Framework for developing a Disaster Resilient Society

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The geographical and temporal span of zones, where life and ecology are exposed to risk of disaster are rapidly increasing. Apart from the severity of a hazard, a society's preparedness and response determine losses, survival and recovery, particularly during the critical first 72 hours. Most existing approaches focus on behaviour or management systems that are deployed after a disaster, and not in daily life prior to disaster. Nor do they provide a methodology for developing such systems. We propose a framework for developing a disaster resilience society (FDDRS). Its basis is a detailed, retrospective analysis of three projects aimed at developing disaster resilient systems. Its structure is derived from existing user-centric design methodologies.

FDDRS includes novel methods, like coupling, and existing methods and concepts such as redundancy and modularization. It is unique in its focus on including users and other stakeholders throughout the process, and in advocating dual-functionality and decentralization of infrastructure and services. FDDRS facilitates the development of systems that ensures their applicability in daily life. This is expected to result in a more intuitive, i.e., faster, response to a disaster, thereby reducing a community's vulnerability and improving the chances of survival and recovery.

Keywords: Disaster Resilient Society, Framework, Decentralization, Design Methodology, Engineering design process

1 Introduction

Unprecedented changes in our climate have led to the spread of events that are disastrous in numbers and magnitude, and the trend shows further acceleration. According to The World Bank "over the past 30 years, more than 2.5 million people and almost $4 trillion have been lost to disasters caused by natural hazards, with global losses quadrupling from $50 billion a year in the 1980s to $200 billion in the last decade. 2017 marked an even more alarming milestone in this trend, with $330 billion in global losses from adverse natural events" [1]. Many areas which previously were not in potential disaster zones have lately witnessed serious threats to life and ecology (Guha-Sapir, Hoyois, Wallemacq & Below, 2016).

[1] https://www.worldbank.org/en/topic/disasterriskmanagement/overview

The risk of a natural hazard causing a disaster not only depends on the severity of the hazard, but also on the vulnerability of a society. In order to abate serious consequences, a disaster resilient society is paramount. Society's preparedness and response determine survival and speed of recovery. In particular, the first 72 hours after a disaster are critical since those affected often have to rely on themselves until emergency services arrive (Public safety canada, 2013). The US National Institute of Standards and Technology found that a society which is trained and prepared for disasters is less vulnerable, less likely to experience disruption, less likely to suffer loss of lives, and is able to recover faster (NIST, 2016a; NIST, 2016b). It is important that reconstruction is: robust, so that assets and livelihoods become less vulnerable to future shocks; fast, so that people can get back to their normal life as early as possible; and inclusive, so that nobody is left behind in the recovery process (Hallegatte, Rentschler, & Walsh, 2018).

A large amount of work exists to reduce disaster risk (NIST, 2016a; NIST, 2016b; NDMC, 2017 & Abarquez & Murshed, 2004) have mainly focus on the development of dedicated infrastructures, such as evacuation centres or shelters to be deployed after a disaster. Not only can these infrastructures be expensive and time consuming to deploy as they are sometimes not available where needed (note the importance of the first 72 hour). Often such dedicated structures are effectively single use structures or services that will normally be under-utilized - or not used at all - and rare use leads to unfamiliarity among its potential users. Moreover, the consequences of failure of the proposed solutions is hardly addressed, if at all, even though this can exacerbate the disaster and recovery. The breakdown of centralised systems such as communication networks, power and water supplies, and transportation systems has grave consequences, as they cannot be restored locally. Recent frameworks and guidelines for disaster preparedness do emphasize the importance of developing community resilience and involving users (Abarquez & Murshed, 2004).

We propose a Framework for Developing a Disaster Resilient Society (FDDRS) based on a detailed, retrospective analysis of three projects conducted over the past five years by the Urban Risk Lab aimed at developing disaster resilient systems. These systems include infrastructure, organisation, services and other elements, as it is a combination of elements that ensures resilience. The projects were chosen because of the underlying unique vision on developing disaster resilience and managing disaster risk.

Systems for disaster preparedness:

- should not just be for use after a disaster has struck, but also play a role in daily life;
- should be able to withstand a natural hazard and function in the event of a disaster;
- should be co-created with the local community, i.e. users should be actively involved in all stages of development, from ideation to use and maintenance to ensure inclusiveness, usefulness and familiarity;
- should allow maintenance and restoration with local competences, tools and materials, and function.

In this paper, we outline the framework and its methods, emphasizing the methods that are specific to reducing disaster risks. In Section 2 we review existing approaches for disaster risk management. Section 3 describes the research methods used to analyse the three

Urban Risk Lab projects. The results are presented in Section 4. In Section 5 we reflect on the framework and outline future work.

