workmanship quality, which was approximately amongst the lowest in all cases, specifically in Case Study 3.

In addition to the material quality and workmanship, several other aspects, such as the size of the house, number of rooms, and the ability to make alterations/expansions, were particularly low. A higher percentage of households have made alterations to their homes, especially in Case Study 1 (Hanguranketha) and Case Study 3 (Akmeemana). The primary reason cited is the need for more space, followed by upgrading the quality. Additional rooms, extensions to or a new kitchen, refurbishing the kitchen and refurbishing rooms are the primary alterations undertaken. This shows that many of the households tend to make changes to their homes in the long term. Whether alterations have been made or not was statistically correlated to satisfaction about the workmanship quality, material quality, lighting & ventilation, and privacy level.

4.1.2 Socio-economic issues

When questioned about their engagement level during their homes' planning and design stages, only a minimal number of recipients stated that they were granted the opportunity to engage in the process or had been consulted. This means that recipients' requirements may not have been appropriately captured during their houses' planning, design, and construction phases. This may have resulted in the considerable number of houses vacated by the original recipients across the three case studies and lower satisfaction levels. Therefore, active community involvement in the process from the very beginning is a key requirement for future housing projects.

5. Discussion

In this section, the research objective related to LTFDR-shelter concept applicability and potential suggested contributions to tackle current approaches' performance issues found in the primary research findings is discussed.

5.1 Physical and technical performance

The major unsatisfactory factors regarding physical and technical performance found in the case study were related to the building material quality, workmanship and provision of alternations. The proposed LTFDR-shelter concept, on the other hand, has the potential to mitigate these issues by broadening the accessible material and structural systems' options available by growing the living material on-site with free mediums existing in the environment, e.g., rain, water and air (Imhof and Gruber, 2016). Consequently, the living material quality in this approach, unlike the T-shelters conventional materials, would elevate over time, reducing the labour demand and providing the opportunity to make alternations. Hence, as elaborated in section 2.4, a variety of aspects of this material would be harnessed by the LTFDR-shelter concept to enhance post-disaster housing material's physical and technical performance, which will be discussed more in detail in the following sections.

5.1.1 Quality of building material

The research findings indicated the building material quality as one of the unsatisfactory factors. Hence, the paramount importance of a new approach facilitating resourcefulness and upgrade of material. Escamilla & Habert. (2015) indicated the proper design and material selection's significant role in the approach's success or failure. Although T-shelter is already making attempts to fix this, according to Félix et al. (2013), its implementation is expensive in practice. Despite its aim towards sustainability, it is not entirely successful in this respect. Moreover, this paper's case study research has likewise shown the material quality's substantial impact on occupants' satisfaction and as an indicator of the performance of post-disaster shelter. Furthermore, according to the literature review, the existing living technologies such as bacterial production of cellulose fibres and bioplastics (Bridgens, 2020), microbially synthesised mineral crystals to replace cement (Jonkers, 2007) and bacterial spore-based materials (Ou et al., 2014) which change shape in response to humidity; provide the proposed LTFDR-shelter concept with a variety of potential characteristics namely self-assembling (Jones et al., 2017; Lee, 2011), in-situ material biofabrication, material specifications enhancement on demand (Jones et al., 2020, Wang et al., 2017, Mishra, 2020, Kwak et al., 2017), and self-healing (Jonkers, 2007) utilising growth mechanism of the living microorganisms incorporated in it. Accordingly, this paper suggests these possible potentials of the LTFDR-shelter approach for alleviating the building material quality issues found in the case study.

5.1.2 Quality of workmanship

Quality of workmanship is another unsatisfactory factor found in this paper's case study research. To "Build Back Better" in recovery and rehabilitation following a disaster, resourcefulness and self-management should be supported (IFRC/RCS, 2013). Intriguingly, in the proposed LTFDR-shelter concept, on account of the shelter operates as a material biofabriaction factory, the shelter recipients would not only be occupants, but they would also be the workforce serving themselves. One strategy suggested by the LTFDR-shelter concept is that the government or other related organisations pay the occupants instead of recruiting another workforce for the sake of this engagement to maintain and upgrade their growing shelter. Consequently, this could ease the desired alternations being executed by the recipients themselves. The LTFDR-shelter is co-created by designers and occupants and provides flexibility to be disassembled and upgraded after the growth and enhancement of the living material. On the other hand, for example, the self-healing (Jonkers, 2007) aspect of living material can assist with diminishing the allocated cost and workforce for construction and maintenance of

LTFDR-shelter. The self-assembly (Jones et al., 2017; Lee, 2011) aspect likewise could potentially dwindle labour demand, with less expertise and training required for the occupants. However, new non-complex training is essential to familiarise occupants with their role in the co-creation process.

