The Resilience of Urban Design to Pluvial Flood

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It has been my dream since I witnessed the Gonu cyclone in Oman in 2007 to study the flooding phenomena with a special depth and attention. There was no other way to achieve this rather within a PhD study. Now that I am almost there, I feel relieved and proud to have nearly achieved my dream; however this has been a very challenging journey, during which I relied on support from various directions to keep me going.

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Abstract:

Resilient urban design has become an essential concern for cities needing to withstand the increasing number of natural and human-induced disasters. Yet cities and their infrastructures are becoming more vulnerable and threatened as flood protection measurements are still following the same line of thinking in terms of nature resistance. The conventional structures of flood protection are increasingly questioned amongst academics, decision makers and communities particularly since many cases of failure around the world. New approaches for characterising the resilience of urban design are urgently needed and worth investing in on local and regional scales. This research calls for a practical approach to investigate the resilience potential of urban design as a man-made solution and to consider the adjacent ecology as the natural surroundings. This aims to develop an ecologically compliant urban design approach that contributes to the mitigation of flood consequences with other infrastructure solutions.

This research aims to shed light on the potential of ecological urban design to demonstrate a resilient urban form that can cope with the escalating flood threats in the Muscat area in OMAN. A shift in thinking is required, towards a paradigm that calls for a breakaway from the closely confined resistance approach to the much more tolerable concept of living with the reality of water dominance. This is going to be realised by carrying out in-depth analysis of the ecological system services along with the physical aspects of urban design.

Chapter 1: Research Rationale

1.1 Introduction:

Gilbert F. White, known worldwide as the father of floodplain management, wrote in his doctoral dissertation in 1942:

'*Floods are act of God, but flood losses are largely an act of man'.*

Floods are part of the natural ecosystem; it is man who creates losses and it is man who should work to fix it. Renaud (2013) argued that disaster risk is increasingly a manifestation of urban growth and its depleting effect on the capacity of ecosystems to support life and biodiversity, and mitigate extreme events, such as floods.

Floods, earthquakes, droughts and other natural hazards continue to be the reason behind thousands of deaths and injuries, and billions of dollars of economic losses each year around the world (Renaud, 2013). Floods are the most serious of natural disasters; they top all natural disasters in terms of frequency of occurrence, economic losses and human casualties (Ning, 2006; Zevenbergen, 2011). The Twenty-First Century has already seen large-scale flood disasters in Bangkok, Thailand (2011); Brisbane, Australia (2011); Guangdong, China (2007); New Orleans, USA (2005); Dresden, Germany (2002); and Taipei, Taiwan (2001), among others (Liao, 2012).

Zevenbergen (2011) declared that the idea of floods as a disaster came from the adverse and unlooked for impact that they have on the functioning of human society. Floods are therefore natural phenomena although it is a human construct to label flooding as acceptable or not. Moreover, Taylor (2004) specified two types of systemic losses associated with natural disasters like floods; the first is indirect losses and the second is secondary effects. Indirect losses are the cost of goods that will not be produced and services that will not be provided, while secondary effects are the consequences on the macro economy. Zevenbergen (2011) also referred to how cities' economic vulnerabilities to flooding lie in respect to the indirect impact on their economic sectors where changes in productive capacities are affected by the change in resource productivities or market demands. In just 2010, 178 million people were affected by flooding worldwide; this represented over 56 percent of all disasters and affected 87 per cent of the reported population (Renaud, 2013).

Houston (2011) mentioned that extensive pluvial flooding is more likely to occur in urban areas because of the greater prevalence of impermeable surfaces. In addition, it is likely to have greater consequences in urban areas because of the density of buildings and people. The scarcity of permeable features, such as soft soil and green areas in and around cities, can multiply by up to a factor of 10 the amount of water that runs off the ground, increasing the peak discharge and flooding (Renaud, 2013).

Most of the money spent on confronting pluvial flooding is invested in the structural and non-structural modes of protection in areas of potential natural threat. Among these threats, pluvial floods are one of the most difficult to manage because of the difficulties associated with accurate predictions and adequate warning times (Houston, Werritty, Bassett, Geddes, Hoolachan, and McMillan, 2011).

1.2 Statement of the problem: why pluvial floods

Pluvial floods have increasingly become the reason behind many floods around Oman and the Muscat area in recent years (Appendix-1). Heavy rainfall, low pressure and tropical storms have impacted Oman generally and the Muscat urban area specifically causing fragmented isolated urban areas by storm water inundation.

Oman is a country located in an arid zone whilst Muscat city is surrounded by mountains. These characteristics are significant as catastrophic floods and prolonged periods of drought are the main 'water-related' challenges facing Oman (Al-Ismaily & Probert, 1998). Houston, et, al., (2011, p.7) argued that pluvial floods have recently been identified as the type most likely to increase in severity as a result of climate change. They are also the most difficult to manage because they are difficult to predict and thus it is challenging to provide adequate warning times. They also indicated that pluvial floods often occur with little warning in areas not clearly prone to flooding. Because of these uncertainties regarding the intensity and location of their occurrence, Houston et al, (2011) considered 'pluvial' (rain-related) floods as an *invisible hazard*. This is because they are less well known by the general public, and less well understood, plus their occurrence is defined as short intense downpours that cannot be managed quickly enough by the drainage system or through infiltration to the ground. Urban developments have expanded across areas of natural features, like streams and flood plains. In addition, floods could be more significant in Muscat due to the lack of storm water drainage systems (Al-Rawas, 2009).

Thus, the positional nature of flood protection infrastructures that are normally positioned and operate in the direction of a clearly defined source of threat, like a river or seaside, make it difficult to deal with this *invisible hazard*, (Houston et al, 2011). A pluvial flood is different in terms of the direction of the source of threat, namely where it is coming from, and their courses of occurrence can take different scenarios in terms of their intensity and location. As such, in an urban area the threat can happen anywhere according to the circumstances of the precipitation. More evidence about the site specific nature of pluvial flood was made by Douglas and James (2015); they mentioned that precipitation is also altered by the urban environment. Considerable evidence suggests that cities create their own rainfall. Indeed, urbanisation appears to affect precipitation by causing increases in hygroscopic nuclei; in turbulence arising from surface roughness; in convection because of increased temperatures; and through the addition of water vapour by combustion processes.

According to Al-Rawas, (2009), most of the investments in addressing the problem so far in Oman are represented by conventional structural and non-structural solutions. Structural solutions include a list of engineering structures, like protection dams, dykes, retaining walls and storm water channels while the non-structural procedures comprise the preparedness, early warnings and capacity building for individuals and institutions. This is the reason why the research considers developing an ecologically compliant urban design approach to cope with pluvial flood consequences.

1.3 The research question

The research posits the following main question:

How can a newly-adopted approach of urban resilience to pluvial flood, developed from within the pure urban design discipline and adjacent ecology, contribute to ameliorating the impact of pluvial floods? The thesis also examines the following sub-questions:

Q1- What is the definition of resilience in urban design? How can resilience thinking address the context of urban design? (Relevant resilience framework)

Q2- How can urban design incorporate physical measures to influence a state of urban resilience against pluvial floods? (Operationalisation)

Q3- How can ecological-urban cohesion achieve a form of urban resilience to flood? (Eco-built resilient approach)

Q4- How can resilience-based urban design influence a new approach to the urban design process? (Paradigmatic transformation)

1.4 Research aim and objectives

The aim of the research is to explore urban design capabilities and ecological potential in order to develop an instrumental framework to guide ecologically compliant urban design to mitigate pluvial flood consequences in Muscat city. This is envisioned through the cohesion between urban form and its adjacent terrestrial ecology, away from the conventional flood protection infrastructure. The intention is to identify the sole contribution of urban design and ecology as disciplines in coping with flood.

The research aim is addressed by carrying out in-depth analysis in the following four areas; Resilience, urban morphology, urban ecology, and pluvial flood. The aim is to identify the potential of the physical dimension of both urban design and terrestrial ecology. To accomplish this aim, the following objectives are outlined:

1- To realise resilience conception that accurately describes urban design.
2- To identify the urban design unit of the urban form through which physical interventions will be introduced.
3- To explore the influential ecological features those are associated with urban design in order to build a resilient urban form to pluvial flood.
4- To develop an eco-compliant urban design approach to pluvial flood within a flexible perspective of urban resilience, and against the existing concept of urban resistance.

1.5 Research motivations

Keeble (1952) argued that town and country planning might be described as the art and science of ordering the use of land, building allocation and communicative routes. It deals primarily with land, and is not economic, social or political planning, though it may greatly assist these other kinds of planning.

Keeble emphasised the importance of the built environment's urban context over other implicit political and socio-economic dimensions. Urban form, in its physical characteristics, accommodates political and socio-economic aspects of the urban life. In a similar context, the second national assessment of natural and related technological hazards calls land use planning the single most promising approach for bringing about sustainable hazard mitigation (Burby, Deyle, Godschalk, & Olshansky, 2000).

Keeble also emphasised the physical character of the urban form, arguing that the idea of town planning was essentially about *physical design*, and hence involved producing blueprint plans for future urban forms. Similarly Voogd (2004) mentioned that any destruction in the built environment in its *physical dimension* disturbs the function of human society, and the economic and social development of the country. Thus, due to its strong connection with human activities, achieving a resilient built environment is of paramount importance in also achieving resilient cities.

Taking advanced steps to achieve resilience in the urban form is also advocated by White (2008) who stated that resilience approaches should not be considered late with structural and non-structural solutions, but rather than originate from within the core of the urban planning process. White (2008, p.4) also mentioned that 'resilience to flood risk should be systematically built into the planning process. Authorities, urban planners, and fund raisers should be provided with tools that allow them to generate complex, resilient and efficient urban tissues (Salat & Bordic, 2011). Hall and Rowsell (2001) also confirmed that modern flood risk management no longer relies solely upon engineered flood defence structures, such as dykes, channel improvement works, and barriers. It also considers a host of other measures that may be used to reduce the severity of flooding, (for example, *land use changes* in upstream catchments) or to reduce the consequence of flooding, by reducing either *exposure* or vulnerability.

Leon (2014, p.251) specified that "urban planning can play a central role, through its ability to integrate multi-dimensional aspects affecting disaster risk reduction. Planning has inherent capacities to systemically and comprehensively influence the *location* and *design* of urban development". Similarly, Salat and Bordic (2011) stated that urban resilience is a hard-to-grasp concept, but will be one of the crucial issues over the next century regarding climate change. Understood as the ability to overcome crisis and shocks, the resilience of cities is an issue that is worth being investigated in the context of climate change adaptation

According to the 2009 UNISDR report, in most of the countries that witness extreme events that lead to flooding, susceptible areas are managed in defensive structural measures. Such structural measures are defined as any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques to achieve hazard-resistance and resilience in structures or systems. The UNISDR also mentioned that it is possible to reduce the probability of a flood with new defences but to still increase the overall risk by placing vulnerable receptors behind the defence which thereby increase the potential consequences. Likewise, Gustin (2004) described the potential outcome associated with dam failure as the worst possible flood event. This is because, when a dam fails, a gigantic quantity of water is suddenly let loose downstream destroying everything in its path.

Donald, (2011) confirmed that pluvial floods have recently been identified as the type most likely to increase in severity as a result of climate change. They are also the most difficult to manage because they are difficult to predict, which thus means there are challenges in providing adequate warning periods. Following severe pluvial flooding in Glasgow in 2002, and across Hull and other parts of the UK in 2007, pluvial flooding has since been given more attention by policy-makers than in the past. Similarly, Houston, (2011) mentioned that extensive pluvial flooding is more likely to occur in urban areas because of the greater prevalence of impermeable surfaces. In addition, it is likely to have greater consequences in urban areas because of the density of buildings and people.

Another challenge associated with pluvial floods that has motivated this research is summarised in Donald's (2011) statement, that pluvial flooding is challenging to predict and planned for as it does not have an easily defined 'floodplain' like rivers and the sea. Buildings, street furniture, kerb heights and drainage capacity all have an impact on surface water flow, making it complex to map and manage. Given the multitude of factors that come together to produce pluvial flooding, it is difficult to produce consistent estimates of the extent of pluvial flood risk

This research, therefore, focuses on urban areas, as key for developing a solution, and not just the boundary of problem. Although it is not that hard to see the potential role that urban design might have in mitigating flood related consequences, it is still difficult to pinpoint the ‘how’ question. Nevertheless, how can urban design influence a city’s resilience to pluvial floods? The role of the urban design discipline in facing pluvial flood is owed to some efforts already undertaken in this discipline. This is where this study will collate the effort to clearly define the urban design role in mitigating the consequences pluvial floods.

1.6 Limitation of the research

Baxter (2008) stated that the case has been determined, it is necessary to consider what the case will not be. One of the common pitfalls intimidating researchers is that there is a tendency to attempt to answer a question that is too broad or a topic that has too many objectives for one study. Hence, this research will focus on the performance of urban design, underpinned by the surrounding ecology, in managing surface water runoff resulting from heavy rainfall. Thus, pluvial floods will be the flooding case tested in this research. The research will tackle flood phenomena from within two interrelated domains, namely from urban morphology and from urban topography - addressed later as geomorphology. It will extract the key urban design characteristics that can play an essential role in mitigating the surface water runoff that results from heavy rainfall.

Neither structural nor non-structural modes of flood control will be included within the spectrum of this research. This was determined in order to clearly identify the physical capacities of the urban design in confronting flood events. This research has value for the potential solutions that could stem from the urban design discipline. The problem will be investigated through two main domains; firstly, through the epistemological domain, which will redefine the problem and solutions, assigning what might be 'safe', and safe for what in light of the current flood protection infrastructure and escalating environmental inevitability. Meanwhile, the second is through the technical domain, and this can be realised in the following two interrelated urban levels:

A. Urban Innovation**:** represented in advancing the technical properties of manmade objects and materials over the ground and the geotechnical aspects of the ground itself in accounting for more adaptive performances in times of flood. However, this is beyond the scope of this research.

B. Urban Regeneration**:** this can be comprehended in terms of the urban design capacities to invest in the physical characteristics of the urban form. The target is to mitigate flood impact by cohesively considering ecological services. This is within the scope of this research.

1.7 Relevant findings and research contribution to the knowledge

A number of recent studies admit that urban planning can play an essential role in confronting flood related problems in urban areas, (Burby, et al, 2000; Davoudi, 2012; Leon, 2014; Mileti, 1999; Voogd, 2004; White, 2008; Wildavsky, 1988). Much of those scholars' findings emphasised the dimension of policymaking and implementation on organisational and system development levels. Less attention was paid to the physical aspects of urban design in confronting the direct effects of flooding in urban areas.

The contribution of Watson & Adams (2011) is worth mentioning in this respect as they carried out a study on design for flooding at the urban level. They addressed local physical improvements and detailed measurements to enhance the responses of individual buildings to storm water. However, their efforts were positioned within civil-based solutions as tools for tackling the problem rather than urban design, in comparison, this research jointly approaches the problem from an urban design perspective with urban ecology. Other studies have linked ecology science with resilience in urban areas (Adger, 2000; Pickett et al., 2013; Renaud, 2013). These studies associated the benefits of maintaining ecological systems with achieving resilience in cities through natural stressor situations. Moreover, Renaud, (2013, p.9) mentioned that, 'the philosophy of the eco-resilience school conclude in the claim that healthy and well managed eco systems can serve as natural infrastructure to prevent hazard or buffer hazard impact'.