2 Review of existing approaches for disaster risk management

The UN's report "Living with risk" (UNISDR, 2004) emphasises the need for a disaster resilient community. In the "Sendai framework for Disaster Risk Reduction," the UN proposes a set of guidelines at an international level. The framework highlights the importance of protecting and strengthening resilience across people, communities and countries, and recommends anticipating and planning the reduction of disaster risk to intricate eco-systems, such as "livelihood, health, culture heritage and socio-economic assets" (UNISDR, 2015, p.10). The Association of Southeast Asian Nations strongly encourages participation of local community (ASEAN, 2016).

A variety of other approaches, frameworks, guidelines and recommendations differ in levels of detail - from general guidelines to dedicated processes - and focus - from infrastructure robustness to community preparedness.

Table 1 enumerates four frameworks that are relevant for us as they focus on reducing risk by developing community resilience through a combination of infrastructure and non-infrastructure solutions. We looked at: a) size of system: large (national or global), medium (regional or urban), small (communal or individual); b) type of proposal: process description or guidelines; c) approach: centralised or de-centralised; d) site specificity; and e) level of user involvement: high (from planning to development and beyond), medium (from need finding, evaluation of prototype to testing of the final solution), and low (restricted to need finding and testing of the solution).

Table 1. Frameworks and guidelines for disaster risk management

	Features				
	Systems	***Proposal***	***Approach***	***Site specificity***	***Community involvement***
Community resilience planning guide for buildings & Infrastructures systems (NIST, 2016a & 2016b)	Large	Process	Centralised	National (U.S.A)	Medium
Myanmar national community resilience framework (NDMC, 2017)	Large to small	Process	Centralised	National (Myanmar)	Low
National preparedness system (FEMA, 2011)	Large to small	Guidelines	Centralised	National (U.S.A)	Medium
***Community Based Disaster risk management (CBDRM)* (Abarquez & Murshed, 2004)**	Small	Process	N.A	International (South east Asian Countries)	High
City Resilience Framework (CRF) (Arup and the Rockefeller Foundation, 2014)	Medium	Process	N.A	International	Low

The US NIST planning guide (NIST, 2016a; NIST, 2016b), proposes an interesting 6 step process with a focus on community resilience for built environments at the local level. Performance goals are informed by the needs of local residents and social institutions. The built environment includes buildings and infrastructure systems for power, communication, water, transportation and waste. We note that a critical point of such infrastructures is their scale and transferability: too costly for many countries and sites; too time consuming to plan and build, and inherently inflexible for use in rapidly changing situations; and, as mentioned earlier, failure of such systems critically affects recovery. Interestingly interactions between "natural capital, built and physical capitals, as well as financial, economic, human, social, political, and cultural capitals” are not addressed. These interactions have a compounding impact on risk magnitude and thus on risk reduction strategies.

Myanmar’s National Disaster Management Committee (NDMC, 2017) framework describes an inclusive process to reduce risk at the household and community level, with three objectives: promote a common understanding among stakeholders; propose coherent approaches with community and rural development; identify potential opportunities for implementing measures to strengthen disaster resilience. However, the sectors on which to focus are predefined, such as rural livelihoods and village, infrastructure, and urban development, limiting the spectrum of possible solutions. The framework also discourages stand-alone projects, as they are expected to be non-scalable. Independent, local solutions, however, may work when the network inherent to the centralized systems fails.

The US National Preparedness System (FEMA, 2011) outlines a national initiative aimed at developing capabilities and resources “across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk”(FEMA, 2015, p.1), such as natural disasters, acts of terrorism, and other disasters. Various tools and resources are made available. Potential indicators and measures of community resilience are under development. NPS includes the National Disaster Recovery Framework (FEMA, 2016) that provides principles for recovery and responsibilities of recovery coordinators so that the communities can rebuild faster and safer. Individuals and communities are kept informed and can comment on the documents.

The Community Based Disaster Risk Management (CBDRM) approach, which focuses on south east Asian countries, actively involves communities at risk in the identification, planning, implementation, monitoring and evaluation of risk reduction strategies (Abarquez & Murshed, 2004). CBDRM also addresses socio-economic issues linked to risk reduction measures, such as gender, poverty, poor governance and discrimination. However, the focus in more on proposing a "conceptual framework" for community participation in order to train and actively engage them in assessment and management processes. It does not provide a systematic approach and details of how to exactly develop strategies and reach up to a practical solution.

The city resilience framework (Arup & the Rockefeller Foundation, 2014) consists of 4 categories: health and well-being, economy and society, infrastructure and environment, and leadership and strategy, to complement the development of a resilient city through proper assessment of resiliency, identification of critical areas and needful actions in those areas.

