

Developing functional requirements for Temporary Housing by integrating Axiomatic Design with the 5 Gaps Model of Service Quality

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Abstract. Temporary Housing (TH) schemes are a controversial component of post-disaster recovery plans, and yet they offer a fundamental service to the homeless population. Their sustainability should be understood and addressed in terms of service quality for all clients, rather than as a matter of product engineering. Since the evaluation of service quality is different from that of goods, value in TH assistance should be measured according to how well it matches clients' expectations. This paper adopts the 5 gaps model of service quality as a framework for TH quality assurance and advances that closing the current performance gap requires tackling issues in the briefing, design, project execution and conformance phases, as well as in communication. Against this background, engineering methods such as Axiomatic Design (AD) can effectively be exploited to reduce the gap between what people want and what they get, considering the needs and objectives from humanitarian actors. Results indicate that AD can reveal conflicts and potential for cooperation between the many "clients" of TH, via the joint analysis of their different needs, and the associated Functional Requirements (FRs) and illustrates via a post-factum analysis what mechanisms need to be in place to ensure better preparedness for future disasters.

1. Introduction and background

This paper explores the integration of Axiomatic Design (AD) to the 5 gaps model of service quality, proposing a framework for Temporary Housing (TH) quality assurance using AD as a means to close performance gaps related to issues in the briefing, design, project execution, conformance phases and communication which happen throughout a TH project delivery. It illustrates the proposal using the 2016-2017 Central Italy earthquakes as a case study focusing on exploring Functional Requirements (FRs) from its two main 'clients': the affected communities (called 'Client 1'), the beneficiaries of the service, and the Public Administration (PA, called 'Client 2'), responsible to deliver the service.

Why are TH actually a service? In contrast with building-centered or product-centred approaches to housing emergency management and Disaster Risk Reduction, temporary housing is increasingly understood as a verb, more specifically as a continued effort to support people's health, security and

livelihood [1]. This means TH requires providing culturally and technically adequate housing and neighbourhood conditions to local communities, its main beneficiaries, but also promoting sustainable building construction practices and employing local resources, responding to governmental objectives related to efficiency and efficacy in project delivery considering its whole life-cycle [2]. These requirements qualify TH as an urban planning service (an intangible component having the distinctive function of supporting a full recovery post-disaster) to the affected communities, and a critical component of building sustainable cities and society to the PA.

In Italy, the TH supply and delivery process involves several actors and stakeholders, among which designers and engineers commissioned by the PA, including the National Department of Civil Protection (NDCP), which is responsible for delivering the service ('Client 2'), as well as TH beneficiaries, i.e., the affected communities displaced by the earthquake ('Client 1') [3]. For experts, reconciling the views and needs of these multiple clients in TH design and site planning is a complex task, which requires a careful management of operational decision-making components - especially those with potential for conflicts' generation [4] – and the consideration of organisational aspects, resources, plans and information from the part of the PA responsible for project delivery.

An important part of a service delivery process, in the built environment, is customer satisfaction, in which a considerable part of it is related to customer perception (ISO 55002), [5]. Customers' perception of the housing building service is important in housing construction projects, as ad-hoc adaptations to a set of non-standard situations are often needed [6]; what applies also to the construction of TH sites after disasters. *The quality of the TH assistance service depends on how it is perceived by all clients*, during the design and construction stages and beyond (e.g., if maintenance and/or buy-back options are included in the TH procurement document). Even when time and budget targets are met, several projects fail to realise the intended value –understood as a manyfold and multi-domain concept - due to approach inconsistencies, misalignments in decision-making, and a reductive focus on costs and project financing rather than on whole-life performance [7].

Thus, to improve, and possibly even measure, TH assistance value, we suggest linking AD [8] and the 5 gaps model of service quality by [9] within a novel TH delivery framework as outlined in Section 2. This will support a joint analysis of multiple clients' needs, revealing conflicts as well as potential for cooperation between top-down and bottom-up inputs. Specifically, in the analysis of a selected case study in Section 3, the 2 main clients of TH plans are separated to better administer the gathering of Customers' Needs (CNs) and discuss associated FRs. The conclusions situate the proposal within the need to support the reconciliation of TH schemes with the context-dependent value drivers of different clients and national disaster recovery policies. This is understood as the first step to address quality assurance in TH planning and control gaps in procuring, designing, and delivering sustainable TH solutions to resolve and/or prevent technical and community clashes associated to TH sites' location and layout choices, as well as TH units' design.