Among the studies already mentioned, a wide range of scholars map out community resilience to natural disasters, focusing on the social and socio-economic aspects of the community by building resilience into people through preparedness and response. In this sense, Chang et al. (2014) also mentioned that much of the work on resilience in regional contexts is either theoretical, with a focus on the role of institutions, modelling-oriented, often with a focus on specific subsystems, or aimed at understanding the resilience of economic entities and systems to infrastructure disruption. Meanwhile, contributions to mitigate or manage flooding in urban areas from within the urban planning discipline are varied in many aspects, and include policy making, land use planning, and technically empowered design for urban physical membranes. Most of the studies on policymaking and strategic planning paid attention to the preparedness and capacity building of individuals and organisations through early warning plans and safety regulations. Other studies within the urban planning discipline have carried out preventive work through land use management to identify vulnerable uses in order to reallocate to safer areas away from flood catchments by retrofitting techniques. Technical research, as seen in Watson & Adams (2011) study manifest mostly at the individual level of a single building, pavement or/and plot. Such studies seek to: increase the permeability of the ground; to reduce the chances of the generation of surface runoff; create green roofs to increase water retention by harvesting and storing storm water; provide other civil intervention, or enhance building foundations walls and floors to withstand storm water inundation.

Meanwhile, in terms of resilience, there are some in applying resilience measures. Most of these attempts were exploratory, based on qualitative analysis, but they are important since they were pioneering in the field and leading the theoretical dialectic of resilience into a more empirical agenda. Significant amongst these is the work of Grosvenor (2015), who specified a six-stage process in measuring cities' resilience. The first step is to identify the key components of vulnerability and adaptive capacity, whilst the second is to seek accurate data on each component from as many sources as possible. The third step is to transfer the data into an ordinal ranking system with the same distribution and units so that data can be merged and averaged. The fourth step is to rank the cities in each individual component of vulnerability and adaptive capacity, so that the relative position of each will be cleared. The fifth step is to distribute the cities by an un-weighted average, to create an overall city ranking for their vulnerability and adaptive capacities. The sixth and final step is to average again the final position of each city depending on its resilience level.

Leon and March (2014) also developed a method to measure rapid resilience in an urban form; a case study was employed after the selection of the city of Talcahuano, which is an industrial port city in Chile, predominantly located on coastal plain 5-10 metres above sea level. The method included five phases, which are: (1) diagnosis of the city's current tsunami evacuation vulnerability; (2) a literature review to obtain a set of urban design recommendations enhancing tsunami evacuation; (3) field work study; (4) the development of a ground based proposal embodying recommendations; and (5) the assessment and synthesising of the proposal. By studying two essential activities, evacuation and shelter, this method was applied to discover the impact of urban morphology upon community specific types of rapid resilience. Results showed that the overall evacuation process can be enhanced quantitatively by specific urban modifications. Design recommendations can also have important qualitative impacts, providing new liveable public spaces, and redefining city's land marks.

Most of these precautionary measures lack the spatial dimension of urban design, and the transition from local to meso to macro scale in an urban context. Like Watson and Adams (2011) study, they emphasise physical resistance and the prevention of flood consequences. In contrast, a three dimensional physical approach defines this research, manifested in the physics of urban design alongside the physics of natural settings within the urban context. The aim will be to manage, and reduce/mitigate devastation of flood. Hence, the contribution of this research will influence the spatial planning discipline through the urban design level, (Figure 27, Chapter 3), with a focus on its physical aspects. This will be achieved by highlighting the key role of the urban (morphological) unit in incorporating resilience measures to cope with flood, in cohesion with the surrounding ecology (geomorphology). The ultimate aim is to rewrite conventional thinking to look at both flooding and urban design through the lens of resilience.

1.8 Gaps in the current knowledge

The idea of resilience has a long history in ecology and engineering, but its application to natural hazard management is relatively recent (Berkes, 2007). Wilkinson (2014) confirmed that the meaning of resilience in practice for urban governance is yet to be thoroughly examined. There is a clear gap between the advocacy of social-ecological resilience in scientific literature and its take-up as a policy discourse on the one hand, and the demonstrated capacity to achieve resilience in practice on the other.

Rose, (2004) identified three difficulties that confront researchers in the field of resilience. At the *conceptual level*, there is the need to identify resilient actions, including those that may seem to violate established norms, such as rational behaviour. At the *operational level*, it may be difficult to model individual, group, and community behaviour in a single framework. At the *empirical level*, it is especially difficult to gather data on resilience to specify models. Likewise, the complexity of a multi-discipline resilience approach was explained by the statement of the strategic environmental planners (SEP) in Kummon-Sweden: 'We see that our questions are experienced as very abstract, special, complicated and/or problematic, because in certain ways from our point of view, when we look at the system, human and environmental, our perspective is that our relationships are complex, things are connected, they interact. The impact that impacts the other, and then it comes back and affects that again' Wilkinson, (2012, p.320)

'There are surprisingly few publications that addresses how resilience approach to planning might be pursued in practice' (Wilkinson, 2012, p.320). Similarly, Liao (2012) stated that what defines resilience to flood remains ambiguous, despite the increasing attention given to the concept of resilience in flood hazard management. Ahern (2011) also stated that, while the concept of resilience is intellectually captivating, it remains largely unpractised in contemporary urban planning and design. Likewise, Shaw (2013) confirmed in this context that there is still much empirical work to be done to explore the various levels of resilience. There is disagreement on both the characteristics that define resilience and the appropriate analytical unit for the measurement of resilience. Heterogeneity in the concept of resilience is partly rooted in the differing intellectual origins and lineages of the different research traditions (Leichenko, 2011).

Chang, et al (2014) also argued that much of the work on resilience in regional contexts is either theoretical, with a focus on the role of institutions, modelling-oriented, often with a focus on specific subsystems, or aimed at understanding the resilience of economic entities and systems to infrastructure disruption, rather than the resilience of the infrastructure systems themselves. There is a need for methods to characterise infrastructure resilience in applied, real-world contexts, based on the limited information at hand regarding performance in extreme events.

In urban design, research is needed to link urban physical systems with human communities, that support the information and communication needs of infrastructure organisations, and that directly address infrastructure decision-making on an urban and regional scale (Chang, et al. 2014). Ahern (2011) also mentioned that while adaptive management has been practiced successfully in natural resource management for decades, its application to urban planning and design is rare. Similarly, Salat and Bourdic (2011) posited the questions; will modernist cities manage to survive the century and hold out against the growing risks linked to climate change; and how will their structure evolve and behave if confronted in a rise in prices due to a scarcity in natural resources? Unfortunately, this adaptation ability, or resilience, is rarely - if never - taken into account in urban policy processes.

Moreover, the Head of the Strategic Environmental Planners (SEP) in Kummon (Sweden) stated that: ‘I don’t believe we manage uncertainties today, at all, I really believe we have a planning view that the world is unchanging. I believe that this is the underlying view. Because the alternative is so difficult that we can’t conceptualize it, instead, everything happening around us nowadays is pressuring us to be more receptive’ (Wilkinson, 2012, p.322). This statement reveals a critical need to re-examine urban planning through the lens of resilience; this stems from the fact that planning practice is inherently based on static, rather than ever changing and dynamic structures.

Chang et al, (2014) affirmed that much of the current literature on urban disasters has emphasised land use planning specifically, and hazard mitigation more broadly, in reducing disaster risk. However, an emerging body of research has addressed planning for post disaster reconstruction and recovery, emphasising the rebuilding of communities' social as well as physical fabrics. In landscape and urban planning, Steiner, (2006) mentioned that early thinking about sustainability tended towards a static conception where it was envisioned as a durable, stable urban form or condition that - once achieved - could persist for generations. However, from a non-equilibrium perspective this conflated view of sustainability and stability is paradoxical; how can a static landscape condition be sustainable in a context of unpredictable disturbance and change? A more relevant position that anticipates failures and strategically considers designs systems is required so that failure is contained and minimised.

Within the urban disaster reduction literature, arguably the largest branch of urban resilience literature, emphasis is placed on enhancing the capacity of cities, their infrastructure systems, and urban populations and communities to quickly and effectively recover from both natural and human-made hazards (Leichenko, 2011). Concerning flood mitigation, Liao, (2004) stipulated that the theory and measurement of flood management indicate that flood adaptation should replace flood control in order to build urban resilience. Ning (2006) also confirmed this argument stating that exclusive dependence on flood-control works is insufficient and falls short of the objectives of reducing losses.

Cities experience a growing challenge, which is represented in two ways; the intensification of storm events associated with climate change, and the increase in the urban development. These events are difficult to contain effectively, due to the very short time available to issue warnings or to enact predefined management strategies (Zevenbergen, 2011). Urban resilience is a hard-to-grasp concept, but will be one of the crucial issues in the century to come regarding climate change (Salat & Bourdic, 2011). Similarly, Godschalk (2003) confirmed that hazard mitigation guidelines typically have not focused on, or identified, the unique needs and characteristics of cities under stress, as opposed to more generic hazard situations. Finally, in the context of the study area, the consultancy services for Muscat area drainage study (2011, p.14) confirmed that; "It is absolutely fundamental to highlight that the main urgent and important actions to carry out after the achievement of the Master Plan are in the urban planning field".

The previous discussions have revealed an escalating need for a paradigmatic shift, from flooding viewed through the lens of flood control to flood management. The need to accelerate the process of looking for new alternatives is realised by the fact that existing flood control infrastructures that guaranteed the safety of cities from flood have failed quite frequently in many places around the world. This is why this research believes it is worth redirecting some of the annually invested efforts and funding into the perspective of urban resilience as a surrogate approach.

1.9 Methodology

The initial problem that guided this research was associated with many public sector projects that were commenced by the government in the two case study areas in Muscat city. These projects aimed to build robust flood infrastructures. Unfortunately, most of these projects did not realise their reimbursements, as the city continued to witness seasonal floods consequences represented in the inundation of large urban areas. This is mainly what informed the literature review and helped to define the research objectives and questions. A literature review was undertaken covering the following domains:

1. Resilience (content)
2. Urban morphology (internal context)
3. Ecological settings (external context)
4. Pluvial flood (change agent)

From these literature domains, a theoretical resilience framework was developed with four key principles identified; this guided the entire qualitative enquiry. The ecological paradigm was also identified in respect to the research orientation and the choice to focus on the physical dimension of the urban form and terrestrial ecology. Finally, the morphological unit of analysis was identified to determine the starting level of any mitigation-based intervention.

Research questions generally guide the research inquiry, which is initially developed through examining gaps in the literature and related governmental reports and documents. The comprehensive resilience framework guides the detailed interview questions and links them back to the main research question. Thematic interview questions were developed from each of the four resilience principles identified in the theoretical resilience framework. This provided the structure for the data collection when undertaking the interviews. For the purpose of maintaining the enquiry's robustness, the resilience principles and questions were grounded in the reviewed literature, as demonstrated in Chapter 7.

A case study method was used, as in depth information was needed in order to understand the underlying factors that construct the flood phenomena in the two case study areas. An interpretivism perspective was used to understand the meaning and interpretation offered by the interviewees of their experiences and views about resilient urban design. Furthermore, this perspective supported the use of the specific language and terminology used by the interviewees that provided further insight into their own experiences. The case study, as a research strategy, comprises an all-encompassing method, covering the logic of design, data collection techniques and specific approaches to data analysis (Stocker, 1991). Case studies generate extensive data that are relevant to the particular context and can provide the rich explanations that are required for an interpretive study (Miles & Huberman, 1994). As a result, a case study approach was chosen as the research questions were mainly concerned with understanding and exploring, including 'how' questions.

In order to understand the variables that influence resilient urban form, case studies were undertaken of two distinguished urban and ecological contexts. In order to elicit the interviewees' perspectives on the variable urban and ecological settings in the Muscat metropolitan area, CS-1 represented a constrained ecology of steep mountains and deep valleys, whereby the urban setting was less restricted with a simple mixed land use mainly dominated by residential use. CS-2 was highly specialised, and mixed commercial-administrative with multi-story residential land use; meanwhile, it was also ecologically diverse and comparatively relieved.

The semi-structured interview was the main primary data collection method. In addition, other sources of data were used including government documents, annual implementation reports, and consultancy studies. A stratified sample of participants was selected for each of the study areas. The total number of participants (16) was interviewed across the two case study areas. Interviewees were managers, urban planners, architects, and hydrologists. This range of roles helped to capture different perspectives and stances, and thus improve the outcomes.

Walsham's (2006) and Blaikie's (2000) principles for maintaining interview rigor were followed; this comprised time keeping, confidentiality, the recording and transcribing of interviews, the role of the interviewer and the authentication of the transcriptions by the interviewees. The quality criteria for the data collection, including the selection of participants from three different orientations, the use of multiple data sources and linking the interview questions to the literature, were applied throughout the two case studies. The two case studies provided a rich source of data and enabled the identification of a variety of variables that influenced the development of the final instrumental framework. These covered, but were not limited to, the following areas:

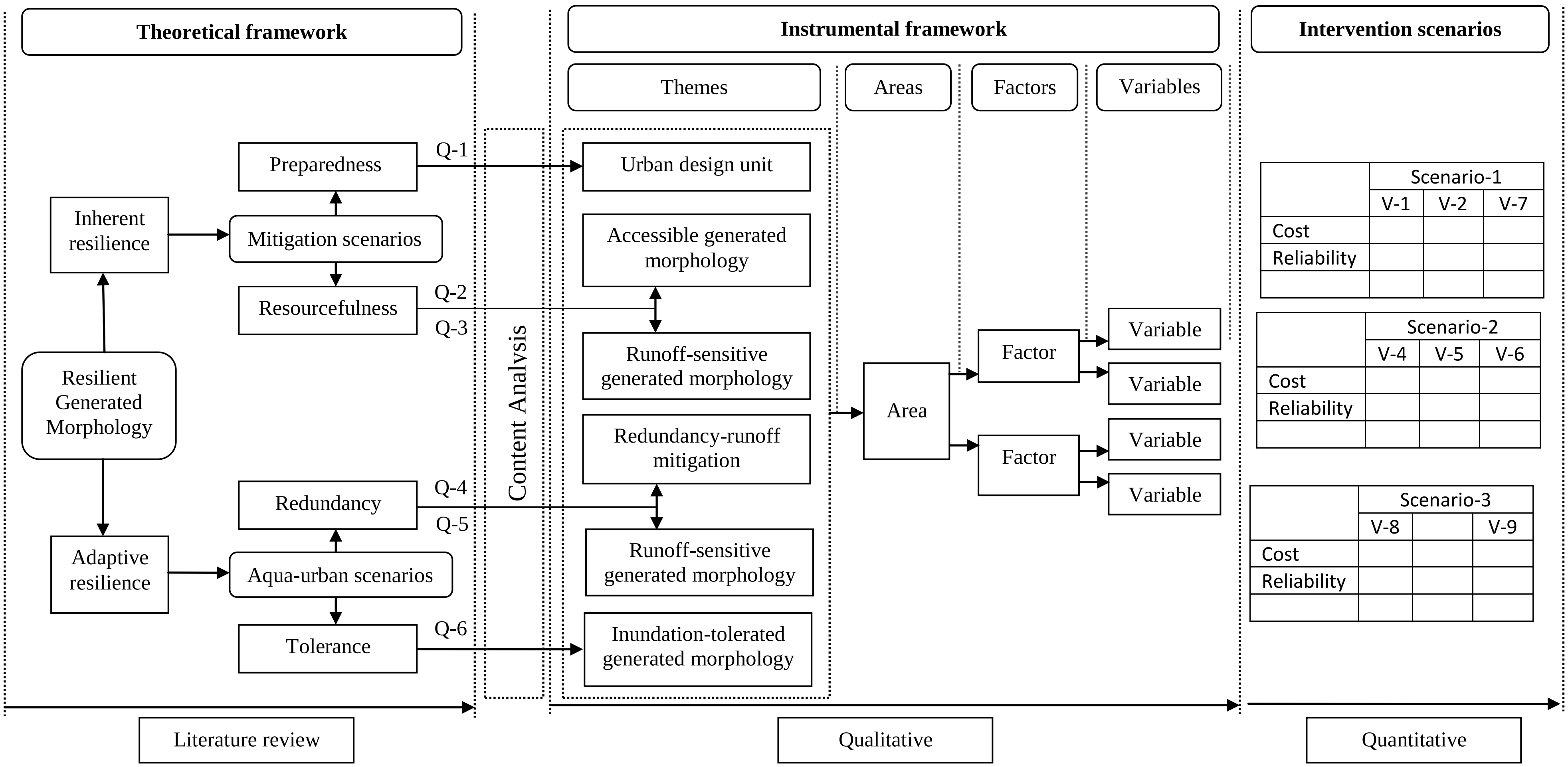
1- Building-space ratio index.
2- Plot-building-block optimisation.
3- Resident-sensitive oriented design.
4- Land use essentiality.
5- Space connectedness.
6- Ecological restoration and compliance.