In addition to these five approaches, the set of 18 principles and practices for disaster risk reduction (DRR) formulated by John Twigg (Twigg, 2015) are relevant for our work. He derived these from a review of experiences and practices with real projects. Such a list can obviously never be exhaustive given the varied nature of disasters and contexts in the reviewed projects but is nevertheless very useful. We strongly believe, however, that it requires the embedding of principles and practices in a structured approach to effectively reduce disaster risk.

Based on these notable contributions, we conclude that all focus on behaviour or solutions to be deployed during or post disaster, not as part of daily life prior to disaster. As mentioned before, this leads to unfamiliarity with the solutions and increases the vulnerability of individuals and communities, leading to a slower response and a larger impact of the disaster in terms of losses and recovery time.

The experiences of the Urban Risk Lab team led to an approach that attempts to address the aforementioned concerns. A study of three projects provided detailed insight into the application of and experiences with the evolving approach. The results of the case studies formed the basis of the framework we introduce in this paper.

3 Data collection and analysis of the three case studies

The three project that have been analysed are the following (see Table 2).

1. Haiti: In this project a national strategy in form of 9 evacuation systems, for 3 different sectors (education, economy and transportation) and 3 different topographies each, were proposed across Haiti. Multiple and flexible options for evacuees during emergencies were generated involving natural infrastructure to support risk-reduction and recovery. It particularly emphasizes the principle of accessibility through mobility and landscape.
2. PREPHub USA: The emergency preparedness hubs (or PREPHub) (Mazereeuw & Yarina, 2017) developed in this project aim to integrate disaster preparedness and response technologies into public infrastructure by activating surrounding spaces with useful lifestyle functions. In doing so the PREPHubs offer day-to-day community focal points and, hence, familiar points in case of disaster when they offer access to information, communication and electricity while being entirely off-grid. Prototypes were installed in different US cities.
3. PREPHub Nepal: This project aimed at translating the PREPHub concept to Nepal, where a historical Patti - a traditional community resting space – was converted into a PREPHub.

Table 2 Summary of three case studies.

Case study	***Project Goal***	***Natural hazards***	***User involvement***	***Project status***
National System of Disaster Evacuation Parks across Haiti	System with building and landscape infrastructure concept for longer period (evacuation and shelter, for long periods)	Hurricane, flooding, and earthquake	Medium	Conceptual design of strategies for sustaining systems
PREPHub USA	For preparing and recovery by disseminating information and providing tools to be used regularly. For shorter periods (72 hours w/o shelter)	Earthquake	Low	Prototypes (versions 1.0, 1.5, 2.0 and 3.0), tested on-site with users
PREPHub Nepal	Preparation and recovery for 72 hours using a converted traditional shelter	Earthquake	High	Complete infrastructure embedded into old structure

The project teams used and mentioned different approaches in each of the projects: no theoretical framework exists. We therefore chose Grounded Theory (GT) (Strauss & Corbin, 1994) as our approach.

3.1 Collecting Data

Data was retrieved by analysing all available project documents, such as journals, reports and log books. Semi-structured interviews with the project leader provided data about the sequence of activities, when this was not clear from the documents. We used 5WH questions to understand the core process because of its effectiveness in identifying the steps and activities, and their interconnections. Once patterns began to emerge, questions were asked about reasons behind transitions and decisions. A total of 14 interviews (700 minutes in total) were conducted over a period of 6 months, some of which involved multiple projects. Data on Project 1 was collected in 5 interviews, on Project 2 in 4 interviews, on Project 3 in 5 interviews and on other projects in 5 interviews, and evaluation of emerging process was done in 6 interviews. The interviews were audio recorded for ease of analysis.

3.2 Arranging and Coding Data

Grounded Theory based open and axial coding techniques were used. Open coding assists in generating categories (codes), classifying phenomenon and inferring meaning from large data set by segmenting and identification of repeating questions like "what is this about? What is being referenced here?". Axial coding uses inductive and deductive thinking to relate codes with each other and reveal themes (Strauss & Corbin, 1994)

Data from the documents was labelled and organized chronologically as an activity diagram for each project. Relevant pictures were linked to the respective data. Most of the interviews used these diagrams or the reports to obtain a deeper understanding, answer open questions, or link data. Data from the interviews was then added to the diagrams and – where necessary – existing data in the diagrams moved or removed. Once data was collected and arranged, repeating activities were identified and coded using terms describing the activities of the team. The code-set became richer with the analysis of successive case studies, and recurring terms were identified, e.g. site-contextualization, region characterization, or risk profiling, were found to be used frequently across projects. The case studies involved expertise from diverse domains, which further enriched the set of codes and concepts. The coded data was grouped into concepts, which – once they were arranged chronologically – revealed the underlying process followed by the project team.

