ICCAUA Proceedings Journal
Proceedings of the international conference of contemporary affairs in architecture and urbanism-ICCAUA
Volume 9 (December 2026), 2610462

Journal homepage: https://journal.iccaua.com/

ICCAUA Proceedings Journal

DOI: https://doi.org/10.38027/ICCAUA2026EN0462

# An Algorithmic Approach for Spatial Design of Post-Disaster Settlements Considering Prolonged Stays

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Received: 28.04.2026
Revised: 28.06.2026
Accepted: 01.07.2026
Available online: 10.07.2026



This article has been selected and peer-reviewed for publication in this journal as part of the 9th International Conference of Contemporary Affairs in Architecture and Urbanism, held on 7–8 May 2026 in Istanbul, Türkiye.

**Abstract**

Post-disaster settlement designs often prioritize urgent needs while overlooking the frequently observed reality of prolonged occupancy. The neglect of diverse long-term needs and expectations commonly leads residents to undertake costly and uncoordinated modifications. This study proposes the creation of spatial variety within the parcels of individual dwelling units in order to enrich and support future modification possibilities. Spatial variety is achieved through the combination of two spatial properties—open/semi-open space and hard/soft ground conditions—resulting in four spatial configurations within each parcel. This approach is developed in relation to the principles of incremental design and long-term experiential quality that is livability. Employing a research-by-design methodology, the study develops a generative algorithm capable of generating spatial configurations of post-disaster settlements while respecting the widely-accepted dimensional standards. The model is tested through a pilot settlement scenario. The findings demonstrate that generative algorithmic approach can support diverse user expectations in post-disaster settlements.

**Keywords:** Post-disaster settlements; Computer-aided algorithmic design (CAAD); Spatial design; Incremental design; User modifications.

## 1. Introduction

Disaster is a major disruption in the normal ways of a community, brought on by a hazardous event that leads to various losses (UNDRR, 2017). Because of the conflicts in various places on Earth, groups of people forcibly leave their houses and settlements. In the first four-months window of the year 2025, 122 million people were displaced because of war and persecution, making it already more than the total number in 2024 (Farge, 2025). For drawing the picture, this number equals to roughly twelve people being displaced every second in the world. On top of these human-made disasters, in 2024, a total of 7.7 million people were internally displaced resulting from natural disasters (IDMC, 2024).

There are five steps of encountering a disaster defined by DHS (2015) as (1) prevention, (2) protection, (3) mitigation, (4) response and (5) recovery. The scope of this paper only covers response and recovery stages. The response stage is characterized by the mobilization of personnel and institutions in order to meet the short-term needs of the affected that are rescue, food provision and shelter. However, although the post-disaster settlements (PDSs) are intended as temporary, they commonly stay active for many years. For instance, after the 1995 Great Hanshin Earthquake, displaced people took almost five years to move to permanent houses and ten years to return to their economic safety (Sakamoto, 2014). The affected population experience poor living conditions and social issues resulting from them, for long periods (Johnson, 2007). Also, temporary solutions are costly in the long term both for economy and ecology (Johnson, 2008) as they may cost three times the permanent shelters (Hadafi & Fallahi, 2010).

As the duration of accommodation in post disaster settlements (PDSs) increases, the needs of users evolve, starting the recovery stage. In the recovery stage, we expect that evacuees' long-term needs can be met and they can sustain a living but the short-term solutions at the response stage do not suffice in meeting this goal. UNHCR (2025) suggests that, considering prolonged stays, PDSs should aim to surpass the widely-known categorization of shelters as emergency, transitional and permanent. PDS designs should envision sustainable solutions, blurring the line between the response and recovery stages. Therefore, this paper works on assisting and enriching the transition from the response stage to the recovery stage in PDSs, with the primary focus on their spatial designs.

There are a number of problems in the spatial design of post disaster settlements, described in the literature. Disasters require urgent response, but this matter conflicts with the effort that must be put for spatial design and livability which are the main problems in the scope of this work. One of the reasons for adopting the traditional approach that focuses on meeting the urgent needs, is that we cannot afford the time for designing PDSs. This issue of urgency is seen as a

justification of the generic inefficient PDS layouts. However, this is not efficient in the long-term. For covering the short-term and long-term, designers could benefit from a mean of making the design process faster.
The traditional approach also foresees fitting as many people as possible to the space allocated for a PDSs. This approach sacrifices open spaces and therefore; privacy, fire safety, sanitation and livability. These issues are addressed in the spatial standards set by Sphere Association (2018). Three of them are the following:

a. The total accommodation units in a settlement aims to constitute less area than one third of the total plot area.
b. The plot area of the whole settlement is at least 45 square meters per resident.
c. The distance between shelters is at least the same as their heights.