The collected data were analysed using within-case and across-cases explanations. A computer aided tool (NVIVO) was used as a data reduction means to help illustrate and present the findings in a visual format. The within-case data analysis entailed, for each case study, an analysis of the predefined themes that were used to build the discussion with participants in each context. The analysis was supported by evidence from direct interviewees' quotes. The cross case analyses were undertaken, where the findings were compared and contrasted between the two cases.

The qualitative part of this research, namely the interviews, forms the major contribution to the data collection; however, the quantitative part that follows helps to identify influential variables from the qualitative inquiry. Mitigation scenario crafting was guided by the participants' recommendations in this area and also followed the researcher's experience of the two case study locations. Scenarios were tested across two complementary phases using two software packages; one package was for the preprocessing phase and the second for the analysis phase. A software aided simulation tool, named Arc GIS (Aeronautical Reconnaissance Coverage Geographic Information System) was used for pre-processing the digital data management.

Meanwhile, the HEC RAS (Hydrologic Engineering Center River Analysis System) software was used in the subsequent phase to simulate flood inundation circumstances in the two areas before-and-after introducing physical intervention scenarios. Positive returns made by applying the scenarios were evaluated in relation to the successfulness and reliability of these physical solutions. Figure 1 demonstrates the logical transition from the literature review to the qualitative and quantitative enquiries respectively, showing, at the same time, the key deliverables at each stage.

Figure 1: Deliverables of the literature review, and qualitative and quantitative enquiry



1.10 Synopsis of the thesis

This thesis structured across the following eight chapters:

- **Chapter 1: Introduction and rational of research**

  This chapter introduces the research background, rationale, questions, aim and objectives. It is also demonstrate the gaps in current knowledge around the topic of the research and shows the intended contribution of the research to current knowledge.

- **Chapter 2: Critical review of resilience concept and correspondence with the research domains**

  This chapter presents the first phase of the literature review. It displays the philosophical stances and critically discusses the concept of resilience. It is also displays resilience parameters concerning type, domain and principles. This chapter will conclude by addressing the resilience principles hybrid model.

- **Chapter 3: Urban-ecological paradigms, a cohesive physical approach.**

  This chapter is the second phase of the two literature reviews. It will display an overview of the concept of urban form morphology. This will be achieved by examining the principle urban morphological schools, and the focus on the physical character of the urban form will be traced across the examined schools. It also discusses the ecological dimension in the urban context. Two paradigms of urban ecology will be examined in order to determine the best one for adoption in this research. The resulting ecological and morphological paradigms, along with the final resilience theoretical framework, will be discussed at the end of the chapter. Close attention will also be paid to flood as a change agent in the problem area, and flood parameters, represented in wave velocity and depth will be addressed.

- **Chapter 4: Adopted research methodology**

  This chapter reviews the literature on research methodologies, and identifies the research choices concerning the appropriate philosophy, paradigm, design and technique that are adopted for the study along with the related data collection protocols.

- **Chapter 5: Data analysis and findings**

  Data collection and analysis for the two case studies will be addressed in this chapter. Analysis will be performed on the two cases through a 'within-case analysis' order and a 'cross-case synthesis' order. The final algorithm of the influential themes, factors and variables will be drawn to ultimately conclude the analysis in accordance with the instrumental framework that will be illustrated afterwards.

- **Chapter 6: Build and test intervention scenarios**

  This chapter represents the quantitative part of the study. Influential variables arrived at earlier in Chapter 5 will be introduced to build scenarios of physical interventions. Scenarios will be chosen in accordance with participants' recommendations, the researcher's experience and the supervisory panel's viewpoints. Mitigating physical scenarios will be introduced and tested through an HEC RAS simulation platform. A comparison between the current prone situation and the new – physically altered - setting will indicate the viability of the variables and the reliability of the mitigation scenarios.

- **Chapter 7: Research testing**

  Discussion in this chapter will address the methodology testing and the procedure that has led to research findings. An instrumental framework validation process will also be highlighted.

- **Chapter 8: Research conclusions and recommendation**

  This chapter will conclude the study by drawing out the important research findings. The critical research contribution to current knowledge will be highlighted, and recommendations for future perspectives that are worth considering will be identified. The whole research journey is structured across the research method and methodology, as demonstrated in Figure 2.

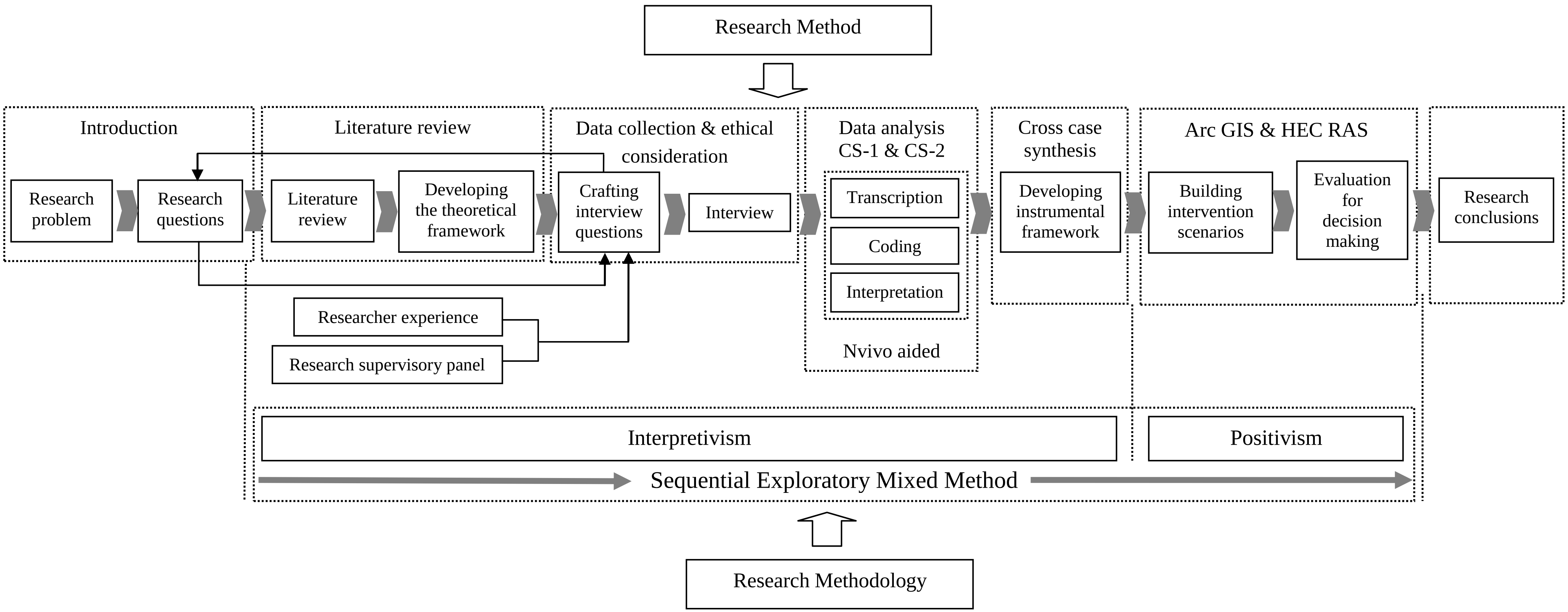


Figure 2: Research Method and Methodology

Chapter 2: Critical review of the concept of resilience and its correspondence with the research domains

2.1 Introduction

A literature review means locating and summarising existing studies about a certain topic (Creswell, 2009). It also defined the selection of available documents on the topic, which contain information, ideas, data and evidence written from a particular standpoint to fulfil certain aims or express certain views on the nature of a topic and how it is to be investigated (Hart, 2005). Stances on the use of the literature vary widely, as do the stances on using a *priori* theory. The literature may be fully reviewed and used to inform the questions actually asked; it may be reviewed late in the research process, or it may be used solely to help document the importance of the research problem. Other options may also exist, but these possibilities point to the varied uses of literature in qualitative research.(Creswell, 2007). Terms, such as location, positioning and contribution, all imply some form of relationship between the research study and prior research. Such positioning is essential in order to demonstrate to others: 1- the relevant domain that informs the work and, 2- the contribution of the work to these domains (Jenkins, 2003). Figure 3 shows the main theoretical research domains.

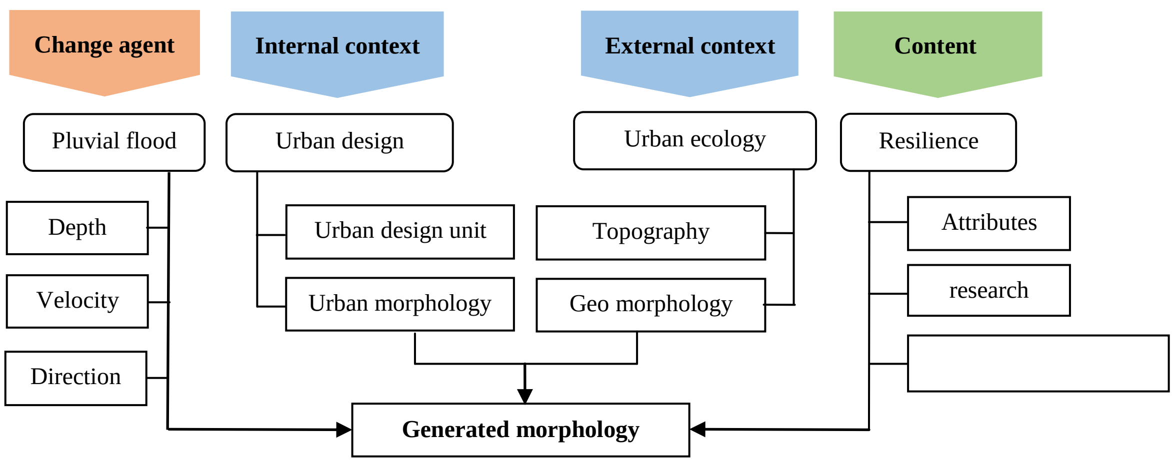


Figure 3: Main research theoretical domains

According to Creswell (2007), the literature will be reviewed early in this research to inform the questions actually asked and to examine its novelty and contribution. The main theoretical domains, addressed earlier, will be examined to inform and guide the subsequent enquiry, (Choice-1 in Figure 4). Nevertheless, the third option of citing the literature in Table 1 was implicitly applied in developing the set of resilience principles. This was done after the Delphi study (Appendix-3), was performed and had produced the desired set of resilience principles. The coexistence of the selected principles was examined in the current literature.

Choice No.	Use of literature	Criteria	Examples of suitable strategy type
1	The literature used to frame the problem in the introduction of the study.	There must be some literature available.	Typically literature used in all qualitative studies, regardless of type.
2	The literature is presented in a separate section as a review of the literature.	This approach is often acceptable to an audience most familiar with the traditional post-positivist approaches to literature reviews.	This approach is used with those studies employing a strategy theory and literature background at the beginning of a study, such as ethnographies and critical theory studies.
3	The literature is presented in the study at the end; it becomes a basis for comparing and contrasting findings of the qualitative study.	This approach is most suitable for the inductive process of qualitative research; the literature does not guide and direct the study but becomes an aid once patterns or categories have been identified.	This approach is used in all types of qualitative design, but it is most popular with grounded theory, where one contrasts and compares a theory with other theories found in the literature.

Table 1: Using literature in a qualitative study (adapted from Creswell, 2007)

2.2 Mapping the literature

Most pieces of research focus on perhaps four or five other key papers/books as the centre of their discussion. If the researcher does more than this, they will lose clarity and emerge with generalities aimed at pleasing everyone, but in fact are so general that they interest no one (Jenkins, 2003). Figure 4 shows the mapping process for one of the main theoretical domains addressed in this research - resilience - and how it has emerged as a way of rethinking systems under stress in ecology in order to extend it to reflect the concept of engineering systems and, most recently, coupled human environmental systems. The diagram shows examples from the pioneer contributors, as the full range of authors who wrote about resilience is much larger than the area of interest for this research, shown in the shaded area below. Nevertheless, vital transitions in resilience thinking are envisioned.

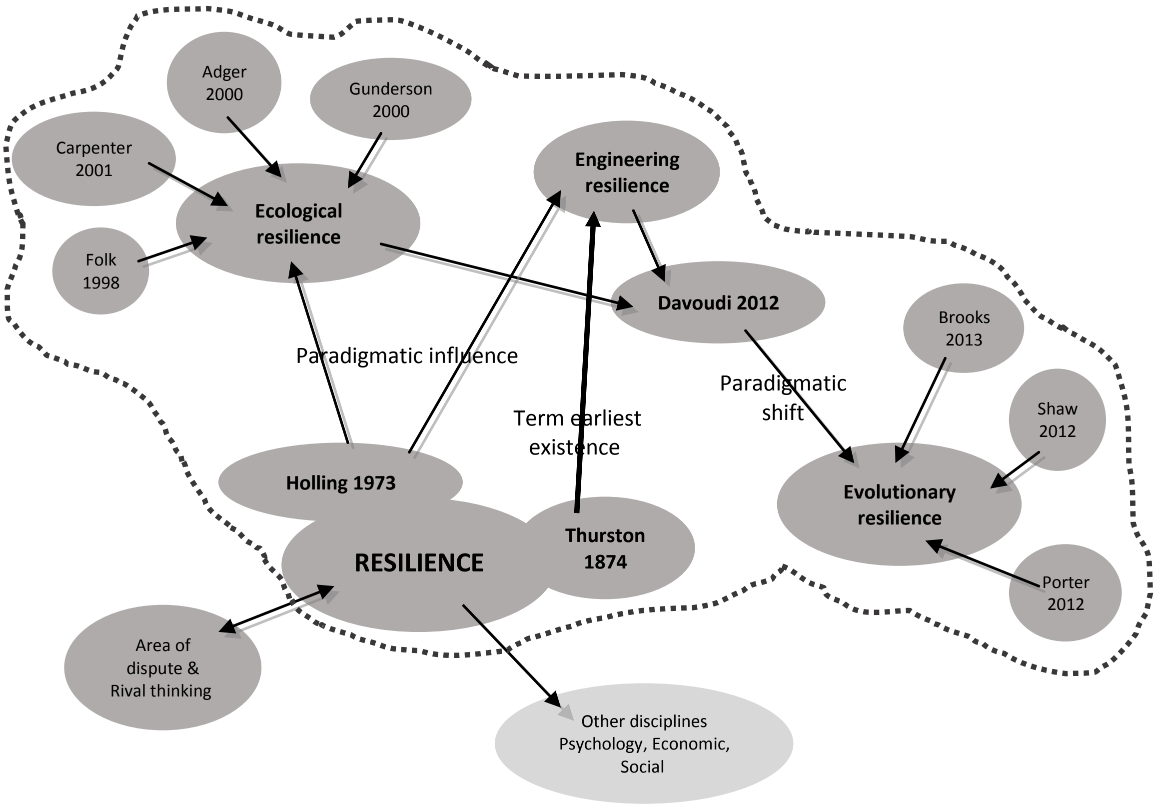


Figure4 : Mapping the field of resilience

The study will carry out an in-depth morphological analysis for the important urban form elements that most influence urban design. This involves a thematic review of the urban morphological theories, with particular attention to those within which physical aspects are prominent. The Conzenian morphology, and Conzen's trilogy, will form the urban physical analysis on this study by identifying the urban design (unit). The systemic involvement of both the urban design unit (the built) and the terrestrial ecology will constitute the generated morphology upon which the analysis will be conducted in the study area. This will help to recognise resilience in an ecologically built context, referred to later as eco-built in this research.