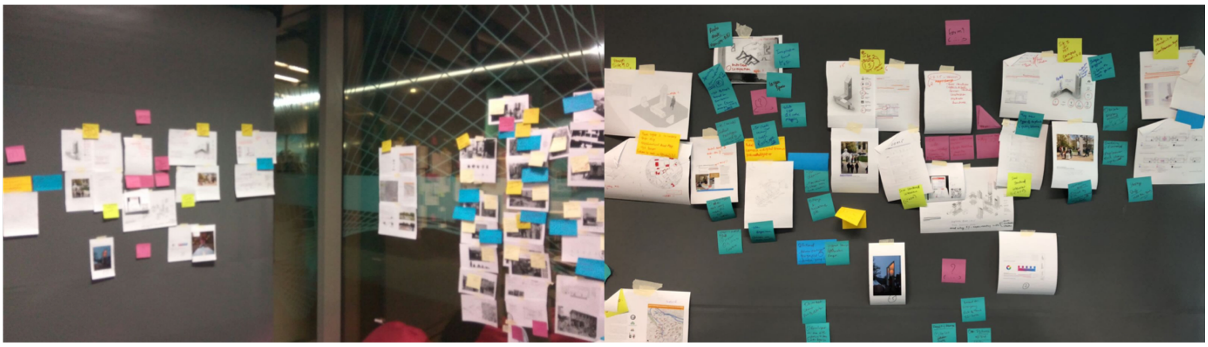


Figure 1. Part of the chronologically arranged data collected on Projects: PREPHub Nepal (right) and PREPHub USA (left)

3.3 Analysing Data

Using the codes and concepts developed in the previous step, we were able to identify inherent structures in the three projects. A cause-effect analysis was performed to better understand the differences and communalities between the projects, the reasons of changes within the projects, and the process flow. Intentions, reasons and consequences of the captured decisions were analysed, as well as the methods and guidelines that were used. This led to a set of preliminary guidelines and some indication of which process steps and activities seem useful under which circumstances.

3.4 Framework structure

Our aim is a framework and a related set of methods and guidelines, which can be used to design solutions for a resilient society. In order to develop a framework onto which the identified processes, concepts and steps can be mapped, discipline and topic specific design methodologies were studied, in particular user-centred methodologies. We adopted the cross-disciplinary comparison-based model by Gericke & Blessing (2012), and the phase definitions and methods of Pahl & Beitz (2013) for the mapping process. Contextualisation, which we found to be a particularly important step, however, did not appear explicitly in these design methodologies. We added it as a separate phase.

4 Development of the framework and its components

The results of the case studies formed the basis of the framework we introduce in this paper; an analysis of existing user-centric design methodologies provided its systematic structure. The proposed framework aims to provide a systematic and adaptive structure to facilitate the development of systems whose location and functionalities allow them to be part of the daily routine of people in the respective community. This is expected to result in a more intuitive, i.e. faster, response to a disaster, thereby reducing a community's vulnerability and improve its chances of survival and recovery and contribute to society's level of preparedness and resilience to disasters.

As discussed in Section 3, this framework is a combination of different elements. Here we focus on guidelines and methods derived from the case studies.

We identified several design approaches used in the case studies. Some were prominent in one case study and some in another. Together they shaped the strategies at local level:

- <u>Participatory system</u>: Partners and stakeholders were involved from the beginning even before finalising the project goal, to learn from and incorporate their strengths, knowledge and experiences in generating solutions and obtaining feedback.
- <u>Bottom up approach</u>: Local leaders and users were actively involved in identifying core problems and deciding risk strategies, supporting localisation of the solutions (see also Victoria, 2002).
- <u>Coupling process</u>: Systems were developed for use in daily life as well as in case of disaster (and not only in case of disaster) in order to help users familiarize with these systems, develop intuitive usage and greatly enhance the usage of the system. Two forms were identified: adapting existing systems for use during and post disaster or creating new disaster management systems that can also be used in daily life.
- <u>Distributed network:</u> The systems were local solutions, but suitable or adaptable to other locations (as PREPHub showed) in order to make a community less vulnerable to break-down in the case of a disaster than the networks of large central infrastructures.
- <u>Redundant and Modular design</u>: For critical needs multiple ways to achieve one function (redundancy) using different working principles were embedded in the solution, e.g. on grid and off grid use to ensure core functions even if the central (grid) system fails during disaster as proposed by Morrish (2008). System modularisation has the same aim, allowing switching between sub-systems in case of failure of one or more subsystems (Allan & Bryant, 2011). Modularisation also allowed the adaptation of the system for other locations.

Figure 3 shows the first version of our framework, its phases and steps. The aim is to bring together and structure existing methods and tools as well as those that were developed by the Urban Risk Lab. The process is not linear as various steps are closely linked, within and between phases. Iterations are essential in any development process: many studies showed that problem understanding and ideation co-evolve. Moreover, the relevance and importance of the individual steps, methods and tools must be determined in line with the context and situation at hand: “opportunistic design styles are not only more common but are also significantly superior with respect to design performance” (Bender & Blessing, 2004, p.5). The inclusion of these steps, methods and tools in the framework ensures that the relevance of the issues they address are considered. The framework also emphasises the need to consider implementation, use, maintenance and end-of-life.