2. Hypothesis and methods: linking TH, AD and the 5 gaps model

[9] advance that clients' evaluation of services quality is different from that of goods, as their satisfaction depends on how well the perceived value of a services matches their initial expectations. Thus, in the 5 gaps model, they use this consideration to define the TH project performance gap (Gap 5), which is seen as the combined result of four different sub-gaps. Using the terminology of [10], who merged the 5 gaps construct with a "project as an information process" model, these four sub-gaps correspond to the briefing (Gap 1), design (Gap 2), execution and conformance (Gap 3) and communication (Gap 4) problems.

According to [11], in each gap service quality can be evaluated according to 5 key determinant dimensions - reliability, responsiveness, assurance, tangibles and empathy - which apply at different stages of service delivery and with different weightings. These, coincide with some of the issues identified as critical in [4], and respectively: (i) TH assistance consistency of performance; (ii) readiness of TH service; (iii) competence of humanitarian professionals to perform necessary tasks and/or deliver the service considering its whole lifecycle; (iv) physical outcomes for process tracking; and (v) attention

to all clients' needs. Figure 1, shows how the 5 gaps model can be applied to the case of TH assistance delivery, for identifying where methodological innovations are needed to reduce current gaps and enhance TH service quality.

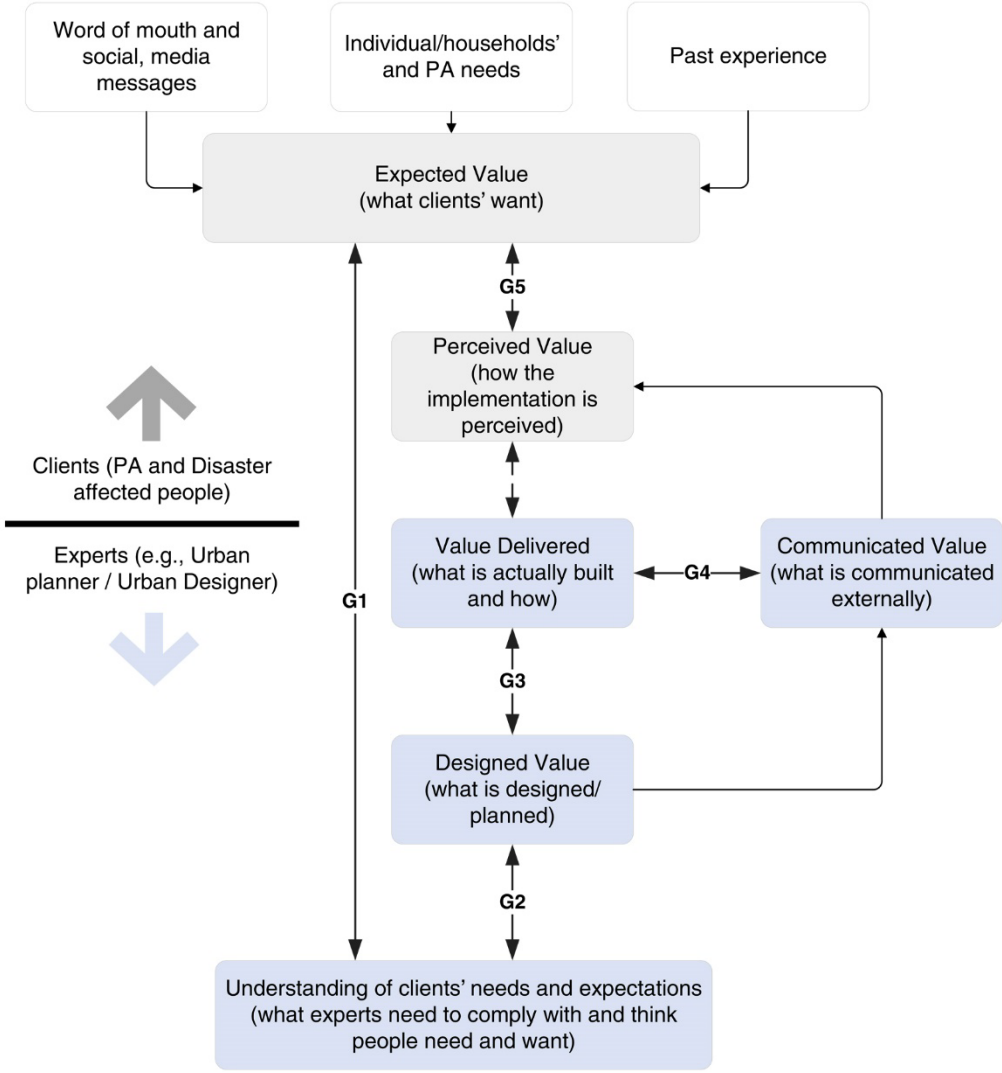


Figure 1. 5 gaps model of TH assistance service quality.