5.1.3 Provision for alterations

According to the research findings, considering the ability to make alternations in the house design stage is necessary. The LTFDR-shelter concept suggests methods to address this and provide occupants with more adaptable and flexible shelter alternation options as time elapses in upgrading materials and size of housing and rooms owing to the in-situ biofabrication of living materials. The LTFDR-shelter approach facilitates shelter's space alternation and addition by enhancing its materials, which was indicated as an essential satisfaction factor in the case study's findings.

Therefore, specific provisions are necessary for both the LTFDR-shelter design and construction methods and the living material design to facilitate the required alternations. Hence, the LTFDR-shelter approach needs to provide both sectors with a framework to help them consider significant issues to make it successful. Particularly, this approach needs to provide post-disaster shelter designers, construction managers and policymakers with a framework to consider future alternative quality functions of different parts of the LTFDR-shelter (i.e., Jones et al., 2020, Wang et al., 2017, Mishra, 2020, Kwak et al., 2017), in the design and construction phase. This is due to living material's transformation and enhancement on-site while occupants reside in it, alongside the design's flexibility, which facilitates alternations to the desired shelter from the very beginning. Therefore, when in LTFDR-shelter, take, for example, a curtain becomes as strong as a window glass or door or the tent canvas transforms into a solid, more durable cladding, it still works properly as an appropriate shelter. The material quality is enhanced by growth. New properties and functionalities facilitate alternation and upgrade from an emergency shelter (tent) into T-shelters according to occupants' needs towards more normality and permanency. Moreover, the growing living material's quantity could increase (i.e., Jones et al., 2017; Lee, 2011), hence more material accessible to be exercised in expanding the size or number of rooms over time.

5.2 Socio-economic issues

The research findings indicated undermining the active community involvement aspect as one of the major unsatisfactory factors. On the other hand, the LTFDR-shelter concept is suggested to address this issue; by adopting co-creation methods to facilitate community engagement in the in-situ process of material biofabrication and shelter construction. Unlike existing approaches, this could also eliminate extra labour and transportation, owing to the living material doing the main production with freely available medium existent in every environment (Imhof and Gruber, 2016). The local community and occupants are to be trained for co-creation methods, i.e., maintaining the living material to optimise appropriately and grow into a material with enhanced properties or change into components with more durable function. Furthermore, financial assistance is another burden on governments (Corsellis, 2012). Correspondingly, as explained in section 2.4, LTFDR-shelter is intended to encourage self-management, alleviate the economic pressure on the government and related organisations, and minimise the disaster-affected population's dependency on the government.

6. Conclusion

Countries worldwide are affected by various natural-hazard-induced disaster events, which often causes widespread loss of houses. The literature review demonstrated that the lack of sustainable performance of post-disaster housing during recovery, rehabilitation and reconstruction mainly stems from the gap between the emergency and reconstruction phase due to either rush or delay, and economically and environmentally unsustainable implemented solutions of current approaches. Such project failures mainly arise from challenges in procuring quality construction materials due to immediate extensive resource demands. This issue is primarily attributed to destroyed local production facilities and supply systems after a large-scale disaster (Chang et al., 2011). Furthermore, the questionnaire survey study captured several key issues concerning unsatisfactory post-disaster housing performance, including physical and technical performance aspects such as the building material quality, workmanship, alternation provision, and undermining active community involvement as the major socio-economic issue. Additionally, this paper lays the foundation for the new LTFDR-shelter interdisciplinary conceptual approach by suggesting its potential contributions to address the existing issues found in the case study research.

The proposed LTFDR-shelter concept is an incremental in-situ process-oriented approach, in which shelter is incorporated with a living growing bio-composite to gradually transform from a light rapidly built emergency shelter to a T-shelter to increase permanency, while occupants dwell in it throughout relief, rehabilitation, and reconstruction phases. This transformation is facilitated by the in-situ optimisation of living growing bio-composite. The prospect of growing living materials on-demand in the next 10-20 years by using programmed living microorganisms (Michael Chui et al., 2020) offers potentials for in-situ bio-fabrication of LTFDR-shelter material to enhance its quality, quantity, and functional properties on-demand on-site. Consequently, this accommodates the transformations of LTFDR-shelter's building envelope's support, control, and finish functions towards a more satisfactory permanent situation and resourcefulness. Accordingly, LTFDR-shelter concept suggests a variety of possibilities to build on the T-shelter approach's characteristics such as reusable, upgradeable, recyclable, relocatable, and resalable by equipping each with added features offered by living technology; for instance, growing, self-repairing, self-assembling, self-power generating (Bedau et al., 2010) employing, e.g., freely available soil, air or rainwater (Imhof and Gruber, 2016). Hence, this is more cost and energy-efficient, bio-degradable, durable, and sustainable (Imhof and Gruber, 2016) than a T-shelter. Specifically, the LTFDR-shelter's components could transform, i.e., form textile in an emergency shelter to components appropriate for a more permanent T-shelter which is more durable, structurally stable, bioluminescent, moisture-responsive cladding that naturally modulates ventilation with an appealing appearance that matches the culture and traditions of the context.