These standards ensure the essential needs can be met. In Figure 1, an example layout is given. The total area of open spaces in this settlement was calculated. It was found that the accommodation units consist roughly %40 of the settlement area; however, the respected standards foresee the allocation of at most the one third of the settlement area. The shelters are also located closely, the gap between two shelters being less than their heights. This risks safety against fire and a follow-up disaster that may happen. Moreover, although not knowing the population, the population density in the settlement is apparently higher than advised since the units have two stories. Figure 2 is also a generic example generated by the authors to show a case in which the minimum requirements for the spatial standards are met. The accommodation units consist the %30 of the whole settlement area, not violating the advised constraint. However, this example which may meet the minimum requirements, creates problems concerning livability, a qualitative property in PDSs.

**Figure 1.** A post-disaster settlement from Ecuador (University of Leeds, n.d.).

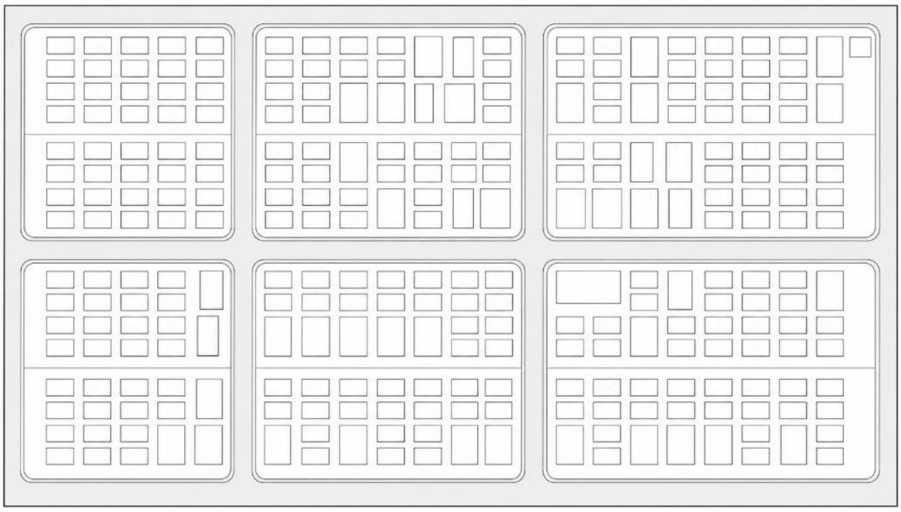

**Figure 2.** A generic post-disaster settlement, drawn by the authors.

To sum up, the challenge is not only to provide shelter rapidly, but also to create spatial systems that support long-term living conditions, and varying and evolving user needs. Addressing this challenge requires a design approach that balances spatial efficiency, livability standards, and adaptability. With this motivation in mind, this study investigates the following research questions:

- What kind of an approach can increase livability within the microsystems of post-disaster settlements (PDSs)?
- What are the potentials of computer-aided algorithmic design (CAAD) in accelerating the design process of post-disaster settlements?
- How can user modifications, which are frequently observed in post-disaster settlements, be supported and guided without compromising the integrity of the original design?

## 2. The Concept of "Livability"

The standards about the spatial design of PDSs, as well as the assessment of their efficiency are focused on their quantitative aspects such as the distances, mechanical performance and population density. These are crucial, yet not enough for the purpose of this work which is to blur the lines between the response and recovery stages, taking into account prolonged stays. For framing this issue of qualitativeness, the widely-used term "livability" is viable, as it is respected by the respected authorities. Livability, as a term, was coined by Appleyard (1980) and later developed by Congress for the New Urbanism (1996) and UN-Habitat (2014). They recognize four criteria for livability.

**Compactness and Walkability**: Essential services should be accessible within walking distance. In PDSs, these facilities should be centrally located. Also, walking experience should be enhanced by safety, comfort and enjoyment.