This study advances that AD can be linked to the 5 gaps model and support quality improvements in TH provision by closing Gaps 1, 2 and 3, ultimately reducing the TH performance gap. Figure 2 shows that some conceptual correspondences exist between AD and the 5 gaps models. In fact, both refer to multiple domains in which: people's needs are understood (customer domain); functional requirements are specified (functional domain); design parameters are chosen to meet the brief (physical domain); and the implementation process is set up to adequately reflect the design intention (process domain). Accordingly, AD could effectively support the mapping of CNs for determining TH functional requirements and their systematic decomposition (Gap 1), the mapping of independent relations between these and candidate Design Parameters (DPs, Gap 2) and the TH supply and delivery process (Gap 3), considering input constraints, by specifying problems and solutions explicitly, in parallel, following a hierarchical order while maintaining data [8]. This proposal aligns with that of [12], who pose that AD could enhance the reliability of disaster response operations, as reliability is one of the 5 key service quality determinants identified by [11].

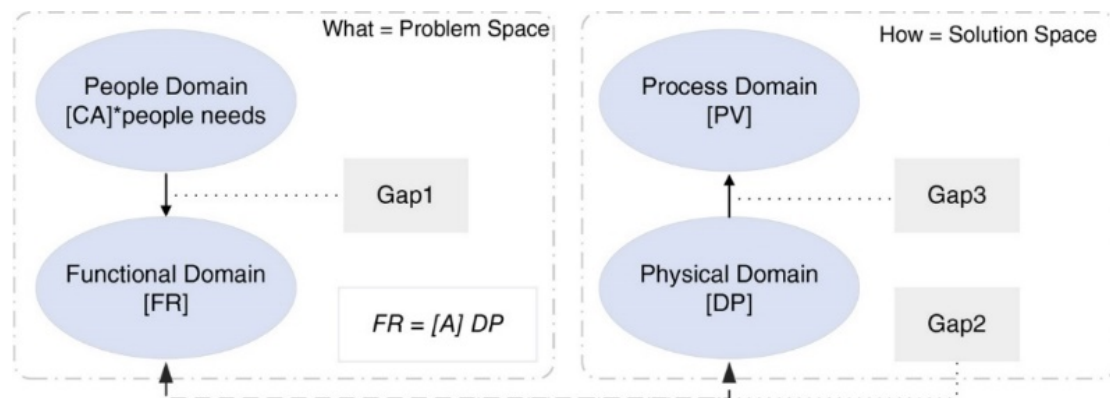


Figure 2. Axiomatic design model and associated Gaps.

Albeit originally intended for product design, AD has been successfully transferred to architecture to help problem-solving [13] and to service design [14]–[16]. For instance, in [14], the authors pose that the mirror decomposition through zigzagging between the functional, the physical and the process domains enables focusing designer’ attention on CNs. In this case, AD is used to design web services for remote patient monitoring by systematically detecting the FRs of all the stakeholders considering also their interactions. [15] use AD to build a framework for optimising the flow of patients in hospitals to improve the efficiency of health services. In [16] AD is adopted to suggest improvements to the service offered to passengers with reduced mobility in airports by linking CNs with process components. These studies address specialised services which require complex process choreographies with several actors, while keeping a focus on costumers’ needs. The authors of this paper pose that the TH assistance delivery process presents similar characteristics, and hence, could be effectively approached by adopting AD to close service quality gaps, while taking into accounts the CNs from all stakeholders.

This point is illustrated in what follows, where AD is exploited to address the TH briefing problem in a suitable test case, covering Gap 1 of the service quality framework. The case of the 2016-2017 Central Italy earthquakes is used to illustrate the approach and explore the setting and reconciliation of a selection of high level FRs from the service deliverer, the PA (Client 2), to the affected community (Client 1).