Each of the phases will be described in more detail below. The focus is on the early phase and its steps, as these are found to be the most critical and most differentiating from other such frameworks and methodologies.

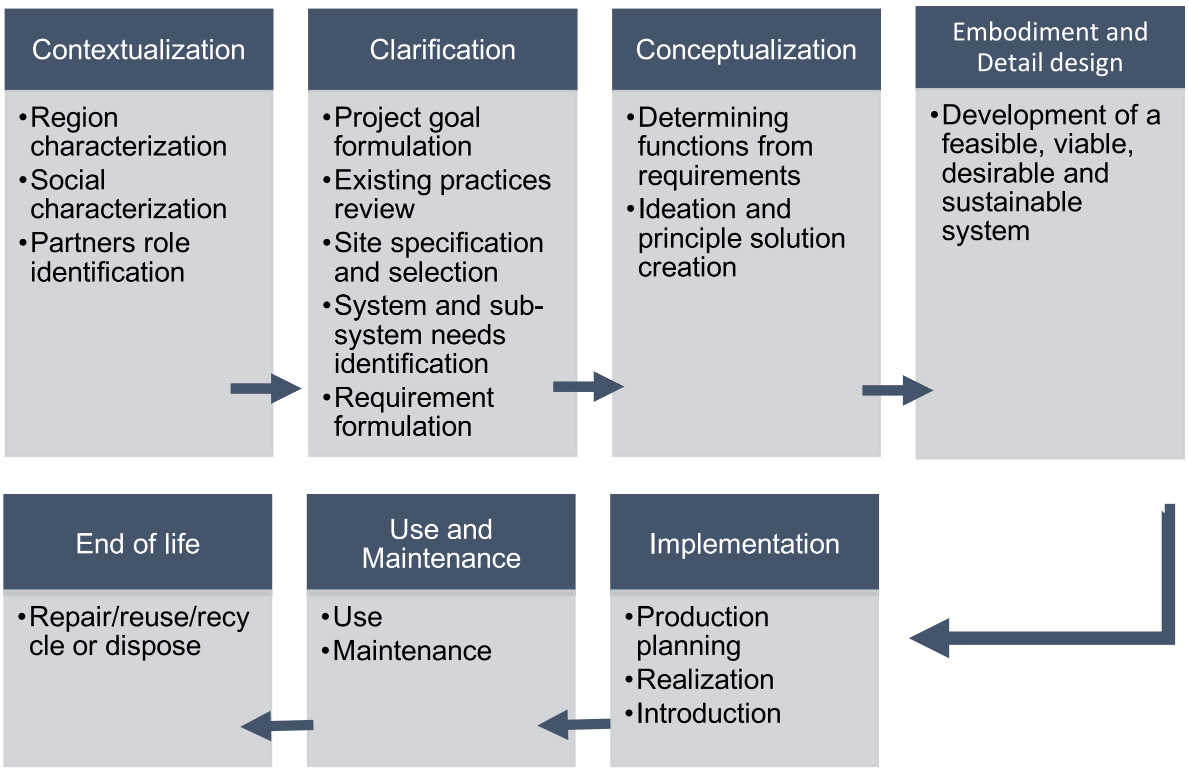


Figure 2. Framework phases and steps

4.1 Contextualization:

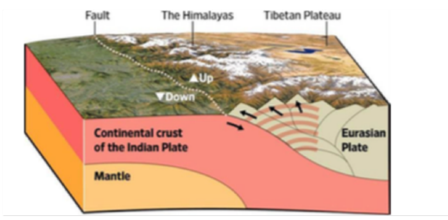
By including a separate phase for contextualization, the framework highlights that for developing resilient societies, contextualisation is extremely important, even before defining the precise projects goals and requirements, unlike typical design processes. Contextualization helps in characterizing the overall project and addresses the current capacity of society in combating adverse situations as we learned from the case studies:

one-size-fits-all solutions are unlikely to deliver the integrated solutions that are necessary to deal with disasters. The essential steps we identified are:

4.1.1 Regional characterization (see Fig 3A and B): It is important to develop a holistic view of how regions are divided, densified and developed to identify type and magnitude of risks and their management. This includes a proper understanding of how the region transforms when exposed to risks, how the local economy functions and what the risks are to social, cultural, economic and environmental pillars in case of a disaster.