**Diversity and Mixed Use**: Diverse user groups and functions should be integrated within the same area.

**Public Space and Social Interaction**: Open spaces, parks, and gathering areas that encourage social interaction and community cohesion should be provided.

**Identity and Sense of Place**: Environments that allow users to establish emotional and cultural connections with their surroundings, often through modifiable spaces, should be created.

The short-term oriented spatial design of PDSs ignores livability. Livability covers a part of the matter that is not addressed in the spatial standards, by taking into account the experiential quality in PDSs. The term emphasizes making walking desirable, welcoming people with different needs, having active open spaces and places which can differentiate from other places within that settlement. However, the traditional approach does not pursue these goals as seen from the examples in Figure 1 and Figure 3. Walking experience is not enhanced, no apparent regard for diversity, no open public spaces, and no consideration of identity and sense of place. It is crucial to enable sustainable living in PDSs. The concept of livability contributes to meeting the needs which come after the urgent ones, supporting sustainability. Aiming for livability in the response stage is important for the success of the recovery stage. Thus, increasing livability is in the same direction with the main purpose of this work, which is to blur the line between the response and recovery stages.

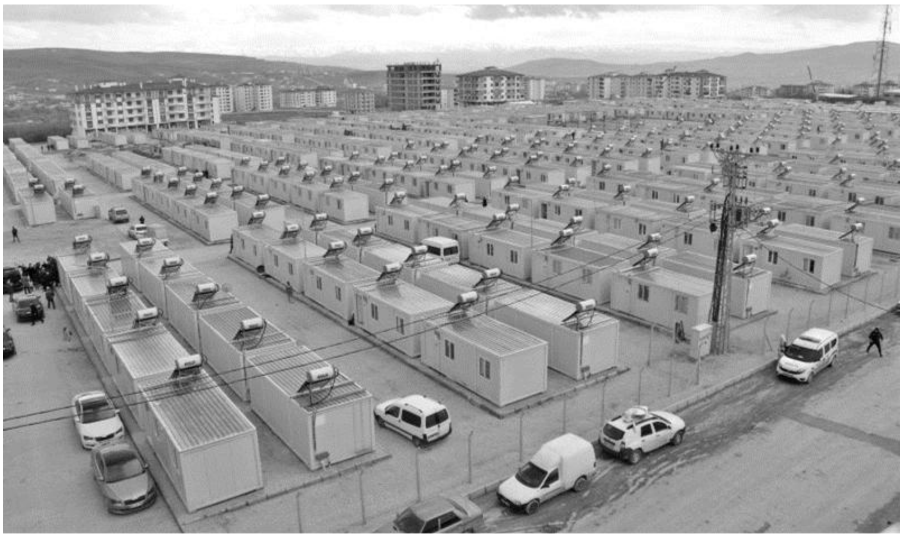

**Figure 3.** Container city from Elazığ, Turkiye (Daily Sabah, 2020).

Livability applies to different scales. These scales are denoted in this work as micro, meso and exosystems (Bronfenbrenner, 1979) which roughly translate into the following in order; direct interaction with close surroundings (e.g., household), interaction between microsystems (e.g., close neighbors, school, workplace, parks), and indirect interactions within the outer layer (e.g., neighborhood, media, governance). Among the aforementioned criteria of livability, those which are for microsystems fully or partly are addressed in our work while those which are not for microsystems were not addressed. The ones which are not addressed are as following; the centrality of essential services, integration of diverse user groups and functions, and provision of parks and spacious gathering areas. The addressed criteria are for the following problems; (1) unavailability of active open spaces, (2) low regard for identity and sense of place, and (3) disorganized user modifications.

### 2.1 Unavailability of Active Open Spaces

Microsystems need shared amenities where the members can have face-to-face interaction, conversation and activities. Saltzman (2011) states that community-building, therefore, social interaction is crucial for recovery; however, disaster management strategies often overlook this need. One of his examples is that in the aftermath of the 2010 Haiti Earthquake, it was observed that some of the affected population had been wandering around public squares and streets all day, having nothing to do. The residents could benefit from having potentials for social interactions provided within their settlement. Thus, having open spaces is needed not only for the urgent needs (safety, privacy, sanitation), but also for social interaction potentials, given that they are active open spaces.