The imaginative act of creating and accepting the metaphor of resilience can be shared by ecologists and urban designers (Pickett et al, 2003). Meanwhile, Renaud (2013) compared the conventional engineering flood protection solutions by identifying that eco-based disaster risk reduction solutions provide multiple benefits for human well-being regardless of a disaster event. This is achieved by involving relatively low-cost interventions and maintenance, hence, eco-based disaster risk reduction solutions can be considered to be a cost-effective, no-regret investment.

As a system thinking approach, Pickett, et al (2013) affirmed that a system consists of parts (components) and is characterised by properties that emerge from the interaction of these parts. When components interact in a system, their initial function differs. Figure 5 shows the theoretical research domains and system components that result from the interaction of these domains. A theoretical resilience lens will shape the investigation to explore resilient responses within the urban form to pluvial floods.

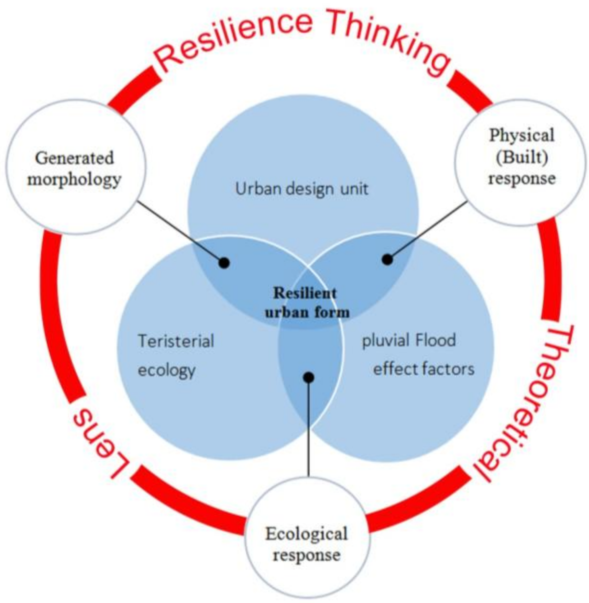


Figure 5: Influential research areas resulting from the literature review

2.3 Resilience

This section introduces the concept of resilience and its parameter according to the urban design elements and characteristics that will be measured. The Oxford English Dictionary defines resilience as: 'the act of rebounding or springing back'. The term resilience is derived from the Latin root *'resi-lire'* meaning to spring back (Windle, 2010). However, the 1960s witnessed the emergence of notions of resilience within the field of ecology where multiple meanings of the concept emerged with each rooted in different world views and scientific traditions. By 1973, Holling coined the term resilience for ecosystems as a measure of the ability of these systems to absorb changes and still persist, and to determine the persistence of relationships within an ecosystem; it is widely recognised that Holling was the first to present the term in ecology (Kreimmer, Arnold, & Carlin 2003). Nevertheless, theoretical investigation reveals that the term's early appearance dated back to 1874 when R.H.

Thurston, an American engineer and the first Professor of Mechanical Engineering at Stevens Institute of Technology, described the resilience of timber wood in machinery parts concerning a membrane facing physical stress before it breaks apart (Thurston, 1874).

The concept of resilience has been frequently used in more metaphorical sense since the 1970s to describe systems that undergo stress and have the ability to recover (Kreimmer, et al, 2003). Correspondingly, Desouza and Flanery (2013) stated that the concept of resilience has often been defined in broad or disparate terms depending on the specific application or field of study. Nevertheless, physical scientists first used the term resilience to denote characteristics of a spring and to describe the stability of material and its resistance to external shock (Davoudi, 2012).

The 2009 report by UNISDR defines resilience as: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. Resilience is the capacity (of a system, community, or society potentially exposed to hazards) to adapt, by resisting or changing, in order to reach and maintain an acceptable level of functioning and structure (Community and Regional Resilience Institute, 2013, p.8). Also, resilience as a concept in physics and mathematics was used to describe the capacity of a material or system to return to equilibrium after displacement (Leon, 2014, p.251).

In planning, the study of resilience began in the late 1990s. At that time, discussions on resilience focused on developing strategies to mitigate environmental threats. This was often related to the physical and infrastructure improvements to prevent the occurrence of disturbance (Pei-Wen, 2014, p.27). Meanwhile, Christopherson, (2010) defined resilience in urban design as the ability to respond to a contemporary sense of complexity, uncertainty and insecurity and to set up a new approach or priority for adaptation and survival. In contrast, in flood hazard management, the use of resistance was more likely to be used to measure the flood prevention performance of a flood-control infrastructure (Liao, 2012). From the same perspective, Liao stated that, in flood hazard management, resistance means flood prevention by a flood-control infrastructure, while resilience is the rate of return from a *flood-impacted state* to a *normal pre-disaster state*.

Weichselgartner and Kelman (2015) conclude that resilience is a concept that is applied in various disciplines and different fields, including geography, engineering, psychology and ecology. One common thread among these disciplines is the ability of materials, individuals, organisations and social-ecological systems, from critical infrastructure to rural communities, to withstand severe conditions and to absorb shock. However, definitions are still being formed within the different disciplines at different rates and thus, this fluidity must be taken into account.

Despite the abundance of research on resilience, there is still no single, universally accepted definition (Sharifi & Yamagata, 2014). Guided by this understanding, and due to the qualitative nature of this research, in the earlier stages of this study the author will be cautious in developing the definition of the term and what it exactly stands for in the urban design discipline. Creswell (2009) confirmed that qualitative researchers tend to delay putting forward decisive definitions from the start of their study. Instead, they might use tentative definitions, or tend to let the full meaning of the phenomena under investigation to emerge through the development of the research inquiry. Nevertheless, a full range of the variety of resilience definitions in different fields is available in Appendix 4.

2.4 Levels of resilience, from complex systems to simplified approaches

Professionals can learn about resilience and how an appropriate balance can be achieved between organisational and other types of resilience. Resilience in complex systems needs to be addressed carefully, as it is reflected from the bottom to the top, from the component sub-systems. Looking at systems through an analytical lens and configuring the main component sub-systems and their interdependencies and redundancies can generally help to draw the line in the status of complex system resilience (Shaw, 2012).

Pei-Wen (2014, p.38) identified that ‘’it is a challenge to examine the process of a vision of spatial development being addressed, transferred and shaping coalitions between actors involved in decision making. This can result in difficulties in managing any spatial development within the consideration of complex issues, which can require a combination of different policies, disciplines and professions, such as climate change and flooding’’. Sharifi and Yamagata (2014) referred to this critical aspect for resilience by stating that; having a set of criteria at hand could be regarded as a good effort towards simplifying the complex issue of resilience and making it more understandable to the various stakeholders. Indeed, by subdividing it into manageable roles and allocating them to different individuals or organisations, the fragmented approaches that prevailed in the past can be seen as an attempt to reduce the complexity of the problem (Hall, et al, 2003).

Being mindful of this understanding is a key purpose of this research. This study aims to identify key criteria for urban resilience to pluvial floods within the urban design discipline, and specifically within the targeted physical dimension. As the urban context is a multi-disciplinary field that incorporates several acting systems that function together, discussing the concept of resilience across all these acting systems at one time is a matter of sheer complexity. This complexity can originate from the variations in key characteristics and critical thresholds for these systems with many attributes. Eventually, reducing the complexity of any field by subdividing it into manageable roles, as stated above, can help to focus efforts at the required level that resilience needs to be addressed.

2.5 Resilience attributes

In order to determine the parameters of resilience for this study, and in accordance with attempts to fashion resilience within the built environment, the theoretical review is structured to help address the underlying paradigm (perspective) of resilience within the internal and external contexts (built and natural). They present an important parameter, namely the resilience domain, which is where resilience actions take place. It is also important to address whether the resilience mode is internally provoked or externally acquired by addressing differences between inherent and adaptive resilience. Finally, the characteristics of resilience responses will be identified by the resilience principles. The following section will explain these attributes in detail.

2.5.1 Resilience perspectives

Three main perspectives of resilience were considered when the idea was initially discussed in the early seventies. C. S. Holling, an ecologist first discussed the idea of engineering resilience in static engineered systems to build a comparison with the ecological resilience in bio-systems. Evolutionary resilience emerged later as the main idea of resilience in more dynamic systems, such as economic, cultural, social and other human systems. According to Carmona (2010), economic, cultural, social and other human systems are known as the soft systems compared to engineering and bio-systems; indeed, they account first and foremost for relational and organisational aspects. The following section will discuss resilience from three perspectives, engineering, ecological and evolutionary, addressing the characteristics of each perspective, and translating the applicability and measurability of each in association with the urban design dimension.

2.5.1.1 Engineering Resilience

Holling (1973) defined engineering resilience as the ability of a system to return to an equilibrium or steady-state after a disturbance. Francis and Bekera (2014, p.93) describe resilience in infrastructure systems as 'the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event'. In this perspective, the resistance to disturbance and the speed by which the system returns to equilibrium is the measure of resilience, the faster the system bounce back the more resilient it is. It is a fail-safe strategy.

In From this perspective, the resistance to disturbance and the speed by which the system returns to equilibrium is the measure of resilience; thus, the faster the system bounces back, the more resilient it is. Therefore, the emphasis is on return time, efficiency, constancy and predictability, all of which are sought-after qualities for a "fail-safe" engineered design (Davoudi, 2012).

Jones and Holling (1975) distinguished between the two strategies of fail-safe and safe-to-fail. The goal of a fail-safe policy strives to assure that nothing will go wrong. Systems are designed to be foolproof and strong enough to withstand any eventuality. Efforts are made to radically reduce the probability of failure. Meanwhile, a safe-to-fail strategy acknowledges that failure is inevitable and seeks systems that can easily survive failure where possible. Rather than rely on reducing the occurrence of failure, this policy aims at reducing the cost of that failure. Later on, Holling (1996) identified the characteristics that discriminates the two strategies; a fail-safe strategy that focuses on efficiency, constancy, and predictability, which are all attributes at the core of engineers' desires for fail-safe design. In comparison, the safe-to-fail strategy focuses on persistence, change, and unpredictability; all of these attributes were embraced by biologists with an evolutionary perspective and by those who search for safe-to-fail designs.

Contrary to the engineering resilience perception, Francis and Bekera (2014, p.100) stated that ‘efforts in design should be allocated to increase emphasis on “safe-to-fail” rather than “fail-safe” provisions’. Figure 6 explains the idea of engineering resilience measured by the rapidity of the process by which a stressed system restores its original stability.

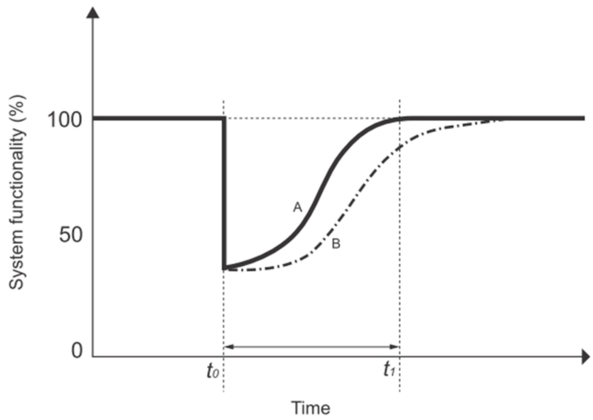


Figure 6: Engineering resilience (Liao, 2012)

Engineering resilience exists in nature. The Axolotl salamander[1], shown in Figure 7, is a superhero of regeneration and a salient case. It has the ability to replace lost limbs, damaged lungs, and a sliced spinal cord; it can even renew bits of its damaged brain. When the salamander loses a leg, a small bump forms over the injury called a blastema[2]. Given its lifespan of approximately 12 years, it takes around three weeks for this blastema to transform into a new, fully functioning replacement leg. Figure 7 shows the transformational phases. This ability is a fact of nature, and it is suggested that researchers should learn how to replicate it in human systems (Zielins et al, 2016). Scientists have long credited the capabilities of the Axolotl Salamander, because its cells have the ability to morph into whatever appendage, organ or tissue happens to be needed or due for replacement (Hoover, 2014). The current focus is now on understanding the process so that it hopefully stands for reverse engineering to human therapies (Godwin, 2009). Replicating the logic and mechanism by which this creature can successfully reproduce and replace a damaged organ can be helpful in studying and efficiently applying engineering resilience.

[1] Axolotl Salamander: any of several aquatic salamanders of the North American genus Ambystoma, esp A. mexicanum (Mexican axolotl), in which the larval form (including external gills) is retained throughout life under natural conditions (see neoteny): family Ambystomidae. (dictionary.com).The name "Axolotl" comes from the Aztec language, "Nahuatl". One of the most popular translations of the name connects the Axolotl to the god of deformations and death, Xolotl, while the **most commonly accepted** translation is "water-dog" (from "atl" for water, and "xolotl", which can also mean dog).(axolotl.org).

[2] A group of cells that gives rise to an organ or part in either normal development or regeneration.(medical-dictionary.com)

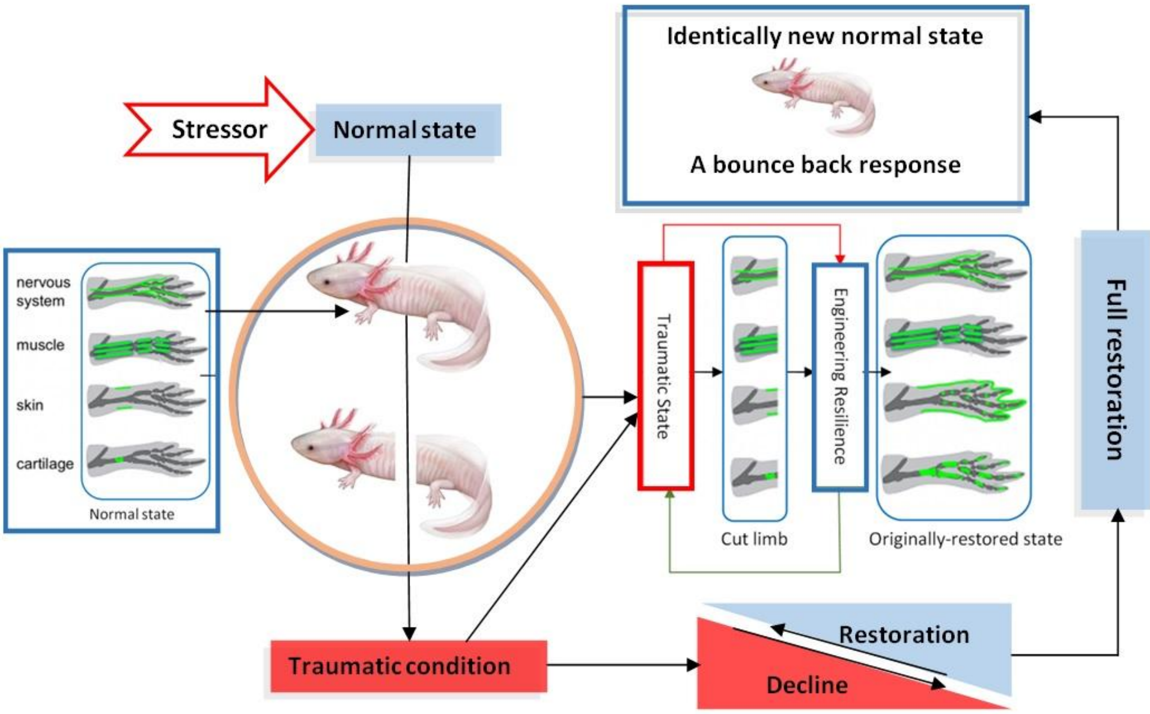


Figure 7: Salamander regeneration process (Engineering resilience)

The regeneration process of the salamander resembles engineering resilience: the ability to restore an amputated limb to an original state without even a scar highlights the philosophical comparison between resistance and resilience. Resistance is an expression of conventional flood engineering infrastructures, while resilience reflects the crucial role of urban design in facing stressors. The amphibian can still walk while its body's biological mechanism replaces the lost limb. In urban design, resilience resembles maintaining the ability ’to walk’, while other partners and systems in the city ‘replace the amputated limbs’.