4.1.2 Social Characterization (see Fig 3C): An in-depth understanding of the region (local society) is required, particularly with respect to its preparedness and response to crisis in the past. This should include information about involved organizations, local governance bodies, persons in-charge, youth forces, etc. We need to consider awareness among locals, communication points for media, literacy rates and list down social resources. Furthermore, the relationship of these elements with economy, market, school, culture, society leadership and institution should be identified.

4.1.3 Partners characterization (see Fig 3D): Formal and informal collaborations with local people and organizations play a crucial role in understanding the contexts of the risk and in designing a locally fit solution. Early partnership with local governments helps in connecting with potential stakeholders and in smooth operation of the project and ensures the solution considers local strategies, and builds on local knowledge and expertise.



A. Regional characterization

C. Social characterization

B. Regional characterization

D. Partners characterization

Figure 3. Contextualisation phase in PREPhub Nepal (Photos from URL team. Reproduced with permission.)

As shown in Figure 3, the contextualisation phase in the Nepal case study focused on 3 key questions: i) how is the region developed, what are the potential natural risks, and what are previous disaster effects (in this case, post Nepal earthquake 2015 scenarios)?, ii) how is society using the local space and what are their daily and post disaster needs? and iii) which local partners can be involved to successfully develop, implement and manage solutions?

4.2 Clarification:

The clarification phase aims to formulate project goals, select suitable sites and formulate an initial requirement list.

4.2.1 Project goal formulation: Project goal(s) need to be in congruence with the requirements of the local people and incumbent social behavior while considering disaster risk.

4.2.2 Existing practices review: Reasons behind successes and failures of past and current strategies should be clarified, not only with respect to the project location, but also similar regions (based on climate, risk type, topography and culture). This includes urban context (population density and pattern and topography), scale (block, neighbourhood and national) and temporality (short term to long term), as well as the connection with such elements as economy, social resources etc. Integration of local knowledge with scientific expertise is encouraged (Mercer, Kelman, Taranis & Suchet, 2010).

4.2.3 Site specification and selection: The framework advocates development of both infrastructures and services for preparedness and recovery. Hence potentials sites and infrastructures are to be identified that can be points of contact during daily life as well as during and after disasters. The process for selecting the site has been divided in three steps.

1. Map each risk to the type of preferred location in case of disaster, such as open space for earthquake prone areas, and include this into the site requirements list.
2. Identify suitable existing sites through characterisation of infrastructure and buildings from institutional and non-institutional systems such as economic, education, religion, and recreation. Include the possibility of investment in additional buildings or infrastructure.
3. Match the potential site identified in (2) to the required type from (1) by evaluating various qualitative and quantitative factors such as accessibility, visibility, stakeholders and community agreement. The aim is to attempt the use of existing sites first, before building completely new systems to optimize resources and to ensure familiarity of the local population with the site.

4.2.4 System and Sub-Systems needs identification: To enhance usefulness of these sites, local sub-systems should be understood, quantified and taken into account in the process, in particular those which provide essential life resources, which may be affected during disaster scenarios. Interviews with stakeholders help discover everyday needs such as securing water, food, education, life stock, etc. and key needs during disaster. These daily needs are coupled with necessities during a disaster. Coupling encourages active usage of sub-systems in daily life and not only in times of disaster which helps in quick response.

4.2.5 Requirement formulation: The requirements list is completed by including all life-cycle phases, including manufacturing/building, transportation, introduction, use, repair and maintenance, both during normal use, when disaster strikes, during the first crucial 72 hours and during the following recovery period. The requirements list should include relevant laws, regulations, and guidelines for normal and disaster situations (Sphere, 2011).