The need for active open spaces in microsystems is also evident in the satisfaction criteria of users. Users view the availability of kitchen gardens as the most important criteria among twenty-four examined (Shrestha et al., 2023). Furthermore, the second and third most important criteria which are high plot size, and feasibility of modifications/extensions also denote that having open spaces is much desirable. However, in a traditionally designed

PDS, users do not have active open spaces for their household and neighbors. Users cannot possess nor conceive themselves a kitchen garden in their small parcels, nor another type of an active open space. Thus, social interaction has low potential of happening in microsystems. For increasing livability, despite the scarcities in the response stage, allocation of more open space for households could be beneficial.

### 2.2 Low Regard for Identity and Sense of Place

In many examples, the layouts comprise repetitive identical units in straightforward arrangements (Figure 1, 2 & 3). This approach does not provide users with identity and sense of place while also not allowing them to satisfy these needs by their own means. Because, the users' future efforts of intervention in their surroundings are not taken into account in design phase.

Identity and sense of place are also closely related to culture. The same design might be satisfactory for one group and not much for the other group. Shrestha et al. (2025) found in their longitudinal study that two different societal groups of Nepal have different expectations from a PDS; for instance, the higher status group view architectural aesthetics as highly significant while indigenous people of lower status view it as not significant. These differences suggest that an all-encompassing initial design for PDSs is not realistic.

### 2.3 Disorganized User Modifications

User are often dissatisfied with generic PDS layouts. To resolve the conflict between the initial short-term-oriented approach and the reality of long-term accommodation, users often intervene with the design of their settlement. After the 1951 Çankırı Earthquake in Türkiye, each one of the shelters built by the government and a half of the custom designed shelters were modified by users (Dikmen & Elias-Ozkan, 2016). Moreover, more than a half of the post-disaster houses built after the devastation caused by 2011 Tropical Storm Washi in Philippines, had been added extensions using open spaces within the first twenty months period (Carrasco et al., 2016). Moreover, in the original design of Villa Verde by Alejandro Aravena, a pioneer in incremental design approach, users had modified the open spaces although the open space was a complete design (Figure 4). Much of the green space had been replaced and parking spaces had been created; seats, barriers and fences had been placed; thus, the design of open spaces diverted from the initial professional design (O'Brien et al., 2020). This is a problem, because disorganized user modifications may cause safety issues, legal violations and disorderly spaces (Carrasco et al., 2016).

**Figure 4.** Open spaces designed as green areas by Aravena, had been turned into hard surfaces by users. Images captured by Google, February, 2024.

Modifications in PDSs are commonly on outdoors. After the 1999 Marmara Earthquake, post-disaster houses in Yeniköy region were analysed and seen that %81 of them were modified, %30 being only outdoor modifications, %3 being only indoor modifications and %48 being both indoor and outdoor modifications (Şener & Gür, 2003). As seen, a majority of these houses were changed by users while the changes were mostly outdoors. Ironically, the outdoor spaces in the built examples of PDSs were rarely considered as design objects by authorities.

For preventing the potential negative impacts of user modifications and for welcoming them both indoors and outdoors; designers must take modifications into account in the initial design phase. Guiding and making space for user modifications may be a solution for these issues. Aiming this, an interpretation of the incremental design approach is adopted in this work, mainly focusing on the incremental design of open spaces inside the parcel together with the shelter unit.

## 3. Approach

In the scope of this research, we are focusing on the problems in the spatial design of PDSs which are having insufficient time for designing and providing low livability. We approach the problem of having insufficient time by utilizing the generative CAAD framework. We implement a spatial interpretation of the incremental design approach that is supported by variations in space types, aiming to provide users with rich modification options. Our incremental design approach targets the parcel units, supporting social interaction within the microsystems. We also consider the potential of shelters to be merged with neighboring parcels in case the household size requires.

### 3.1 Rapidness of the Generative CAAD Framework

CAAD is efficient in solving time-sensitive problems, using the high processing power of computers. The initial design load can be lightened by utilizing design algorithms on computers, making an efficient start to the design process.

Naturally, PDS plot areas and shelter units available for use may vary from one settlement to another. So, an algorithm that generates spatial layouts must be able to work with these variations. After this, layout generation can be done by the algorithm instantly. Though, realistically, this algorithm would only serve as a pre-design tool while saving organizations more time and resources for considering long-term needs.