2.5.1.2 Ecological Resilience

Ecological resilience is defined as, 'the magnitude of the disturbance that can be absorbed before the system changes its structure' (Holling, 1996, p.33). Accordingly, ecological resilience is not only defined by the time that the system takes to bounce back after a shock, but also the how much disturbance it can take and still remain within the critical thresholds.

In identifying the main difference between ecological and engineering resilience, Davoudi (2012, p.301) stated that ecological resilience rejects the existence of a single, stable equilibrium and instead acknowledges the existence of multi equilibria, and the possibility that systems flip into alternative stability domains. Davoudi also ordered the distinctions between the two perspectives to consider the notion of a stable equilibrium, 'be it a pre-existing [state] to which a resilient system bounces back (engineering) or a new [state] to which it bounces forth (ecological) (Davoudi et al, 2013).

Figure 8: Ecological resilience concept (Liao, 2012)

''The idea of design for ecological versus engineered resilience in socio-technical systems is an emerging concept that advocates the design of engineered systems based on the ecological principles of diversity, adaptability, interconnectedness, mutual evolution, and flexibility'' (Francis, 2014, p.93). This conception is facilitated by Jones and Holling's (1975) understanding between the two perspectives (engineering versus ecological), as stated earlier; this is the difference between a safe-to-fail strategy, which resembles the ecological perspective, and the fail-safe strategy, which resembles the engineering perspective. Figure 8 represents the threshold stages upon which systems bounce-forth in ecological resilience.

An example of an ecological resilient-based response can be seen in the type of housing people developed in the Himalayas' seismic-active regions. Sharma (2001, cited in UNHS, 2007) stated that indigenous people living in the Himalayas regions developed a type of vernacular house that was build to survive frequent earthquakes; these were called Kat-Ki Kunni, (shown in Figure 9). The replacement of stone built houses with a new type of building where wood bonding was arranged in vertical intervals with mud masonry from the outside to give the structure flexibility for earthquake resistance (shown in Figure 10). Even though these were multi story buildings, Kat-Ki Kunni were the last standing structures after the Kangra earthquake hit the Himachal Pradesh region in 1905.

Figure 9 : The Kat-Ki Kunni house
materialinks.wordpress.com

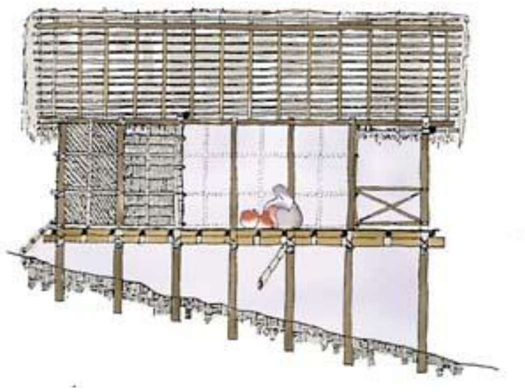


Figure 10: Structure of Kat-Ki Kunni house
www.downtoearth.org

The ecological resilience of the Kat-Ki Kunni manifested in departing from the previous non-efficient stone-based type of building to an entirely new, eco-compliant wooden-based structure. The new type of buildings represent a shift from the old stone building state to the new stable state (addressed above as new equilibiria) but within the same ecological regime. This new equilibiria was achieved by adopting ecologically reliant material like wood, which was ecologically abundant, and a physically feasible structure, that used wood bonding in vertical intervals.

2.5.1.3 Evolutionary Resilience

The third key perspective is evolutionary resilience. Shaw, (2012, p.310) argued that "in an analysis of post-recession urban developments in London and Hong Kong, rather than seeing resilience as a process of bouncing back, a more radical deployment would view it as a dynamic process in which change and constant re-invention provide for social, economic, and/or environmental strength". Furthermore, Francis (2014) defines socio-economic resilience as the ability of the system to maintain its identity in the face of change and external shocks and disturbances. The components of this system, the relationships among these components, and the ability of these components and relationships to maintain themselves constitute the system identity. Meanwhile, Davoudi (2012) stated that revolutionary resilience challenges the whole idea of equilibrium stating that the system may change over time with or without an external disturbance. Some commentators call this socio-ecological resilience; however, Davoudi's argument concords with a focus on resilience through an evolutionary lens. It is defined as not returning to normality (the pre-disaster state), but rather as the ability of complex socio-ecological systems to change, adapt, and, crucially, transform in response to stress and strains.

Kinzig (2006) also stated that evolutionary resilience is embedded in the recognition that the seemingly stable state that we see around us in nature or in society can suddenly change and become something radically new, with characteristics that are profoundly different from those of the original. Meanwhile, Davoudi (2012) mentioned that evolutionary resilience is principally the vehicle for the adaptation and evolution of dynamic natural and social systems. Advances in evolutionary resilience have been made largely in the fields of social and ecological systems. In contrast, in the built environment, ‘’the ‘inertia’ of urban resilience emerges from a combination of undiminished geographic advantages, long-term investment in infrastructure, and place-dependant business networks’’ (Vale & Campanella, 2005.p.346).

O’Neill and Scott’s (2011) study advocates transformative approaches to flood risk management under the inevitability of the climate change measures; they stated that calls for a transformation in urban design involves moving beyond a focus on construction-based interventions or simple sequential land-use modes of governance aimed at flood risk ‘defence’ and/or ‘accommodation’. Instead, it entails a holistic reassessment of the relationship between the built and non-built components of urban environments. The dynamics of an evolutionary holistic approach to resilience by incorporating social, economic and ecological dimensions is also reflected in the work of Pescaroli and Nones, (2016). They call for new assessment methodologies to integrate social, physical and structural drivers, taking as reference, respectively, the community, environment and buildings in defining the sensibility of areas to flood-triggered cascading.

In the case of evolutionary resilience, the transformability character, which calls for a departure to a new regime, is a crucial threshold. It is unlike ecological resilience, which is measured by the readiness to tolerate stressors while exhibiting one ecological regime. Instead, evolutionary resilience is a totally new stable state that the system successfully arrives at after the old ecological regime is destructed. According to its dynamic description, evolutionary resilience is more applicable to socio-economic systems, as discussed above. The evolving mechanism to new stable status can follow all the way through to full operationalisation in single or multiple stressing event/events, due to their system’s non-static nature. Yet, it is difficult to spot such evolutionary responses in complex socio-economic systems like cities. Therefore, the following example was selected to exemplify the evolutionary resilience of a species that has a dynamic complex life style and survives a deluge by having the ability to undertake such a response.

Figure11 : Fire ants' colony in normal and flooding situation (Adapted from inhabitat.com)

Fire ants, shown in Figure 11, live in colonies in the soil. If a colony is flooded during rainfall, or other water-logging situations, the ants cling together and form a living raft that floats on the flood water (Adams et al., 2011). The pattern demonstrated by fire ants encompasses a number of mechanisms to survive a flood. The way the colony confronts this stressor, is by having all the valuable assets of the colony in the safest place, namely on the floating living raft. The queen is situated in the middle, maintaining the important identity of the colony and by saving the next generation by reaching the safety of the nearest dry land. Fire ants have the ability to set themselves free from the physical boundaries of their endangered shelter. The whole colony transforms into a transitory phase of a mobile colony to avoid drowning; thus, transformability characterises the resilience survival techniques of the fire ant.

In the case of evolutionary resilience, the transformability character, which assigns a departure to a new regime, is the crucial threshold. It is unlike ecological resilience, which is measured by the readiness to tolerate stressors while exhibiting one ecological regime. Instead, it totally departs for new stable state that the system successfully arrives at after the old ecological regime is destroyed or departed.

2.5.1.4 Linking the efforts of the two domains: urban design and resilience perspectives

Building on the concept of engineering resilience, the main characteristics concern; firstly, regaining the same system stability in a timely efficient manner, secondly, a predominant emphasis on the system's functionality through its system efficiency, thirdly, the fact that engineering resilience promotes the desired system robustness, and finally, by looking at the first system state. This is a bounce-back labelled perspective.

Meanwhile, according to the nature of the bio-systems from which it emerged, ecological resilience calls for system multi-stability before the system shift into a new regime; it also considers system functionality. Ecological resilience relies on maintaining the existence of a system's function while undergoing external stresses, looking at the quality of the new system state. It is likely that such an approach addresses the contemporary urban form of resilience, where urban design helps to progressively absorb the flood impact to uphold new critical stability. It is this new stability in which urban design maintains a minimum required level of functionality, a safe-to-fail strategy with a bounce-forth perspective.

Transformability is the principal value that distinguishes evolutionary resilience from engineering and ecological resilience (Davoudi, et al., 2013). Evolutionary resilience considers the various levels of a system's response as a process for future desired trajectories. This goes all the way through an effective system change, looking mainly at the process of the system under stress, which has arrived at an entirely new stable state. Evolutionary resilience best fits social, economic and/or political systems. Although it is not unachievable in the urban form, it takes longer due to the lengthy process of cumulating experiences. This is also very much owing to the inertia of physical structures Cheshire (2006). Urban form can yield the benefits of the long process of its contemporary responses, reaching maturity and viability for evolutionary reconstruction. This achievement marks the culmination of a long-term process. A restructure followed destruction, a bounce-forward perspective.

Systemic inconsistency between the dynamic character of evolutionary resilience and the inertia of physical development in the urban context (Vale & Campanella, 2005), actually mark the inflexible physical constructions that shape our cities. The static nature of these long-term constructions customarily hindered the developmental natured policies and programs. Cheshire (2006) referred to the conflict between the dynamics of policies and programs, and the rigid nature with which the city structure is addressed. Cheshire stated that cities have so far appeared to be not just complex but rather robust systems. Thus, policy has had to be clearly demonstrable but often very unexpected and adverse effects. This seems to be mainly because of the inertia of cities. Cities have much more inertia than super-tankers and policy takes a long time to demonstrate any significant effect at all. One obvious reason is the durability of the built environment. Hall and Pennning-Rowsell, (2011) realised the shortcomings of stationary character by relying solely on the engineered solutions in flood management. They argued that modern flood risk management no longer relies solely upon engineered flood defense structures, such as dykes, channel improvement works and barriers. It also considers other measures that may be used to reduce the severity of flooding, such as land use changes in upstream catchments or to reduce the consequence of flooding by reducing either exposure or vulnerability. Therefore, the increasing recognition of non-stationary means of flood risk management is considered in order to face the ways in which flood risk may change in future.

The research addresses the notion of resilience within the physical dimension of both the urban form and the natural environment. Thus, the engineering domain is the base line on which the notion of resilience will be addressed, but it will not be the final station on which concluding assumptions will be drawn. The streamlining of resilience will count mainly for the perspectives of engineering and ecology due to their applicability and cohesion with research objectives. Table 2 exhibits how resilience is considered in the research by overlapping the characteristics of three perspectives of the term.

haracteristics	**Resilience perspectives**		
	Engineering	**Ecological**	**Evolutionary**
Domain	*Man-made structures*	*Bio-physical*	Socio-economic
Objective	Single stability	*Multi-equilibria*	New regime
Philosophy	*Bounce-back*	*Bounce-forth*	*Bounce-forward*
Target	Efficiency	*Existence of function*	Efficiency in new structure
Focus	State	*Quality*	Process
Stability	Previous state	*Within system* *Before shift*	*Transformability*
Activity	Static	*Bounded-dynamic* *Within-system dynamics*	In momentum

Table 2: Characteristics of three resilience perspectives

As seen in Table 2, the characteristics of ecological resilience link two opposite stances of engineering and evolutionary resilience. The characteristics of the ecological sense intermediate the distance where the two far ends of the engineering and evolutionary stances can theoretically associate. A balanced state between the rigidity and inertia of the the engineering perspective and the dynamics of the evolutionary perspective can be found in ecological perspective; it encompasses the virtues of both these perspectives.

Ecological resilience mediates the distance between engineering and evolutionary resilience. Its virtues mainly manifest in the system departure towards a new stable state before it breaks apart, seeking a within-system new stable state. Ecological resilience also facilitates pathways to overcome the inertia and stationary of manmade structures. The inertia of urban structures makes them difficult to examine through the holistic dynamic perspective of evolutionary resilience, especially over a short time span where the flood phenomena is taking place. Therefore, this research is going to examine the resilience of urban design to pluvial floods in Muscat city from the perspective of ecological resilience. Table 3 outlines the cohesion between the ecological resilience characteristics and the urban design parameters.

Ecological resilience	Reflections on the physical urban context
Bio-physical	Generated morphology incorporates natural topology & urban morphology as one hydrological unit
Multi-equilibria	Temporal uses and emergency-based measures
Bounce-forth	Cumulative experience from ongoing events to place urban physical fixes
Existence of function	Minimum functionality (accessibility)
Quality	Providing Minimum required service
Within system Before shift	System altered internally within the same structure to meet current challenges
Bounded-dynamic Within-system dynamics	(Restructured/Reorganized/Redistribute) within system new characteristics

Table 3: Linkages between ecological perspectives and research domains

2.5.1.5 From eco-built resilience to future transformability (Evolutionary)

The contemporary process in Figure 12 theoretically resembles the system's first resilient response to maintain essential functionality when undergoing external stressors by bouncing back/forth to previous systems or new stabilities. Correspondingly, with the system experiencing multiple stressors over time, the accumulation of experienced responses will initiate a system transformation from its old settings. Building on previous responses, and in due course, the system ultimately bounces forward to an entirely new stability. Figure 13 illustrates the relationship between urban design and resilience three perspectives against the time factor, where frequent stresses from multiple events erode a system’s structure, magnifying the overall maintenance cost, and hurdling the process of political decision making. This will ultimately shape the evolutionary response of the system over future courses.