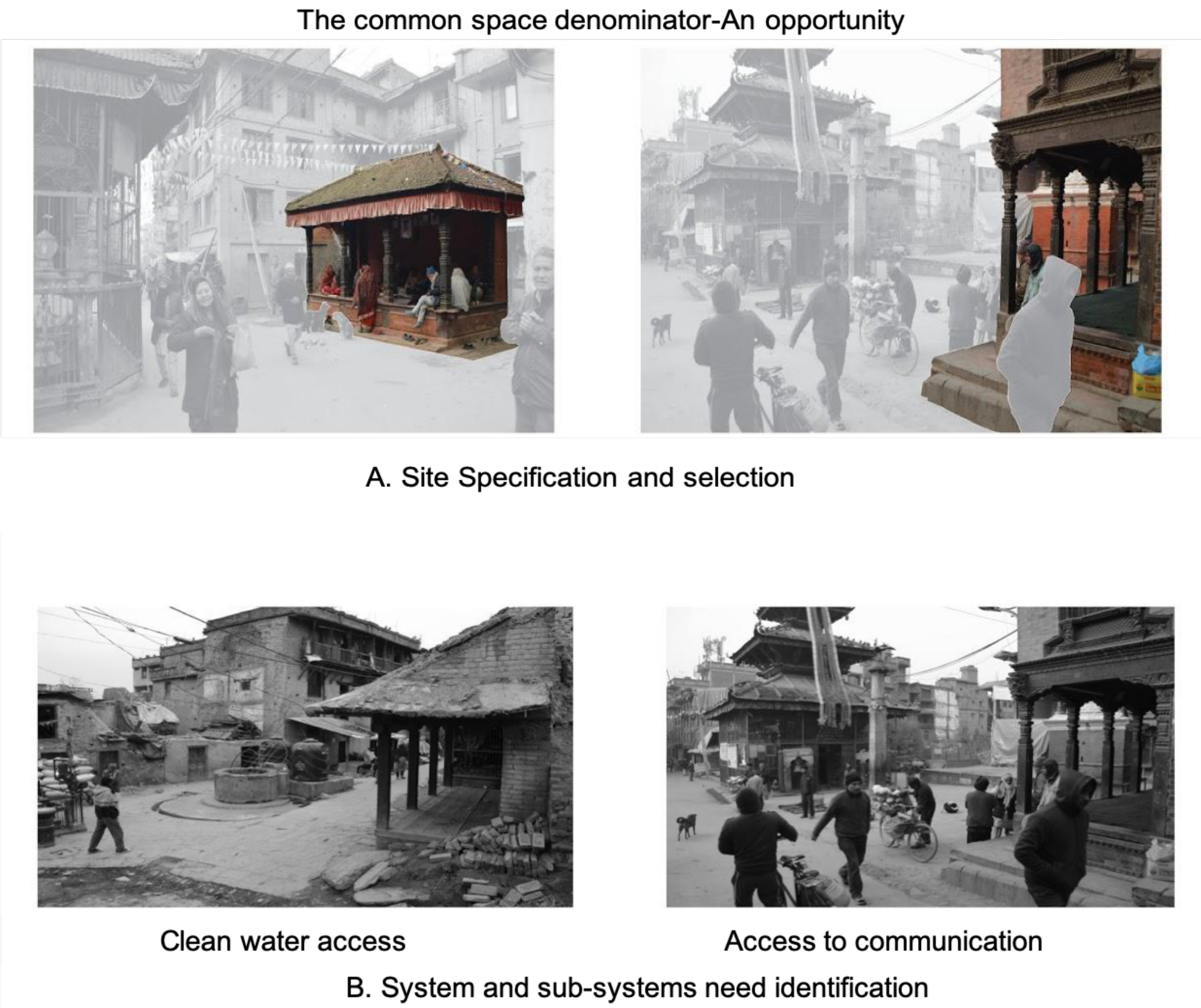


Figure 4: Clarification phase in Prephub Nepal case study (Photos from URL team. Reproduced with permission.)

Figure 4 illustrates (4.A) the site specification and selection phase and (4.B) system and sub-system needs identification phase. Both steps fulfil the needs of community in both daily routines and disaster recovery.

4.3 Conceptualisation

During conceptualisation, the principle solution is created (Pahl & Beitz, 2013). Functions and sub-functions are established based on the list of requirements. Working principles for the functions are selected and brought together into one or more solutions, while considering strategies such as modularisation and redundancy. We argue in favour of a decentralised concept with multiple strategies.

4.3.1 Determining functions from requirements: Functions and functional relationships between input and output of existing and required systems are formulated. The foundation for redundancy and modularity for building resilience are laid in this phase.

4.3.2 Ideation and principle solution creation: Working principles are chosen to realize the different functions, taking into account both normal and disaster related scenarios. Working principle or physical principle redundancy is an important strategy to reduce risks. The working principles are combined into one or more principle solutions.

4.4 Embodiment and detail Design

Embodiment and detailed design stages elaborate the principle solution(s) into user-friendly, technically feasible and economically viable solutions with consideration of safety, ergonomics, production, assembly, transportation, installation, operation, maintenance, recycling, costs and schedules to the point that these are ready for production (products) or implementation (services). Following are some guidelines derived from our case studies:

- Functional design: Design for dual use, for everyday and disaster scenarios for e.g. the PREPHub radio acted as source of entertainment under normal use and a source of critical information during disaster.
- Hedonistic design: Design to draw attention and stimulate curiosity for all type of users in the interest of attracting and encouraging interaction with the system on a daily or at least regular basis.
- User-centred design: Co-create with multiple local generations through workshops, public engagement programs, and other forms of community mobilization to ensure cultural and community understanding of the solution, the inclusion of community preferences, and of the needs of vulnerable people in the community. This affects, e.g. the use of signs or language, or the limitation to certain uses, PREPHub, for example, allows mobile phone recharging, but only as far as required for emergency calls to ensure recharging resources are available to many.
- Prototyping: Develop 3D models, small scale or real size prototypes to understand "how people acquaint themselves with every day and emergency functions, and to improve user comprehension and comfort" (Mazereeuw & Yarina, 2017, p.70).