3. The two clients: conflicts and overlaps in the Italian case.

Identifying high-level FRs starts by independently mapping in detail the needs and aspirations of both clients, so they can be analysed to assess the presence of matches (common FRs), explore the overlap of tolerances when FRs converge (completely or partially) and flag potential conflicts between FRs from Client 1 and Client 2, so they are assessed with regards to their logical inconsistencies. The authors adopt a traffic light system to label these different types of FRs denoting:

- ‘G’ (green) to FRs which are either common or completely converge with regards to tolerances required from Clients 1 and 2.
- ‘A’ (amber) to FRs which partially converge with regards to tolerances required from Clients 1 and 2.
- ‘R’ (red) to FRs which are in conflict and are flagged for special scrutiny in a context-based analysis as: (i) they might be ignored by Client 2; (ii) their range of tolerances might have no overlap with the range of tolerances for Client 1 FRs; or (iii) their simple proposition might conflict with FRs from Client 1 altogether.
- ‘N’ (neutral) to FRs which are from Client 2 only and do not necessarily affect Client 1 expectations, needs or aspirations.

As pointed by [8] the writing of FRs is one of the most important parts of a design process and can take several iterations so conflicts are avoided and convergences are carefully crafted so the needs of multiple stakeholders are addressed. The authors therefore focus on assessing FRs from Clients 1 and 2 by inferring them based on CNs selected from different documentary sources. To detect the needs, and in some cases the FRs themselves, of the PA (Client 2), the TH procurement documents used in Central Italy, namely the “Capitolato Tecnico D’Appalto” [17] and [18] are used as core references together with the Sphere handbook [2], which is a key international standard used by most NGOs and governments in post-disaster situations. These documents also allow extracting systems constraints (Cs), i.e., bounds on acceptable solutions, which in this case are identified as regulatory restrictions related to the provision of TH in Italy.

In the Italian case, the definition of the TH brief involves multiple experts, who, in different phases, contribute to its refinement. The process begins with the loose drafting by the NDCP of the technical document of the strategic framework agreement for TH post-disaster procurement (in forth referred to as the “Capitolato”). This seeks to translate TH needs into a set of “solution neutral” FRs about TH supply and delivery. Tender’s participants respond to the brief by presenting a technical and an economic offer (including the design of TH units), detailing the service they will provide. The actual number and type of TH units needed (including for instance special accessibility requirements) is decided by public authorities only after a disaster strikes, following a detailed assessment of damage to the housing stock and of TH needs. Next, candidate TH sites’ locations are identified. When the plots become available for construction, the TH purchase order is raised, and the supplier is contracted to design the layout of the TH sites by the PA. The professionals working for the supplier, i.e., experts in the firms’ technical office, need to translate the requests detailed in the supply order into a workable project brief, by refining the lower-level constraints and FRs, considering all the contractual, regulatory, site-specific, planning and design inputs. Within this framework, civil protection actors seek to include in the strategic brief of the “Capitolato”, in later executive ordinances, and in the purchase orders their understanding of people needs, translated into Client 1 FRs. The same is presumably done by town planners and designers, according to their professional ethics, albeit normally within the framework set up by the PA, and possibly through a negotiation process with other stakeholders. Thus, the final list of FRs for TH units and sites is determined following what seems to be a mainly top-down and multi-staged process.

Although, in principle, the community should be directly involved in the process of defining the project brief to implement a truly people-centred TH programme, the way the TH assistance delivery process is currently organised makes this task particularly challenging, especially due to its tight time constraints. In addition, organisational and technical constraints may as well prevent civil protection actors from delivering what disaster-affected people expect. Thus, to detect the needs of TH occupants (Client 1) this work uses a mix of first [19] and secondary information [20] from official documents and semi-structured interviews.

3.1. Context independent common FRs

Some important common FRs, which open the door for setting converging tolerances in relation to DPs required to fulfil them, are illustrated in Table 1 (all assigned to group G). These mainly come from non-context specific documents such as [2] (used as guidance by humanitarian agencies) and – albeit in minor part - the “Capitolato”, which attempt to respond to the needs and aspirations of both clients in coordination.

Table 1. Common FRs which are context-independent either at a national or international level.

FRs from Client 1 & Client 2
Site planning and design
G.1 - Optimise delivery timing.
G.2 - Provide water, sanitation facilities and drainage.

G.3 - Locate new settlements at a safe distance from actual or potential threats and/or remove hazard from sites and repair any serious environmental degradation.

G.4 - Provide acceptable distance and safe travel (or transport) to essential services and facilities.

G.5 - Provide essential services and livelihoods opportunities including child-friendly spaces, gathering areas, and spaces to respond to religious needs.