### 3.2 Designing Open Spaces for Livability within Microsystems

Having open spaces is a pre-requisite for livability. Implementing the spatial standards given by Sphere Association (2018) makes open spaces available. We turn them into active open spaces in shelter parcels for assisting social interactions within the parcel. Moreover, active open spaces inside parcels are placed in a way that provide visual communication between neighboring parcels, further supporting social interactions; therefore, livability.

The criteria of identity and sense of place and user modifications are met by adopting an incremental design approach. Intentionally leaving certain parts of a building to be built by its users, the incremental design approach, is most notably introduced by Turner (1968) with an emphasis on the freedom of users in their own environment. The well-known architect Alejandro Aravena has been carrying the flag of incremental design. A user of Aravena's famous work, Villa Verde, says that he is proud of his own modifications to the house and always curious about new ideas on what more he can do (O'Brien et al. 2020).

Modification allowance and guidance invite sense of place and social interaction; therefore, contribute to livability. In this work, for solving the issues of identity and sense of place, the traditional practice of placing identical units in straightforward arrangements is abandoned. The parcels welcome modifications as the area surrounding the shelter is left open. Modifications are cued within the parcels by providing shelters with extensions on two sides. Furthermore, we allocate four types of space within each parcel. These types are created by the combinations of hard/soft ground and semi-open/open space. This approach aims to give richer modification options to users. This way, we assist users in distinguishing their parcels from others; thus, creating identity and boosting the sense of place. Moreover, we propose a solution for adapting to the changes in the household size and abandonement of shelters by enabling the merge of adjacent parcels through building extensions to shelters which is to be done by users.

## 4. Results

This study considers the problems in the spatial design of PDSs which are having insufficient time for designing and providing low livability. We aim to increase livability through a spatial interpretation of the incremental design approach mentioned in the Section 3.2. This approach is integrated into the computer algorithm we created using the built-in Grasshopper algorithmic modeling environment within Rhinoceros 3D (Version 7; Robert McNeel & Associates, 2020). The algorithm is able to generate post-disaster settlement layouts rapidly while respecting livability.

The algorithmic generation is useful for a rapid start in pre-design process. The algorithm is used on Grasshopper interface, through number sliders. Firstly, the dimensions of a rectangular shelter parcel and the dimensions of the shelter unit planned for use are entered on the interface by the designer. Then, the algorithm automatically generates the parcel boundaries including the variety of open spaces and the shelter unit with two extensions while meeting the minimum requirements of the aforementioned spatial standards; therefore, making one parcel unit. One example of a parcel unit is seen in Figure 5, before and after an example of user modification. Moreover, a surrounding path is present in the parcels, serving as setback and passage. Setback distances were parametrized with the shelter height; so, changing the height also changes the setback distance to the minimum amount allowed by the standards. After the generation of the first parcel unit, the axes which the parcels will be located on and the number of parcels in each axis are entered on the interface, mirroring the parcel unit along the axes, completing the generation. At the end, the designer is able to finetune any of the given parameters if needed, by using the same number sliders, with real-time algorithmic generation. This framework aims to speed up the pre-design process in the spatial design of PDSs.