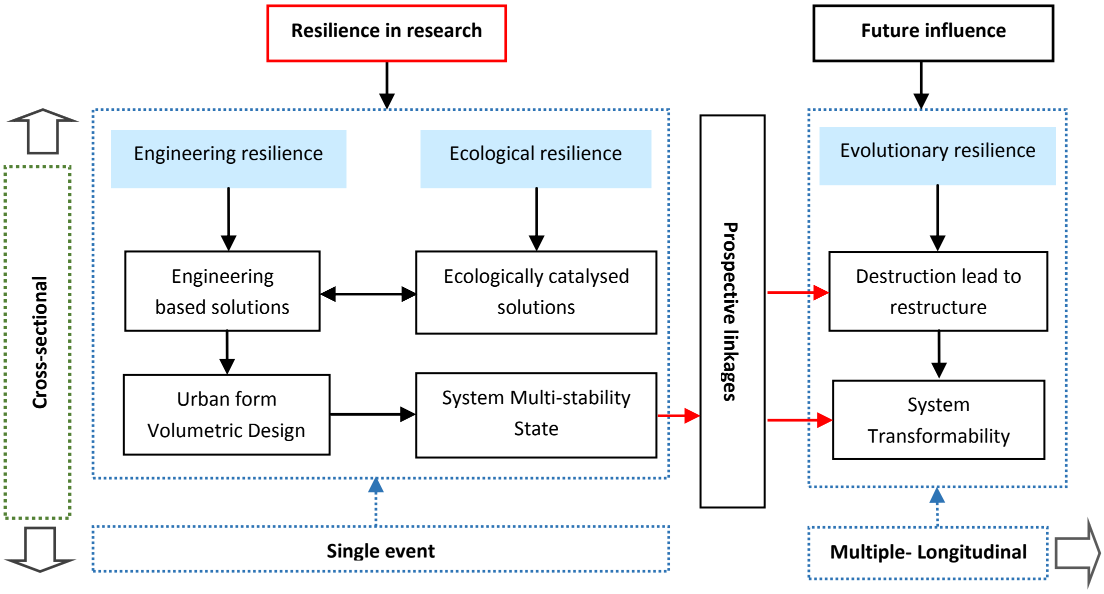


Figure 12: Research stance within the three resilience perspectives

The position of this research in addressing the resilience of urban design to pluvial floods, as mentioned earlier, relies on the effective cohesion between the physical dimension in both ecology and urban form. This depends on a single or several extreme events. Figure 14 illustrates the ultimate achievable resilience response within the eco-built paradigm and the zone of departure from which the whole process leaps forward to a new regime in the evolutionary course. In another way, the eco-built scenario could - under circumstances of increased mitigation cost - depart from the eco-built paradigm towards a point (or zone) of a new critical state that facilitates a shift to stability in a totally new paradigm.

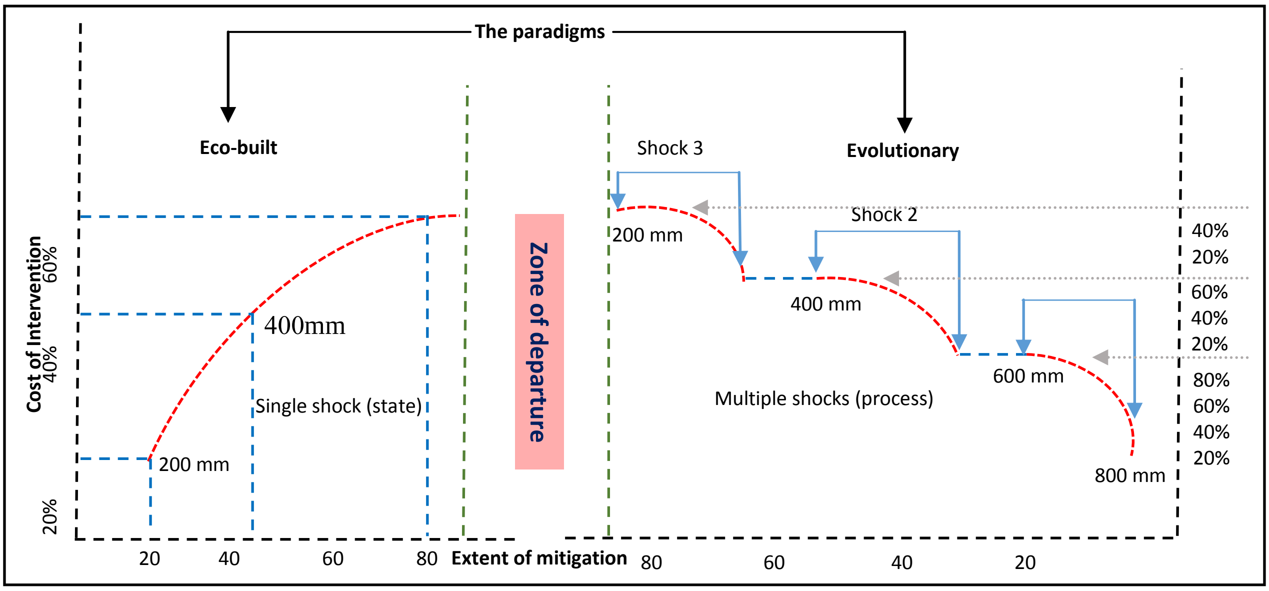


Figure 13: Threshold between two interrelated paradigms

2.5.2 Types of resilience

The Multidisciplinary Centre for Earthquake Engineering Research (MCEER) considers two types of resilience depending on the circumstances that any system encounters, crisis and non-crisis circumstances. These types are; inherent resilience, which refers to the entity's ability to function well during non-crisis situations, and adaptive resilience, which refers to an entity demonstrating flexibility during and after disasters (Tierney & Bruneau, 2007). Similarly, Rose (2004) distinguished two types of resilience: firstly, the inherent ability under normal circumstances (e.g. the ability to substitute other inputs for those curtailed by an external shock) and secondly, the adaptive ability in crisis situations that emerges due to ingenuity or extra effort (e.g. increasing input substitution possibilities in individual business operations).

Zevenbergen (2011) referred to the antecedent conditions as site-specific processes between the physical-environmental subsystem and the socio-economic subsystem, and they include the inherent characteristics that allow the system to absorb flood impacts. The resilience capacity is well suited to an adaptive approach to planning and design, where innovation is pursued through responsible experimentation, developing a culture of monitoring, and learning from modest failures (Ahern, 2011). Meanwhile, Leon (2014, p.251) stated that 'Planning has inherent capacities: to systemically and comprehensively influence the location and design of urban development'.

Gallopin (2006) referred to inherent resilience as an internal property of the system and not related to the exposure to perturbations. However, the operationalisation of these capabilities is clearly deployed when interacting with the characteristics of the flood system to yield immediate effect (Zevenbergen, 2011). Also, Walker et al, (2006) described the inherent resilience within systems for those systems to be proactive and self-determining, rather than just reactive and outside determined. Adaptive resilience was identified by Vale and Campanella (2005), who stated that a building's resilience capacity requires planners and designers to identify the stochastic processes and disturbances that a particular landscape or city is likely to face, the frequency and intensity of these events, and how cities can build the adaptive capacity to respond to these disturbances while remaining in a functional state of resilience. Indeed, 'Resilient cities would be built on principles derived from past experience with disasters in urban areas' (Godschalk, 2003, p.137). In general, building resilience is said to be achieved by reducing the exposure and sensitivity to shocks, as well as by increasing its adaptive capacity (Weichselgartner, & Kelman, 2015, p. 254).

Cities have always adapted to changing environmental conditions through autonomous adaptation; the dynamics of climate change may warrant adaptation of the building stock to better cope with increasing flood risk, through planned retrofits and/or a redesign of its structure during its life time (Zevenbergen, 2011, p.15). Frommer (2013) also drew attention to the adaptive resilience in referring to the Fourth Assessment Report of the International Panel on Climate Change (IPCC), which provided evidence that climate change is already occurring. There has been a noticeable shift in the rhetoric about climate change, moving from mitigation only to mitigation and adaptation strategies. Resilience in urban areas should be considered an adaptive process that does not necessarily require the system to return to a state of equilibrium after having been hit (Sharifi & Yamagata, 2014). Engle, Bremond, Malone, and Moss (2013) also described resilience as a system's ability for short-term coping and long-term adaptation.

2.5.3 Domains of resilience

Drakakis-Smith (1996) demonstrated five domains of resilience, asserting that there are elements for consideration that demonstrate a sustainable view of urbanisation. These are shown in Figure 14, where five components are identified: social, economic, political, demographic and environmental.

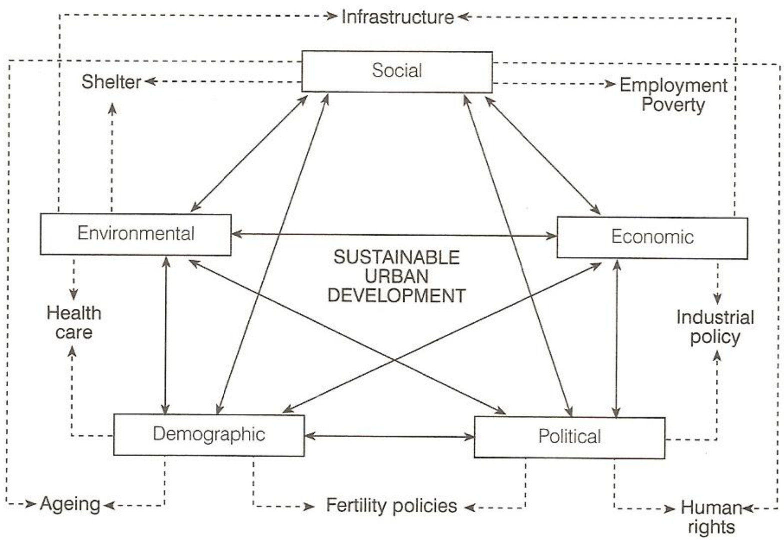


Figure14 : Domains of resilience (Drakakis-Smith, 1996)

Infrastructure and other components are represented as a sub-network located between the interactions of the five main system domains. When they described a resilient system, Tierney and Bruneau (2007) also assigned four fundamental components, which are: the technical domain, the organisational, the social, and the local and regional economies. Moreover, Kotzee and Reyers (2014) considered 24 resilience indicators in a study area in South Africa. These indicators were taken from the main domain of resilience that they had earlier developed, which were: social, ecological, infrastructural and economic, and later they add the institutional aspect. Da-Silva (2015) specified four domains for resilience, and argued that these four all occupy integrated resilience in the city, specified as: knowledge, place, people and organisation.

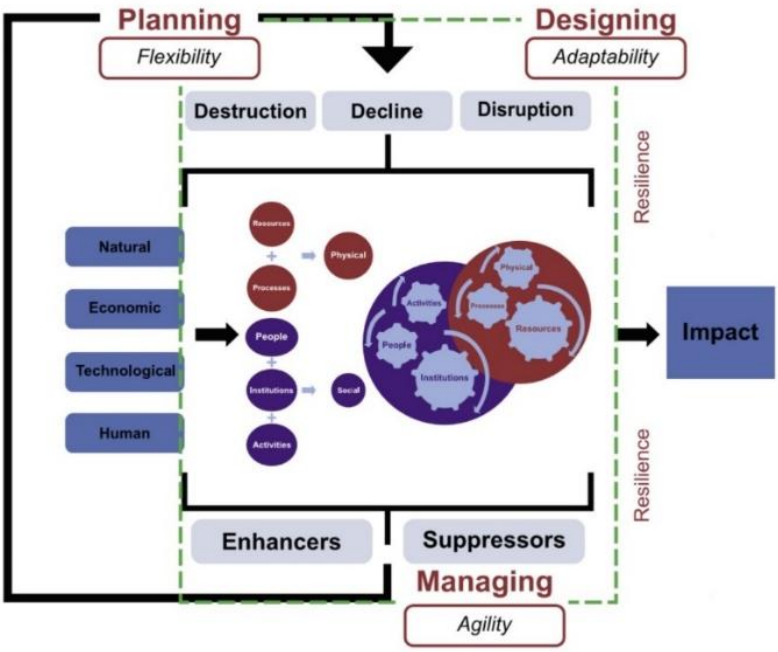


Figure 15: Resilient cities (Desouza & Flanery, 2013)

Desouza and Flanery (2013) describe a comprehensive conceptual framework for a resilient city, addressing the stages of shock as Destruction-Decline-Disruption. They also assign two major domains within the city - the physical and the social (shown in Figure 15),- with their central components, and in a similar scenario they label the resilience domain with four sub-constituents, which are natural-economic-technological-human. In reflecting on the parameters in Figure 15, the approach in this research similarly identifies a relationship between the physical of the natural domain.

Nevertheless, within scale are affective domains that should be addressed; Niemczynowicz, (1999) stated that urban hydrology is a special type of hydrology applied to cities with very high levels of human interference with natural processes. All hydrological sub-processes in urban areas must be considered in much smaller temporal and spatial scales than those in rural areas. It is clear that solutions should be source oriented, and applied on a small scale to mitigate formation of storm water runoff. Likewise, Shaw (2012) argued that, as an umbrella concept, resilience provides the opportunity to analyse the integrations between domains and between scales.

Building on the previous discussion, the physical characteristics of the two domains, namely the natural (geomorphology) and the man-made (urban morphology), will be tested to mitigate surface runoff generated by pluvial floods. These two domains will be manifested in the urban context as one effective unit of analysis, referred to as the Generated Morphology. In this research, interventions and alterations in the generated morphology will vary in respect to size and location categorisations, and according to the scale of intervention that combines three interconnected hierarchal levels. These levels are; firstly, the technical (positional) where interventions are concerned with innovation in objects and materials used as water responsive solutions which represent the smaller level of intervention; secondly, the physical (locational) which represents the level of urban design characteristics of open space and building mass. The physical is a level that intermediates between positional and the third, regional (organiational) level, which embodies interdependencies and relationships between larger areas (cross-urban). These are shown in Figure 16.

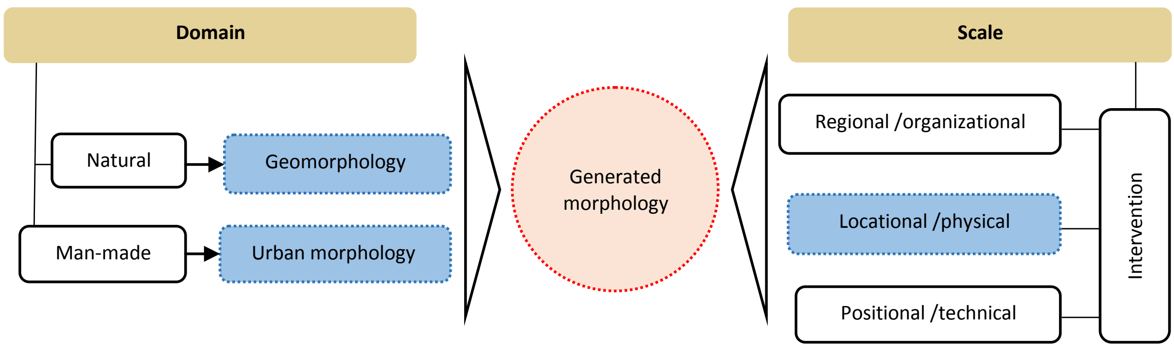


Figure 16: Domain and scale of resilience in research

2.5.4 Resilience principles

This section will summarise all the principles that provide the subject matter of this Chapter. They are extracted from the literature and synthesised to highlight agreements between the accepted concepts. Authors of these principle frameworks have tried to encompass representative principles each of which are in cohesion with their discipline. The research is going to cross-examine, analyse and integrate these principles in a Delphi study, where the aim is to synthesise an urban design-representative resilience framework.

Bruneau, (2004) stated that resilience is measured in terms of reduced failure probabilities, reduced consequences, reduced time to recovery. Resilience for both physical and social systems can be further defined as consisting of the following properties: Robustness, Redundancy, Resourcefulness and Rapidity, as detailed in Table 4.

No.	Principle	Attribute
1	Robustness	The ability of a system to elements and other units of analysis to withstand disaster forces without significant degradation or loss of performance.
2	Redundancy	The extent to which system elements or other units are substitutable that is capable of satisfying functional requirements if significant degradation or loss of functionality occurs.
3	Resourcefulness	The ability to diagnose and prioritize problems and to initiate solutions by identifying and mobilizing material, money, information, technological and human resources.
4	Rapidity	The capacity to restore functionality in a timely way, containing losses and avoiding disruption.

Table 4: Detailed framework of resilience principles (Bruneau, 2004)

Wildavsky (YEAR) advanced a rich index of a resilient system by describing six principles and providing a detailed definition for each of these principles. This is shown in Table 5.

Biggs (2012) also discussed six principles of resilient systems whose classifications slightly resemble Wildavsky's set of principles, Biggs' focus was on (1) Maintaining diversity and redundancy, (2) Managing connectivity, (3) Managing slow variables and feedback, (4) Fostering complex adaptive systems thinking, (5) Encouraging learning, and (6) Broadening the participation table (6).