Housing Design

G.6 - Provide living space, toilet and bathing facilities, spaces for sleeping, food preparation, cooking and eating, socialising, and play areas¹.

G.7 - Provide optimal lighting conditions, ventilation, and thermal comfort.

G.8 - Consider local culture and lifestyles

3.2. FRs from Client 2 – Anticipating issues

FRs from Client 2, listed in Table 2, are found both in context-independent documents (in [2] Client 2 is not uniquely defined and could be the local PA as well as an international NGO) as well as in country-specific strategic documents related to the case study under examination [17], where they are stated as duties of the PA. These FRs mainly refer to speed of delivery and catering for social and environmental sustainability and can be understood as convergent with community FRs. However, since tolerances for these might vary between what is expected from the two different clients, they are labelled as ‘A’ rather than ‘G’. These FRs should be carefully analysed with regards to the range of tolerances expected by each client, to ensure they have at least some alignments so they can be resolved throughout the design process.

Table 2. FRs from Client 2 assessed with regards to how they align with expectations from Client 1.

FRs from the Public administration (Client 2)

Site planning and design

N.1 - Optimise cost-efficiency.

N.2 - Ensure modularity in TH solutions and site layout.

G.9 - Restore TH site after occupation to allow the local population to use it.

A.1 - Consider the placement of essential services within the settlement, if possible.

A.2 - Consider the expected lifespan of the settlement to determine what essential services may need to be expanded or developed.

Housing Design

N.3 - Use environmentally sustainable construction techniques and materials.

G.10 - Ensure that price and quality meets market standards.

G.11 - Ensure any energy supply options meet user needs, and provide training and follow-up as needed.

A.3 - Salvage and reuse, recycle or re-purpose available materials, including debris.

In addition to these, and as part of the duties from Client 2, it is not uncommon to find constraints related to the urban context which imply working within a geographically defined area-based approach to better understand community dynamics and demands to follow standards for safety, protection and dignity in

¹ Here tolerances may need to be adjusted at lower levels as what is considered sufficient in terms of space by different clients is context dependent.

construction and planning, ensuring public health and safety as well as providing physical security, dignity, privacy, and protection from the local weather. For transparency purposes [21], it is also expected that Client 2 follows appropriate and traceable tender, bidding, procurement, contract and construction management processes and codes of conduct.

3.3. *The reality brought by adding context – Mismatch of tolerances and potential conflicts.*

When examining a real context and seeing FRs from the PA (Client 2) and the community (Client 1) involved in the Central Italy earthquake of 2016, the situation gets far more complex than what is assessed in sections 3.1 and 3.2. FRs in [18] and in the many disaster-specific NDCP ordinances issued from 2016 to 2018 get far more specific, and pragmatism needed from the PA to deliver TH plans using established resources can easily overwrite community FRs related to demographics and sense of place.

Table 3 uses the same traffic light systems adopted in sections 3.1 and 3.2 to assess commonalities, explore the overlap of tolerances and flag potential conflicts between FRs from Client 1 and Client 2. The reality of the Italian case study shows that when FRs are defined for a given context, special attention needs to be dedicated to their writing at lower levels, considering the range of tolerances expected by each client to ensure minimum alignment for DPs to fulfil them. For instance, some of the disaster specific FRs from the PA (e.g., A.7, A.8, A.13) present a rather limited range of tolerances which can well be in conflict with FRs from the community (e.g., R1, R4 and R2) once further decomposed into second level FRs. In fact, Table 2 shows that most of the conflicting FRs identified (R.2 - R.8) can arise from decomposing high-level FRs into low-level ones, exposing a set of community FRs not featured as part of TH project objectives.

Table 3. FRs from both clients extracted from [17], [18] and observations and interviews with the community.

FRs from the Community (Client 1)	FRs from the Public Administration (Client 2)
Site planning and design	
<u>G.12 - Minimize land use change and keep people close to destroyed areas.</u>	
R.1 - Provide design solutions which fit accessibility in mountainous context.	A.5 - Provide design solutions which respect site topography.
R.2 - Provide collective structures and plenty of green areas for urban gardening.	A.6 - Provide green infrastructure with local species or suitable to local climate inserted in the local landscape but with minimal plants and urban furniture.
R.3 - Provide paved walkways to access TH units, which don't get muddy when it rains.	A.7 - Provide hierarchical internal road and pedestrian path infrastructure with 2 parking spaces per TH unit.
	N.4 - Optimize construction speed.
Housing design	
<u>G.13 - Connect TH units to the grid for water, energy electricity, sewage, phone, gas.</u>	
R.4 - Give special consideration to accessibility for the elderly.	A.8 - Provide 3 TH units typologies (40, 60, 80 m ² to host a max of 2,4,6 people respectively) with 20% of these ensuring disabled accessibility if necessary.
R.5 - Provide spaces to house caregivers to those without easy access to care services.	A.9 – TH units' structure needs to be prefabricated and units to be combined to reach two-stories with external individual access.
R.6 - Ensure energy systems provided are affordable.	A.10 - Use passive design strategies and minimise thermal energy demand.