This in-situ incremental construction material procurement method aims to dwindle quality material distribution demand for making alternations, extensions of space, upgrading and reuse into more permanent shelters. Correspondingly, the LTFDR-shelter concept intends to reduce the disaster-affected population's dependency on external support and mitigate the economic pressure on the government and associated organisations. It also adopts co-creation methods to promote self-management and community engagement in the in-situ process of material bio-fabrication, shelter design, construction, upgrade, and maintenance. This concept necessitates collaborations between shelter designer and living material scientists. It will be of interest to post-disaster housing stakeholders, governments and humanitarian agencies in the decision making, design and manufacture process.

The LTFDR-shelter approach presented is conceptual and requires further validation. However, the concept has been compared against current literature extensively to add validity to the discussion in this paper. In further research, novel process-oriented methods of living material design and biofabrication, shelter design and construction, and co-creation and collaborations methods must be developed for this approach. LTFDR-shelter concept takes a proactive approach to accelerate its adoption pace, which relies on different variables, such as commercial availability, regulation, and public acceptance (Michael Chui et al., 2020). Therefore, it paves the way for further research to alleviate potential ethical, economic, environmental, cultural, societal, and technical challenges regarding living technologies' application in a post-disaster context. Furthermore, as part of the current doctoral research study by the first author, research is being undertaken to investigate and evaluate the applicability of living technologies in the post-disaster context to formulate the LTFDR-shelter approach in-depth and develop a framework for its practical implementation.

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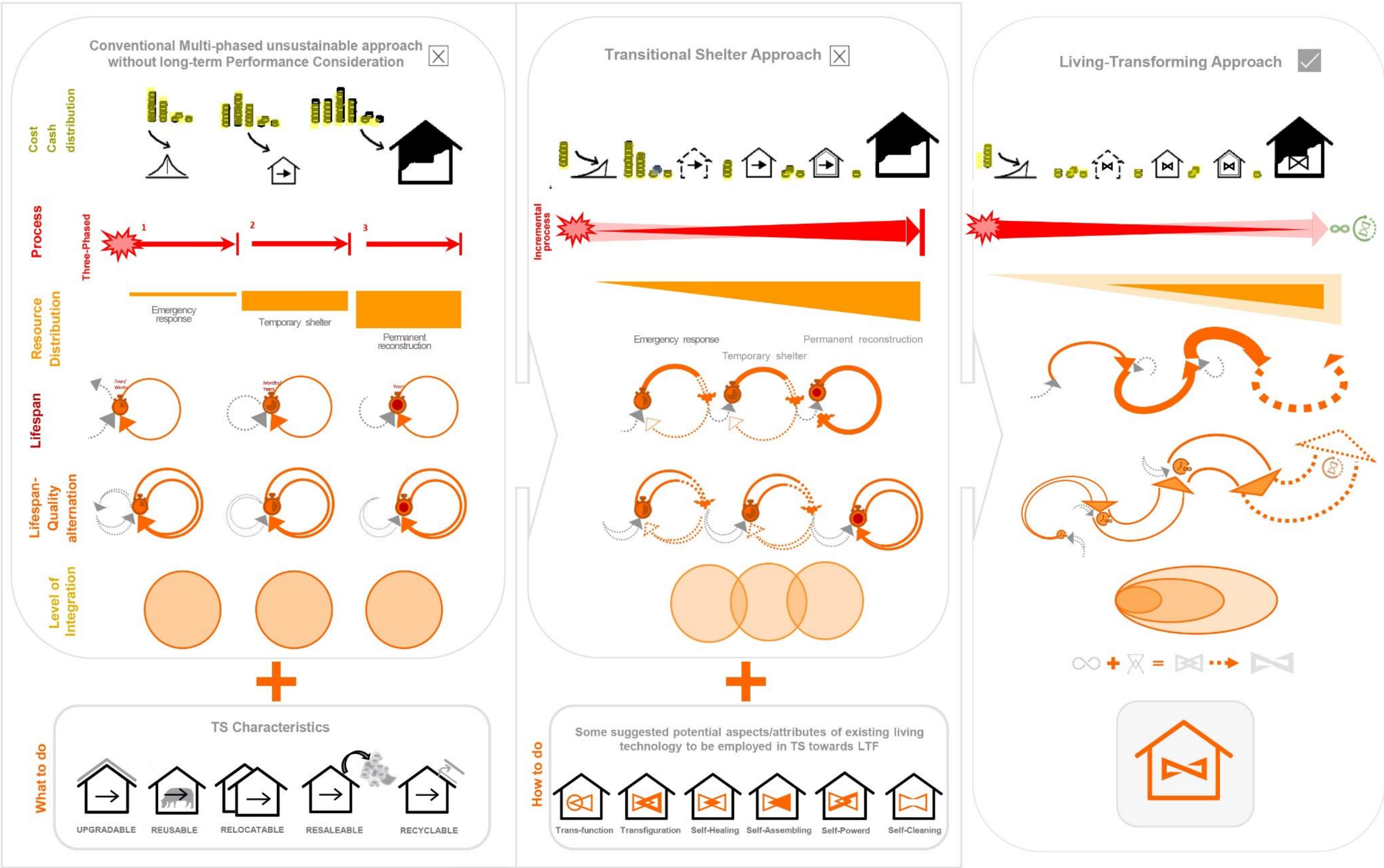