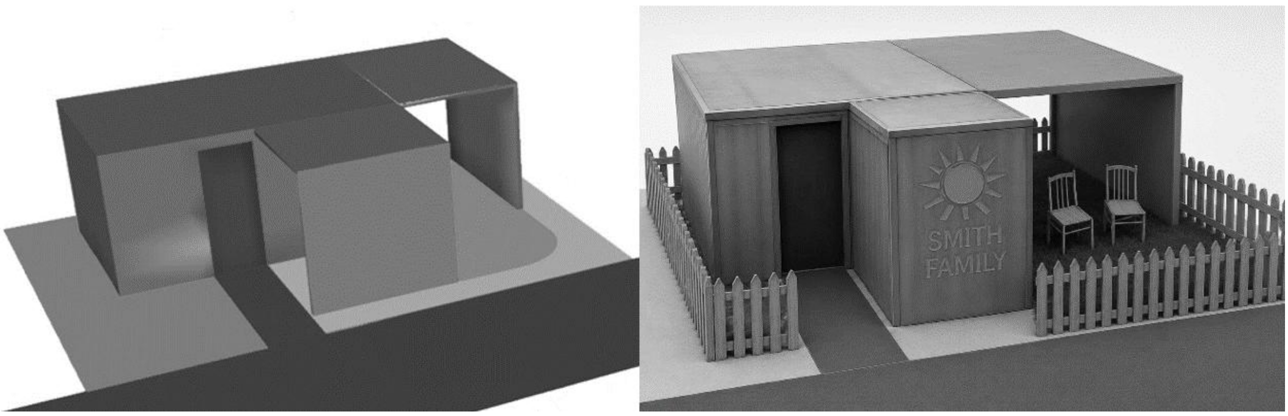


**Figure 5.** 3D view of an example parcel unit generated by the algorithm, and a rendering of another parcel unit which has undergone an exemplery set of user modifications, which differentiates the parcel unit from neighboring ones.

The spatial parameters in the algorithm, available for manipulation by the designer, are listed in Table 1. The parameters consist of dimensions of the shelter and parcel. Their constraints are set in compliance with the spatial standards mentioned. The distance between shelters is constrained to be more than their height and active open spaces are allocated unlike traditional layouts. The constraints were further tuned, aiming to provide units of usable sizes. For example, an extension generated by this algorithm may have a minimum area of 4.48 square meters with width-to-depth and depth-to-width ratios ranging between 0.5 and 2. This makes the extension convenient in the case household members decide to modify it to make an additional room. By parametrizing the spatial constraints, PDSs may be spatially designed more efficiently.

**Table 1:** The parameters in the algorithm available for manipulation by designer, with their constraints given in meters.

| PARAMETERS | Minimum | Maximum |
|---|---|---|
| Shelter width (w) | 3.5 | 4.4 |
| Shelter depth (d) | 2.24 | 2.8 |
| Shelter height (h) | 1.8 | 2.6 |
| Door distance from side | 0.4 | 1.8 |
| Door width | 0.6 | 0.8 |
| Parcel width | 8 | 10 |
| Parcel depth | 6 | 8 |
| Extension 1&2 heigh | h | h |
| Extension 1 width | 2 | generated |
| Extension 1 depth | d | d |
| Extension 2 width | 2 | generated |
| Extension 2 depth | w/2 | w/2 |
| Setback distance back | 0.6 | 1 |
| Setback distance front | 0.6 | 1 |
| Setback distance left | 0.6 | 1 |
| Setback distance right | 1 | 1.5 |
| Service road width | 3 | 6 |

To assist livability, active open spaces are utilized inside parcels. To further enhance livability, user modifications are supported by utilizing a spatial interpretation of the incremental design approach. This spatial interpretation of the incremental design approach foresees leaving the open spaces in each parcel and the extensions of the shelter incomplete, inviting user modifications while also guiding them. The open space in each parcel is divided into four spaces, namely; open hard surface, semi-open hard surface, open soft surface, and semi-open soft surface (Figure 6). The semi-open soft and hard surfaces are produced by the shelter extensions. The variety in open spaces allows a variety in modification options. These open and semi-open spaces may be modified to become additional rooms, kitchen gardens, playgrounds, animal shelters, sitting areas, passages or any other function the users prefer. This approach aims to support identity and sense of place by encouraging modifications while preventing disorganized user modifications by guiding the modifications.