R.7 - Provide climate responsive roofs & plumbing.

R.8 - Provide complete design including finishes, and easy to maintain.

A.11 - Ensure TH units are flexible and adaptable to change of use in the same site and removeable.

A.12 - Ensure TH with a minimum lifespan of 10 years fully furnished and ready to use.

A.13 Provide external private spaces for THs with 25% of net floor area.

Table 3 shows that as soon as a context is brought into place and FRs need to be further decomposed towards the development of a tangible solution, the lack of community involvement on the process becomes not only evident but also a potential problem. Narrow tolerances for overlaps as well as conflicts are unfolded as potentially unsolvable whereas they could have been resolved through early consultations and iterative conversations among Clients 1 and 2 throughout the decision-making process. Since time is a tight constraint for emergency management in the aftermath of a disaster, a post-factum analysis of this sort is essential to extract lessons to be learned for informing future endeavours. An important one is that community interactions should be featured in preparedness plans in a pragmatic way to ensure a better post-disaster response.

4. Conclusions and suggestions for future work

The post-factum application of AD to the analysis of the case of the 2016-2017 Central Italy earthquakes enables lessons to be learnt from a strategic TH procurement, policy, and tactical planning perspective. Results indicate that the Italian PA should revisit its approach to problem definition. They also show local authorities should raise awareness of disaster risk and engage with communities likely to be affected by future hazards about TH response plans to discuss FRs with them early, as part of preparedness. In this way both clients would already know each other and be therefore in a better position to ensure FRs from Client 1 are extracted rapidly when needed so design objectives can be negotiated/reconciled promptly. The relationship between candidate DPs and the resulting FRs could then be systematically mapped on a case-by-case basis using the matrix representation $\{FR\} = [A] \{DP\}$, to check for factors' independence and enhance the completeness, consistency, and plausibility of processed information, enabling the delivery of more sustainable and context-based design proposals. As construction supply chains as well as climate and culture can change from region to region, this approach could support a shift of focus from the design of universal shelter solutions to the proposal of a sound design workflow without slowing down the process of TH assistance delivery.

The aforementioned case can well be used as a prompt to consultations with a focus on rehearsing mitigating mechanisms to refine and/or re-write conflicting FRs and poorly convergent tolerances, as proposed by [8], so that they can more flexibly accommodate a successful design response at a time of crisis, by for instance:

- Increasing the range of FRs' tolerances.
- Increasing the range of DPs' tolerances.
- Integrating DPs to respond to multiple FRs.
- Searching for independent FRs.
- Negotiating and establishing priorities between FRs so a strategic plan can be in place.

Notably, the analysis made a simplification in the number of clients and related needs to be considered in post-disaster situations which in reality is rather large and could extend, for instance, to comprehend NGOs, volunteers and other local residents in addition to TH occupants and the PA. The latter can also be further subdivided into national and regional governments, different local authorities, professional bodies, the army, different civic protection bodies etc. Nevertheless, AD does not differentiate according to their number. On the contrary, it enables to flexibly reconcile all clients' needs within a unique framework without considering the distinctive characteristics of different clients and

their different power relations which can visibly play a role in the FRs' selection and refinement processes.

Future work should therefore focus on investigating and developing mechanisms to ensure all different stakeholders, especially Client 1, are involved from the beginning in the TH decision-making process so the 5 gaps framework in connection with AD can be effectively applied when a disaster strikes, preventing it to simply pay a lip service to the affected community. Better preparedness plans are indeed essential to enhance technical procurement documents for TH supply and delivery services. By embedding in those the possibility to include the value drivers of all the clients of TH schemes in different contexts, designers will be better instrumented to perform the hard task of rapidly delivering context-sensitive TH solutions which foster the sustainable recovery of settlements impacted by rapid onset disasters.

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