Figure 5: Interaction of different users with the PREPHub USA prorotype version 1.0 (left) & version 2.0 (centre and right). (Photos from URL team. Reproduced with permission)

Figure 5 illustrates how the design of PREPHub USA encouraged the engagement of different users (old or young) in different forms in daily life. PREPHub is designed such that the system is functional during disaster scenarios as well, e.g. when the electricity grid or internet might fail. Pedal power (central image) is used to charge mobile phones if the power grid fails, yet also works under normal conditions attracting children to the Hub.

4.5 Implementation

Acceptance and approval of partners, users and involved stakeholders is required to implement the solution. This requires their early involvement in the process, i.e. they need to play an active role in the Contextualization and Clarification phases. Then onwards, planning and production can be initiated. Important steps are the identification of construction partners, local regulations and standards, construction methods, required resources (material, labour), site preparation needs, etc. Working as much as possible with local resources will benefit use, operation, maintenance and end of life.

4.6 Use and Maintenance

The framework encourages active involvement of the community not only in development and implementation, but also to provide feedback and to ensure maintenance. As highlighted earlier, this requires the community to have been involved from the beginning, and the consideration of use and local maintenance during the development stage.

Interviews, photos and videos can provide useful feedback on e.g. how users familiarise themselves and interact with the system, how intuitive the system is to use, how reliable the system is, and what issues have to be addressed in the current or future versions of the system. This requires monitoring over a longer period.

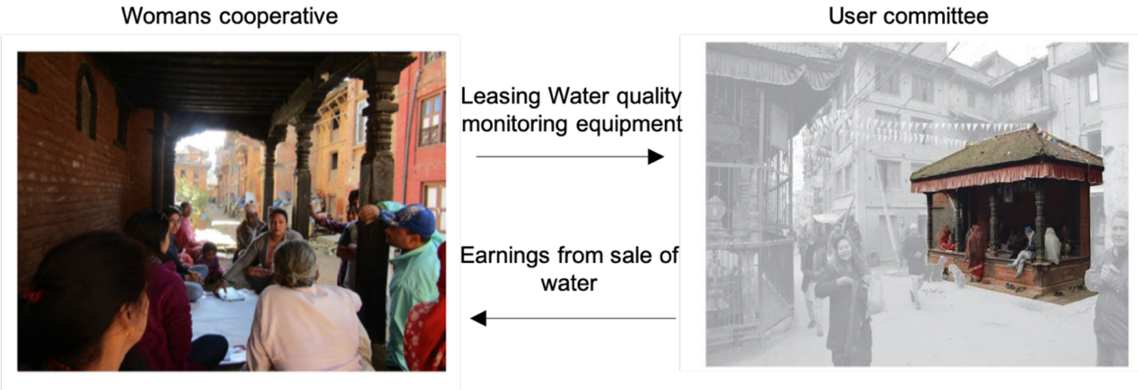


Figure 6: An example of including a local partner (womans co-operative) to maintain the site and quality of water in Nepal PREPHub. (Photos from URL team. Reproduced with permission.)

Figure 6 shows the involvement of local partner and the community in the daily maintenance of the site, benefitting for daily use as well as easy operation during emergencies. The local women's cooperative and a user committee played an important role in maintaining the PREPHub and the quality of the water provided in the PREPHub by leasing water quality test equipment and monitoring quality of water in return for earnings from the sale of water sold by the user committee.

4.7 End of life

Well organised and executed maintenance will extend the life of the system, but eventually the system or its components become ineffective, inefficient or obsolete. Considering end-of-life of the system during the development process, through strategies such as design for recycling and modularisation, has a large effect on the possibility to reuse and recycling, as well as on safe disposal of the system or its individual components.

5 Conclusion and future work

This paper describes the outline of a novel framework (FDDRS) for developing systems to increase disaster resilience in society. This first version is based on a detailed analysis of 3 case studies. The framework is unique in its focus on including users and other stakeholders throughout the system development process and throughout its life, and in advocating dual-functionality (daily life and disaster scenario's) and decentralisation of infrastructure and services. FDDRS emphasises on developing existing infrastructure and strengthening intra-social relationships. The introduction of existing design process models gives a proper structure to the proposed framework and brings concepts such as working principles.

We plan to test and improve the framework using additional case studies from the Urban Risk Lab, as well as other groups. The studied cases mainly focused on infrastructure and were restricted to preparedness and recovery phases of disaster risk management. More diverse cases studies will be included, such as services for early warning and response phases.

Future work includes the mapping of existing methods for developing a disaster resilient society into FDDRS and the investigation of their relevance for particular contexts and risks. Our initial focus will be on risk and vulnerability assessment methods.

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