No.	Principle	Attribute	Researcher approximation
1	Homeostasis	Systems are maintained by feedbacks ‘between the component parts which signal changes and can enable learning. Resilience is enhanced when feedbacks are transmitted effectively	Resilience: effectively transmit feed backs
2	Omnivory	External shocks are mitigated by diversifying resource requirements and their means of delivery. Failures to source or distribute a resource can then be compensated for by alternatives	Diversifying resources
3	High flux	The faster the movement of resources through a system, the more resources will be available at any given time to help cope with perturbation	Speed by which resources transfer
4	Flatness	Overly hierarchical systems are less flexible and hence less able to cope with surprise and adjust behavior. Top-heavy systems will be less Resilient	Resilience: simplicity clarity
5	Buffering	A system which has a capacity in excess of its needs can draw on this capacity in times of need, and so is more resilient	System autonomously access essential needs
6	Redundancy	A degree of overlapping function in a system permits the system to change by allowing vital functions to continue while formerly redundant elements take on new functions	Vital functions determined by system redundancy

Table 5: Wildavisky's principles (Wildavisky, 1988)

No.	Principle	Attribute
1	Diversity / Redundancy	Maintaining diversity and redundancy
2	Connectivity	Managing connectivity
3	Feedback	Managing slow variables and feedback
4	Adaptive thinking	Fostering complex adaptive systems thinking
5	Learning	Encouraging learning
6	Participation	Broadening participation

Table 6: Principles for resilient systems (adapted from Biggs, 2012)

Woods (2006) envisioned a set of essential resilience principles; he stated that monitoring and managing resilience, or its absence or fragility, is concerned with understanding how the system adapts and to what kind of disturbances in the environment, including properties such as: buffering capacity, flexibility versus stiffness, margin, and tolerance, (shown in Table 7).

No.	Principle	Attribute
1	Buffering capacity	The size or kind of disruptions that the system can absorb or adapt to without a fundamental breakdown in performance or in the system's structure
2	Flexibility versus stiffness	The system's ability to restructure itself in response to external changes or pressures
3	Margin	How closely or how precarious the system is currently operating relative to one or another kind of performance boundary
4	Tolerance	How a system behaves near a boundary – whether the system gracefully degrades as stress/pressure increases or collapses quickly when pressure exceeds the adaptive capacity.

Table 7: Woods' principles of resilient systems (adapted from Woods, 2006)

Jackson and Ferris (2012) studied the resilience principles in engineered systems, and set 14 sub-principles, or variables, that are organised and structured under the tent of four main resilience principles. They are shown in Table 8:

No.	Principle	Attribute
1	Capacity	Absorption, physical redundancy, functional redundancy, layered defense
2	Flexibility	Reorganisation, human-in-the loop, reduced complexity, reparability, loose coupling
3	Cohesion	Localised capacity, drift corrections, neutral state
4	Tolerance	Inter-node intersections, reduced hidden intersections

Table 8: Resilience principles for engineered systems (adapted from Jackson & Ferris, 2012)

Jackson and Ferris (2012) identified their principles as: **capacity**, or the ability of the system to survive a threat; **flexibility**, or the ability of the system to adapt to the threat; **tolerance**, or the ability of the system to degrade gracefully in the face of a threat, and **cohesion**, or the ability of the system to act as a unified whole in the face of a threat.

The work of Da-Silva (2015) did not go much further than the resilience principals of Wildavsky, Biggs and Bruneau. Instead, Da-Silva proposed a slightly different setting of seven major resilient system principles, which are: Robust-Redundant-Resourceful-Flexible-Reflective-Integrated and Inclusive. Within the extent of the similarities and the barely distinguished approaches of the resilience principles, the UK's approach to resilience focuses on four main principles, and they are: (1) resistance (2) reliability (3) redundancy and (4) response/recovery (Weichselgartner & Kelman, 2015).

2.5.4.1 Examining current approaches of resilience principles

Looking at the mentioned approaches of resilient system principles, one can notice that in spite of the generality of these approaches, they still reflect the tone that drove them, whether describing social, economic, technological or infrastructural fields. However, the analysis in this study finds the approach outlined by Bruneau (2004) quite simple, clear and built to reflect resilience in physical infrastructure. Meanwhile some conceptual insights from Biggs' approach are of relevance to the research objectives, which are (adaptive systems thinking and connectivity). Accordingly, a hybrid set of resilience principles were developed by combining all previously addressed principles. This was achieved by performing the Delphi study with five experts (Appendix-3), which resulted in the set of resilience principle shown in Figure 17.

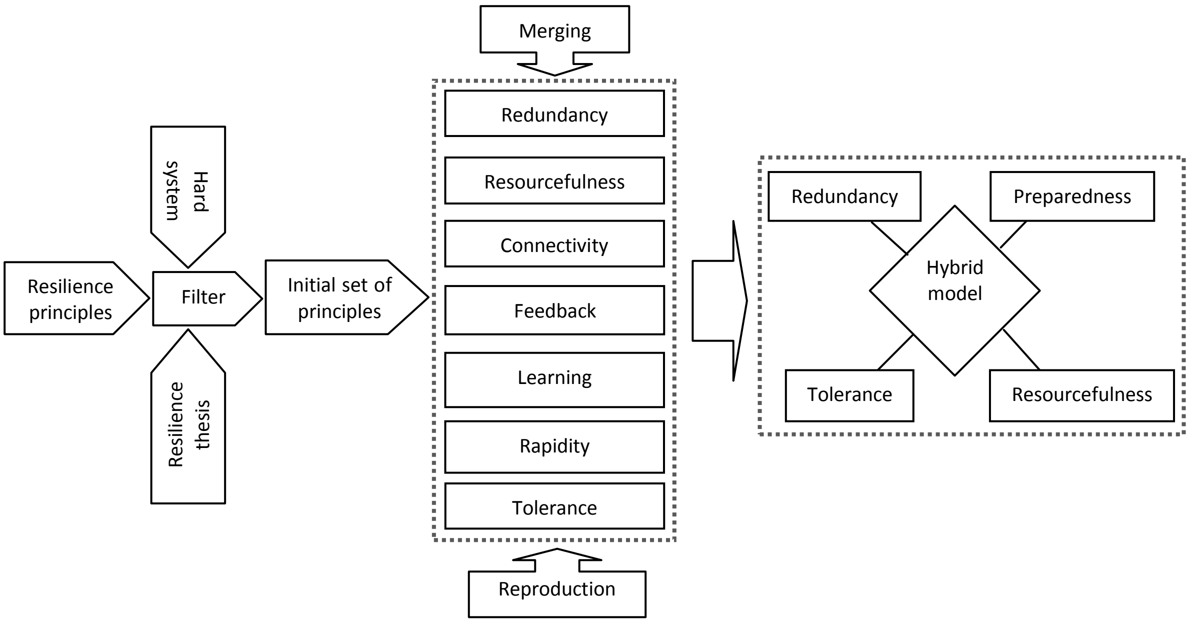


Figure 17: Resilience principles' final model

2.5.4.2 Coexistence of resilience principles in the literature

The resilience principles resulted from experts' judgments that were gathered throughout three sessions; each of these sessions followed evaluated, compared and sorted the judgements offered. The following section identifies relevance of the selected principles in the current literature. Comparisons, explanations and similarities will demonstrate the significance of the selected principles in the literature. This aim is to substantiate and approve the final selected resilience principles.

2.5.4.2.1 Preparedness

Cutter et al., (2008, p.603) mentioned that, when communities use shared experience to modify preparedness and mitigation measures, they contribute vastly to improving antecedent conditions before future shock. Francis (2014) stated that the idea of what should resilience combined is that efforts in design should be allocated to increase emphasis on “safe-to-fail” rather than “fail-safe” provisions. If urban planning and design is truly innovative and adaptive in their pursuit of sustainability and resilience, they will have an inherent potential to fail. To reduce the risk of failure, innovations can be ‘piloted’ as ‘safe-to-fail’ design experiments (Lister, 2007). Hence, resilient urban design to pluvial flood is more about safe-to-fail rather than fail-safe scenarios, which entails an effort of manage and minimise the disturbance rather manage and control.

The severity of any resultant flooding will typically be governed by the number of defences breached or overtopped, as well as the vulnerability and preparedness of the assets and people within the flood plain (Hall & Rowsell, 2011). Leon and March (2014) referred to the importance of investing in the city's safety-related characteristics. The principle of a city's physical preparedness is related to the readiness of accepting losses and minimising its effect to the minimum which still allows the city's form to function at the essential level during the extreme event, without having any emergent intervention in place. This helps to prepare the city to safely transfer from a stable state to a disturbance situation Likewise, Aecom (2015) referred to the city's resilient design as the critical buildings and infrastructure that are designed to fail 'gently' rather than cataclysmically, emphasising the proactive measurements for the city structure in preparing for the worst.

2.5.4.2.2 Resourcefulness

Tierney & Bruneau (2007) identified the principle of resourcefulness as the ability to diagnose and prioritise problems and initiate solutions by identifying and mobilising material, monetary, informational, technological, and human resources. In defining city resilience as (1) the degree to which the system is capable of self-organising versus the lack of organisation or organisation forced by external factors, or (2) the degree to which the system can build and increase its capacity for learning and adaptation in more reductionist terms, these definitions reflect systemic integrity, coordination and self-improvement in relation to local conditions. Moreover, they are all dependent on the functional network, or connecting and signalising the components in the local environment (Desouza & Flanery, 2013).

2.5.4.2.3 Redundancy

Redundancy is the extent to which system components are substitutable (Bruneau et al. 2003). Redundancy is achieved when multiple elements or components provide the same, similar, or backup functions; it is linked to the spread of risk across time, across geographical areas, and across multiple systems. When a major urban function or service is provided by a centralised entity or infrastructure, it is more vulnerable to failure. When the same function is provided by a distributed or decentralised system, it is more resilient to disturbance (Ahern, 2011). Vale and Campanella (2005) set an example of system redundancy in the nonhierarchical street grid of Manhattan and Chicago; if nodes or links were destroyed, traffic could simply reroute around the damage. This was demonstrated in the collapse of the Oakland expressway and the closure of the San Francisco Bridge following an earthquake; neither of these events led to disruption in the transport system because of the high degree of redundancy in the metropolitan transport network.

Two types of system redundancy are addressed in respect to the redundancy behavior of system components; the first concerns multi-functionality, which is where the redundant part or component serves another urgent function that took over from the original one for the sake of the well-being and survival of the rest of the system. The second is when the system maintains the same - or minimum required level - of functionality by sacrificing part of the system that blocked or absorbed an external disturbance. To protect against progressive failure, networks need devices, such as fuses or circuit breakers, which sacrifice themselves for the sake of the system (Vale & Campanella, 2005).

Although it can be an effective quality in increasing urban resilience to flood, redundancy can be a costly. In this respect, Longstaff et al (2010) importantly acknowledged that the redundancy and maintenance of physical assets can be expensive, and communities will have to weigh the tradeoffs of allocating funds for long and short-term reserves. Douglas and James (2015, p.105) referred to the redundancy of natural features, stating that unstable areas often make good urban green spaces and wild life refuges that provide many ecosystem services.

2.5.4.2.4 Tolerance

Jackson and Ferris (2012) defined tolerance as the ability of the system to degrade gracefully in the face of a threat. Meanwhile, Liao (2012) mentioned that urban resilience to floods is defined as the capacity of the city to tolerate flooding and to reorganise when physical damage and socioeconomic disruption occur. Furthermore, Ning (2006, p.249) pointed out that, “We need to discipline and restrain human behaviour, reduce social activities that lead to flooding disasters to accomplish harmonious coexistence between man and the flood. With such efforts, we will be able to promote benefits, avoid hazards, and mitigate losses resulting from flood”.

Zevenbergen (2011, p.40) also stated that the idea of floods as a disaster came from the adverse and unlooked for impact that they have on the functioning of human society. Floods are therefore natural phenomena and it is a human construct to label flooding as being acceptable or not. “Before the nineteenth century there was no real scientific way of measuring floods; such analysis and interpretation was based on the devastation produced, and the impression made on the people who experienced them” (Doe, 2006, p.25).

In his comparison, Ning (2012) differentiates between engineering resilience as a function of (resistance + recovery) while ecological resilience is a function of (tolerance + reorganisation). Ning's sound distinction between the engineering and the ecological perspectives of resilience also provides a clear distinction between the main fail-safe and safe-to-fail strategies where tolerance replaces resistance. Finally, Holling, (2001) significantly associates resilience with tolerance when addressing resilience as the degree to which cities tolerate alteration before recognising a new set of structures and processes.

2.6 Resilience value of urban design

Within the abundance of definitions addressing resilience, the overall meaning refers to the capability to withstand and recover quickly from an extreme event. The concepts could be considered at levels ranging from individual to national (Chang, et al. 2014). Resilience in this research is associated with the urban form as the principal commodity. Francis and Bekera, (2014, p.92) asserted that the ultimate goal of resilience is the continuity of the normal system function, which is defined according to the fundamental objectives obtained in system identification.

Discussions about the fundamentals of a system in the built environment correlate with the thoughts of Marcus Vitruvius, a Roman architect. His thoughts were one of the earliest and most valuable contributions in modern human history within the field of architecture. Vitruvius identified three essential components of any architecture, which are commodity, firmness and delight. According to Vitruvius, the three components are not problems that can be solved in isolation from each other, but rather, architecture that must be considered simultaneously from the three perspectives (Daas, 2014; Jones, 2003). His account of the three elements of architecture was translated into English by Henry Wotton in 1654. Wotton was a Seventeenth Century translator, who stated that in, 'Architecture, as in all operative arts, the end must direct the operation; the end is to build well. Well building hath three conditions; commodity, firmness, and delight' (Wotton, 1907). Building on the argument of the three essential components of architecture, the remainder of this section will try to chase the main commodity in the urban form through times of natural stress. This is to help steer efforts to achieve the minimum required level of the principle function in the urban context, and thus achieve a resilience response.

Vale and Campanella (2005) mentioned that, on one level, urban resilience implies a physical capacity to bounce back from significant obstacles. Godschalk (2003) also realised the importance of physical accessibility when he suggested that, for cities to be resilient, their roads, utilities, and other infrastructure systems must be designed to continue functioning under extreme hazard conditions. He also identified that transportation was the first key service addressed in the National Research Council's broad vulnerability mitigation program in the USA.

Vale and Campanella (2005, p.353) define urban resilience as an interpretive framework proposed by local and national leaders and shaped and by accepted citizens in the wake of a disaster. Urban resilience to flood is about successful management and not about preventing flooding or even minimising flood losses. The absolute prevention of flooding is an impossible task. Instead, urban flood management is about maximising and maintaining the performance of a city as a whole (Zevenbergen, 2011). Although definitions of resilience differ, they imply that resilient cities can absorb shocks (from extreme events, such as natural disasters) while still maintaining function (in terms of providing the basis for residents' well-being) (Chang, et al, 2014). Likewise, the measurability of city resilience is related to the functionality of an infrastructure system after a disaster (Tierney & Bruneau, 2007).

The assumption of resilience in urban design can be driven by the essential function of the urban context; this builds on the system's definition of resilience as maintaining the minimum level of functioning. Lynch (1981) identified five performance dimensions of urban design, and they are as follows:

- Vitality: the degree to which the form of places support the functions, biological requirements, and capabilities of human beings.
- Sense: the degree to which places can be clearly perceived and structured in time and space by users.
- Fit: the degree to which the form and capacity of space matches the patterns of behaviours that people engage in or want to engage in.
- Access: the ability to reach other persons, activities, resources, services, information or places including the quality and diversity of elements that can be reached.
- Control: the degree to which those who use, work, or reside in a place can create and manage access to spaces and activities.