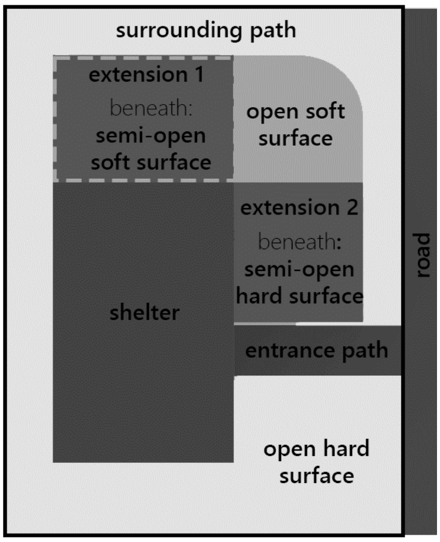


**Figure 6.** Top view diagram of one parcel unit.

Another contribution to livability is by supporting community cohesion. The algorithm mirrors the initially generated parcel unit along the axis on its shorter side which accomodates the open hard surface, generating the neighboring parcel. Then, it mirrors the two along the axis in the middle of the service road and generates another pair of parcel units on the opposite side of the service road (Figure 7). This module of four is repeated throughout the settlement. This way, the open spaces inside each group of four parcels become visually connected, supporting social interaction within these parcels, boosting livability. Furthermore, two adjacent parcels can be merged later by users, if the household size requires it. This type of a modification also merges the neighboring open hard spaces seamlessly, providing a wider open space for one household. Example renderings of a module of four parcel units in an exemplary post-disaster settlement (PDS) generated by the algorithm, before and after the mentioned modifications, are shown in Figure 8. In short, community cohesion is supported by further enriching the modification options by making the merge of the open spaces possible in neighboring parcels.

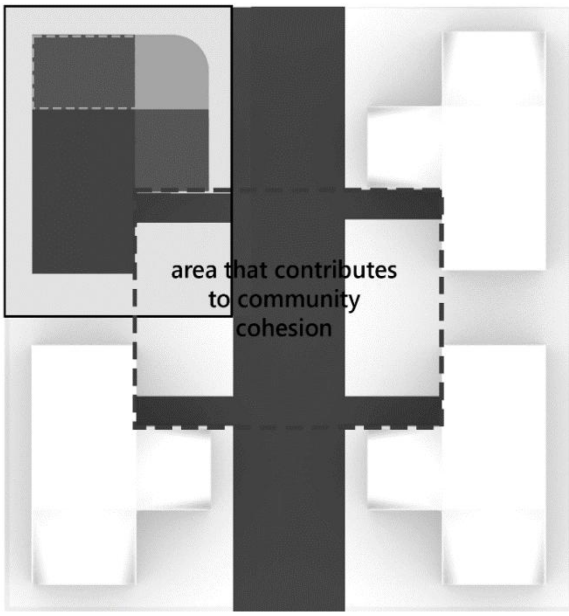


**Figure 7.** Top view diagram of one module of four parcel units.

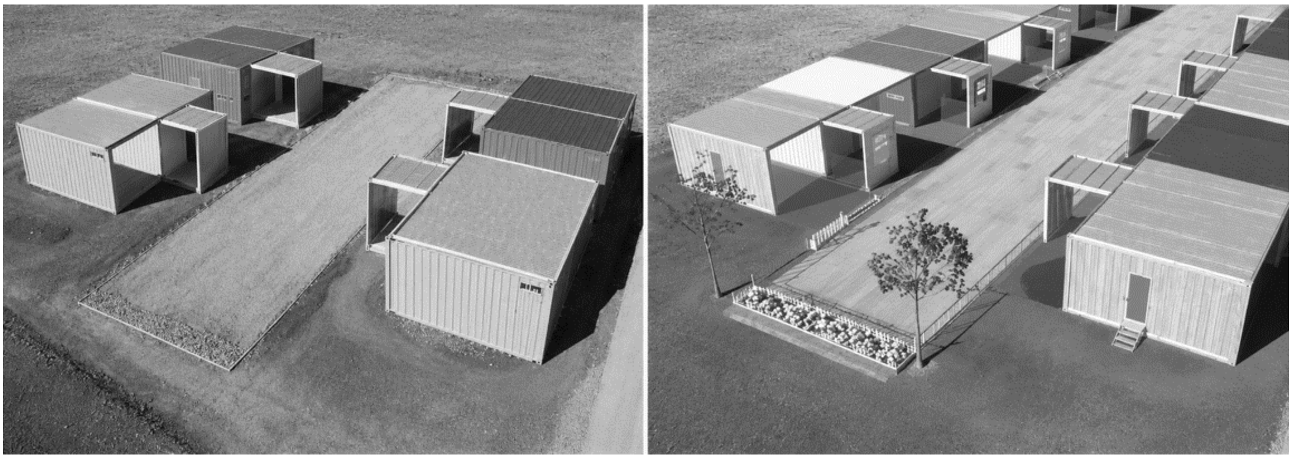

**Figure 8.** Example renderings of a module of four parcel units in an exemplary post-disaster settlement (PDS) generated by the algorithm, before and after the mentioned modifications.