Figure 1 - Comparison of existing shelter provision approaches with in-situ process-oriented LTFDR-shelter concept

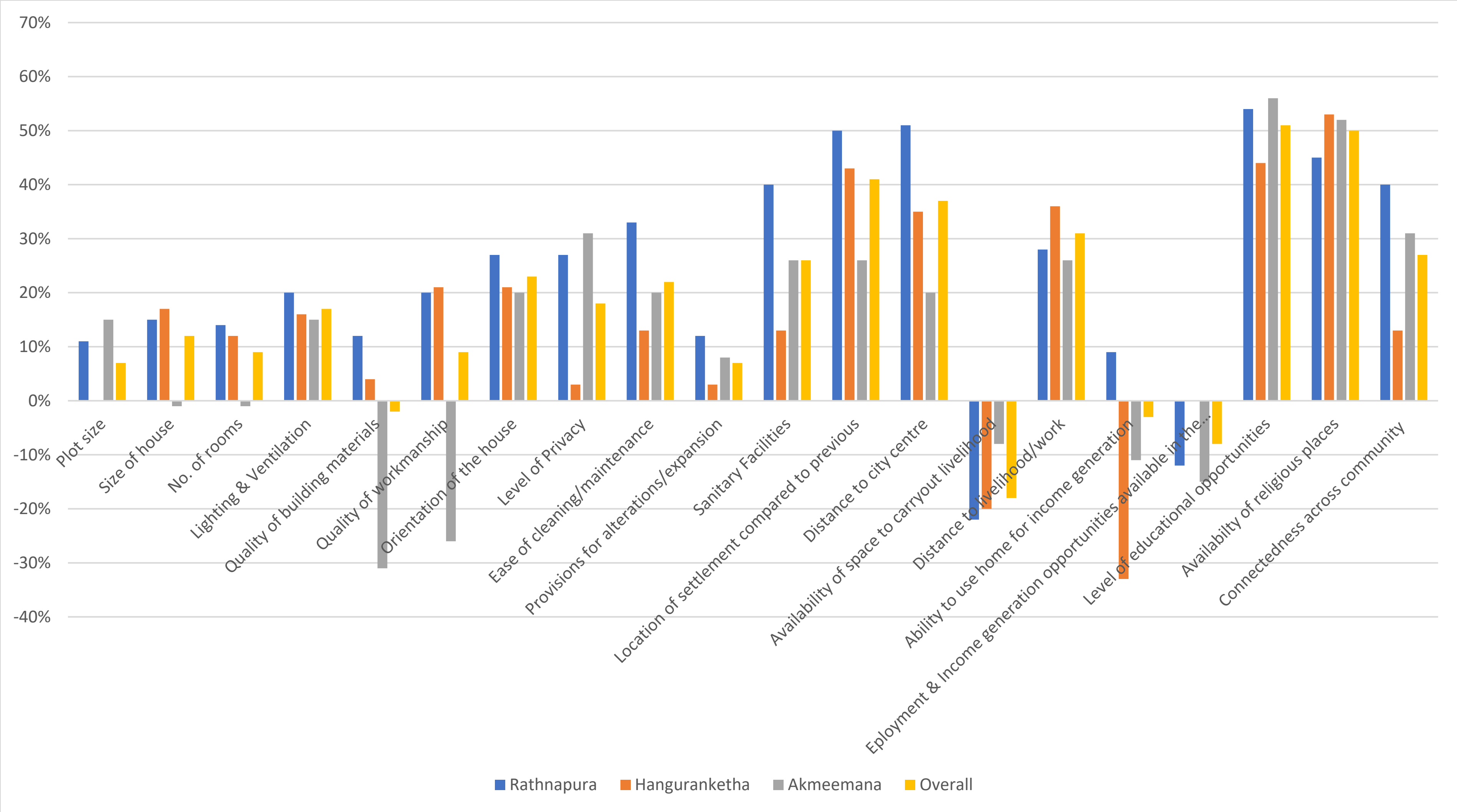

Figure 2 - Level of satisfaction (as a percentage) relating to physical, technical, and socio-economic issues