**5. Discussion**

The main purpose of this study was to assist blurring the line between the response and recovery stages. Traditional approaches often prioritize speed during the response stage, while ignoring long-term occupation. The findings of this study suggest that the conflict between having insufficient time for designing and long-term viability of post-disaster settlements (PDSs) may be alleviated utilizing the rapid nature of computers. Through the use of a generative CAAD framework, spatial layouts were rapidly produced within the respected spatial standards while also acknowledging livability criteria.

One implication of the study is that livability criteria commonly discussed qualitatively may be translated into actual spatial design. The spatial standards quantitatively ensure minimum levels of safety, sanitation, and privacy, yet they do not answer many of the qualitative needs in recovery stage. Within the livability criteria, concepts such as user modifications, identity and sense of place, and active open spaces are desirable objectives in PDSs, yet they are rarely implemented directly into the methods by which the settlements are spatially designed. In many cases, these qualities are evaluated after construction or addressed through later interventions. The proposed framework adopts a novel approach by incorporating livability criteria within the microsystems, into the generation process itself. In this respect, livability is treated not only as an assessment criterion but also as a design input.

This study also serves as an experimentation on the utilization of the incremental design approach. As a novelty, this methodology utilized the incremental design approach in the generation of open spaces. It is known that users apply modifications on their shelters mostly on outdoors; so, the consideration of the open spaces in incremental design framework is necessary. The results indicate that open spaces can play a more active role in post-disaster settlement design than is commonly assumed. Rather than functioning as residual areas between shelters, these open spaces become potential places modifications. This framework, therefore, activates the passive open spaces in parcels by making them viable for modifications, even encouraging them. Furthermore, a variety of modification options were created so that the parcel units can have distinct identities following the modifications. This richness of options together with modification allowance and guidance, serves as a mean for creating identity and sense of place later, by users. Since the effectiveness of the incremental design approach is already known, this spatial interpretation of it as employed in this work is also justified.

## 6. Conclusion

This study demonstrated the potential of a computer-aided algorithmic design (CAAD) framework for supporting the rapid spatial design of post-disaster settlements (PDSs). The spatial constraints implemented within the algorithm ensured compliance with widely accepted spatial standards. The generated layouts maintained appropriate ratios between shelter units and open spaces while also respecting minimum distances between shelters, thereby ensuring fire safety, sanitation, and privacy requirements.

The implementation of spatial standards enabled the integration of active open spaces within shelter parcels. These spaces not only support social interaction, but also allow and guide future user modifications. Although the effectiveness of modification guidance requires verification through real-world applications or dedicated evaluation metrics, the study contributes to addressing the modification-related problems frequently discussed in the literature on post-disaster settlements.

This research also draws attention to the issue that is often overlooked which is the prolonged occupancy in PDSs. The proposed framework addresses two major challenges in post-disaster settlement design: limited design time and low livability. The rapid processing capacity of CAAD supports time-sensitive design processes by enabling the instant generation of shelter layouts once the spatial data and shelter parameters are defined. At the same time, livability is enhanced through the incorporation of active open spaces that encourage social interaction and support identity formation and sense of place.

In addition, the study adopts an interpretted incremental design approach to support and guide user modifications within parcels while maintaining the coherence of the overall design of the settlement. The allocation of four different spatial configurations within each parcel further enriches modification possibilities and adaptability to changing household conditions.

While the spatial standards applied in this research were verified through comparative analysis, the livability-oriented aspects of the framework require further evaluation through simulation-based or real-world studies. Future research may extend the framework by incorporating meso- and exosystem scales into the design process. Furthermore, the spatial constraints used in the algorithm may be refined according to cultural preferences, universal standards, or individual needs. Finally, establishing measurable evaluation criteria for livability in PDSs remains an important direction for future studies.

**Acknowledgements**

No non-authorial contributions were received.

**Funding**

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

**Conflicts of Interest**

The authors report no conflicts of interest.

**Data Availability Statement**

The research materials supporting this study are not publicly available.

**Institutional Review Board Statement**

Not applicable.

**CRediT Author Statement**

Conceptualisation: M.Y.; Methodology: M.Y.; Investigation: M.Y.; Visualisation: M.Y.; Writing – original draft: M.Y.; Supervision: A.G.; Writing – review & editing: A.G. All authors have read and approved the final manuscript.

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