Tarbatt (2012) set out the principles of urban design, identifying ten principles based mostly on socio-economic, convenience, and aesthetic factors. The first of these, 'more convenient access to facilities', like Lynch's five performance dimensions, relates to the perception of space, its aesthetic dimensions, and to human behavior. Access constitutes the chief utility that links the urban components represented in the physical aspects of buildings, streets and blocks and the non-physical aspects of people's activities. Building on Tarbatt's first principle, and Lynch's five performance dimensions, where both are related to the perception of the space, its aesthetic dimension, and to human behaviour, access can constitute the chief utility that links the urban components, represented by the physical aspects of buildings, streets, and blocks and the non-physical aspects of people and activities.

Access can maintain the flow of goods and services throughout the city during harsh times; Smith & Ward (1998) mentioned that the consequences of flooding include the direct damage caused by the flood and the indirect disruption to society, infrastructure and the economy. Taylor (2004) also identified the indirect losses of floods as the cost of goods that will not be produced and services that will not be provided during the event and in the aftermath. Cities are resilient if they absorb shocks, maintain their output of goods and services, and continue to provide their inhabitants with a good quality of life according to the standard of time (Grosvenor, 2015). Similarly, Vale and Campanella (2005) confirmed that the simplest way to crash a network is to block or sever a crucial link. The importance of connectivity was directly referred to in the aims of the final phase of the Muscat area drainage study in 2011. The study reported that it was initiated to establish the Master Plan of the Drainage of Muscat Area and included all the calculations and fieldwork related to the implementation of new drains. These works, designed to extend and improve the reliability of the drainage system in the city, must guarantee the continuity of traffic in the central districts and allow communications to be extended to the the surrounding districts.

Chang (2014) refers directly to the importance of traffic alternatives when considering the city's resilience to flood. Chang states that increasing resilience, which is equivalent in the diagram to reducing the loss triangle (shown in Figure 18), can be accomplished through ex-ante measures, such as installing backup generators for a hospital, or ex-post actions, such as rerouting traffic. Ahern, (2011) stated that, when an urban landscape is understood as a system that performs functions, connectivity is often the critical parameter. Moreover, the lack of *connectivity* is often a prime cause of malfunction or the failure of particular functions; thus, connectivity is arguably a primary generator of the sustainable urban form. Ahern also drew attention to the importance of connectivity in the natural landscape (geomorphology) stating that, in urban environments, the connectivity of built systems is generally robust, but in natural systems is typically greatly reduced, often resulting in fragmentation. This means the separation and isolation of urban landscape elements with significant impacts on the specific ecological processes that require connectivity.

Urban design, therefore organises, activates and links the ecological processes of cities encompassing the socio-economic networks, and as far as the fundamental objectives of the urban design is concerned, it is crucial to safely distribute these activates by properly allocating them through the city layout and effectively linking them by maintaining proper access.

Accordingly, *accessibility is the essential commodity of an urban form. Achieving a minimum required level of this commodity by flood responsive urban design will maintain the connectedness between the affected parts of the city, and correspondingly, is built for a resilience response. Accessibility is a function of ecological urban resilience response.*

2.7 Measuring resilience

Even with the abundance of research on resilience, there is still no single, universally accepted definition; the complexity lies in the normative concept of resilience where it is not easy to be presented in quantitative terms (Desouza & Flanery, 2013). Shaw (2014) also asserted that, while recognising the definitional propriety and conceptual rigor, reframing resilience should necessarily involve operationalising the concept of resilience and recognising the need to directly engage with practice. The rapid uptake of resilience thinking by development agencies and foundations has forced the issue of resilience implementation and challenged the research community to make the leap from theory to practice to metrics. Even with the complexities associated with precisely defining it, Holling (1973) assigned the first definition for resilience incorporating its measurability, stating that, resilience is a measure of the ability of the systems to absorb changes and still persist.

Resilience is more a strategic than a normative concept; this is because, to be effective, resilience must be explicitly based on, and informed by, the environmental, ecological, social, and economic drivers and dynamics of a particular place. Moreover, it must be integrated across a range of linked scales (Pickett, Cadenassso, & Grove, 2004). Similarly, Weichselgartner and Kelman (2015) suggested for the resilience agenda to be operationalised, it needs to be reconnected within the wider, well-established context of risk and sustainability. This would connect the descriptive and the normative, allowing the concept to be liberated from its ideological legacies, permitting missing empirical evidence to be obtained, and allowing the necessary pragmatic pathways for implementation.

Frankenberger, Muller, Spangler, & Alexander (2013, p.7) argued that the concept of resilience is useful because it provides an overarching organisational scheme within which the vulnerability, shocks, and heterogeneity of recovery pathways may be understood, measured, and modeled. Meanwhile, Shaw (2014) referred to the complexities associated with a comprehensive resilience framework, where an appropriate balance between organisational resilience and other types of resilience can be operationalised. Shaw stressed that, although cross-discipline resilience thinking is important, it is worthy of future examination.

Weichselgartner and Kelman (2015) expressed the danger represented in turning the term ‘resilience’ into an empty signifier that can be filled with any meaning to justify any specific goal. To avoid this, they stress the importance of providing the base line for turning the description(s) into a normative agenda leading to operational tools, policies and actions. Quinlan (2014) also referred to that very threat for reasons associated with the lack of quantifiable metrics for evaluation purposes. The resilience value arrived at earlier in this chapter was driven by the theoretical analysis of the essential function of urban design, identified as the accessibility of the urban form. It will be the sole utility according to which the resilience of the urban design will be measured during extreme flooding events.

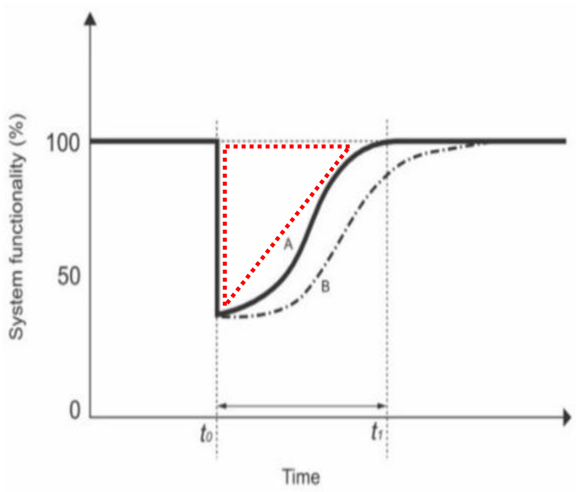


Figure 18: Resilience triangle (adapted from Liao, 2012)

In Figure 18, the system’s resilience is measured by the area of the triangle. The smaller the triangle, the more resilient the system is, and this is linked to the time needed to restore a system’s full functionality from an external shock. The shock, according to the sequential occurrence, takes three interlinked stages, refered to by Allen, (2016) as destruction-decline-disruption. Figure 18 represents the sudden impact when destruction occurs, which is almost the case in natural stressors like the earthquaqes and tsunamies, when huge natural power is deployed in a mater of seconds bringing devastating consequenses to large areas. Chang, (2014) represented the idea of urban resilience by referring to the minimum functionality of the system under an extreme event; this was the system robustness, which is the degree to which a system function is not forced to zero. Moreover, the time consumed to gain full system functionality is known as the system rapidity, shown in Figure 19.

As stated by Zevenbergen (2011) and Tierney & Bruneau, (2007), the concept of urban design resilience is based on the realisation of the minimum required functionality level of the system. Meanwhile, the concept of infrastructure efficiency is based on the optimisation of system functionality, described as system robustness. The two ideas are not necessarily contrasting, but rather meet different critical goals.

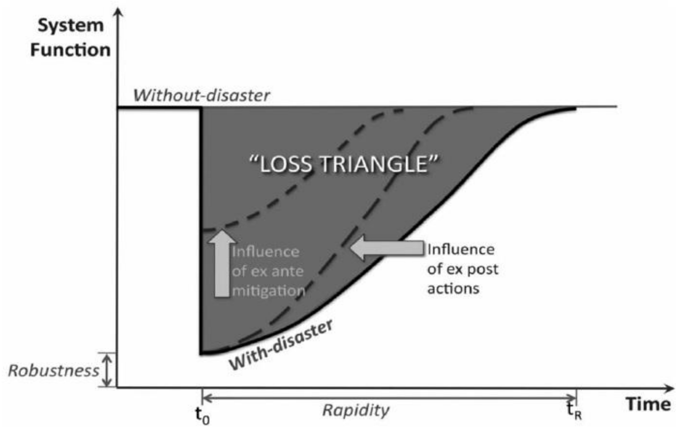


Figure 19: The idea of resilience (Chang et al, 2014)

In circumstances of pluvial floods, the system performance takes different scenarios reflected in the behaviour described in Figures 18 and 19. These. courses of urban context behaviour might be represented in different graphs where the stage of destruction gradually occurs in the system functionality, either like a gentle or rapid slop. From this, it keeps degrading in the declining stage until attaining a full system decline where no further degradation can take place in the system functionality and the stage of disruption is at its peak. In practice, there are no clear cut lines between these stages, and they are, to a great extent, interrelated and intersected, as shown in Figure 20.

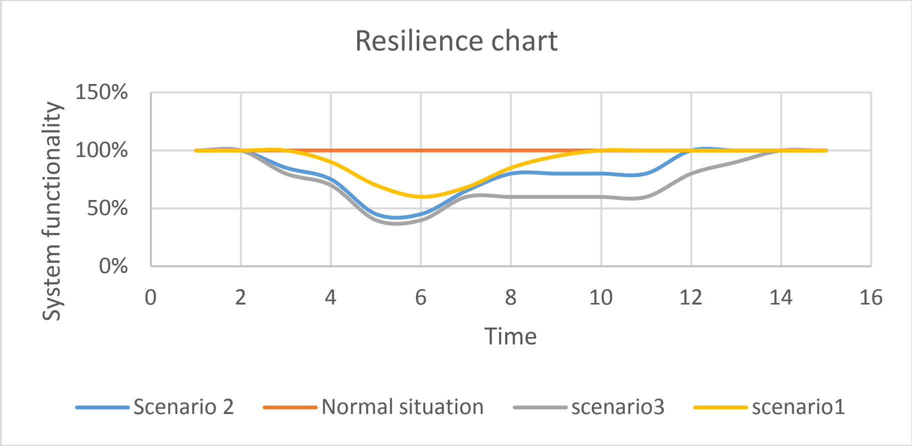


Figure 20: Resilience chart

The system functionality in Figure 20 showcases four possible scenarios in responding to a flood event. The resilience of the system in this scenario depends on the system's internal characteristics to function at the minimum required level until full restoration is achieved. Hence, in scenario (1) the smaller the area between t1 and t8, the more resilient the system,. The system behavior in scenario (1) can be referred to as the system inherent resilience. Meanwhile, in scenarios (2) and (3), the system tolerates the maximum amount of disturbance during which the system still delivers the minimum functionality required to maintain the access necessary to produce important goods and provide necessary services (Grosvenor, 2015). This will be addressed in the research as the adaptive resilience, when the system undergoes a prolonged stressor and manages to operate at the minimum required level. Malone and Moss (2013) also described a system's resilience as the ability of *short-term* coping and *long-term* adaptation. Adaptive resilience operates when the system recovers quickly and keeps a steady level of inundation, achieving a quasi-stable situation (t8 to t11 scenario 2) and (t7 to t11 scenario 3). This is where the system can deliver the minimum amount of necessary services required until the system regains full functionality in a prolonged restoration process.

The acceptance of scenario (2) or scenario (3), where system functionality is demoted to 80% and 60% respectively, is highly dependent on the urban form characteristics, embodied activities, surrounding natural settings, and/or other socio-economic drivers. The research will carry out an investigation into the urban context tolerance limits to accept a certain level of flood inundation while working out an effective restoration. Inherent resilience and adaptive resilience are not at the far ends of the resilience continuum, but rather they are the 'first operates' to achieve a relatively short system restoration course. The 'second operates' to achieve the minimum acceptable system functionality under a prolonged inevitable stressor are shown in Figure 21.

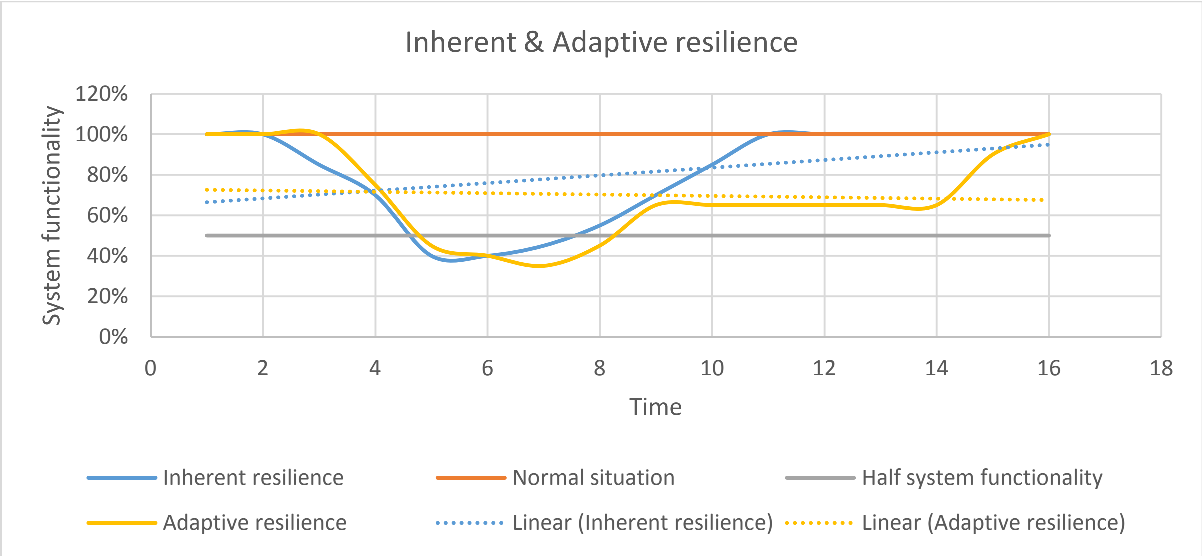


Figure 21: Inherent and adaptive resilience

The rethinking of urban design as an important tool to maintain a resilient status is one of the important goals of this research, along with the resilience approach itself. In this context, Quinlan (2014) affirmed that, in resilience thinking, the main objective is to re-conceptualise a system or an issue from an alternative perspective; thus, through the lens of resilience and with a focus on interactions, new insights emerge and interventions can be better informed.

By identifying resilience attributes, the research addressed the idea of resilience by taking it from descriptive approach towards a more normative agenda by identifying resilience principles. This is to facilitate a more measurable resilience approach through two interrelated steps; the first step is the development of an instrumental resilience framework for urban design to pluvial floods, while the second step is to empirically apply and test the scenarios resulting from that framework. The role of resilient urban design to pluvial floods constitutes the two main types of resilience addressed earlier in this chapter:

I-Inherent urban design resilience is about a system's immediate response, aiming at rapid recovery that is based on system internal characteristics.

II-Adaptive urban design resilience is about a system's persistence to preserve the minimum functionality during prolonged stressors.

2.8 Approaching resilience measurability in the research

The initial theoretical resilience framework (Figure 22) will be developed in cohesion with the urban and ecological paradigms that are going to be established in the next chapter. The resulting theoretical basis will lead the qualitative enquiry. A twofold method will be followed to realise the urban form of resilience towards pluvial floods; the first is going to be accomplished by carrying out the qualitative inquiry. A content analysis of from the interviews will develop the instrumental framework concerning physical intervention. The second will apply measurement quantitatively by testing selected scenarios from the instrumental framework through the flood simulation platform. The final results will evaluate the viability of the suggested physical intervention.

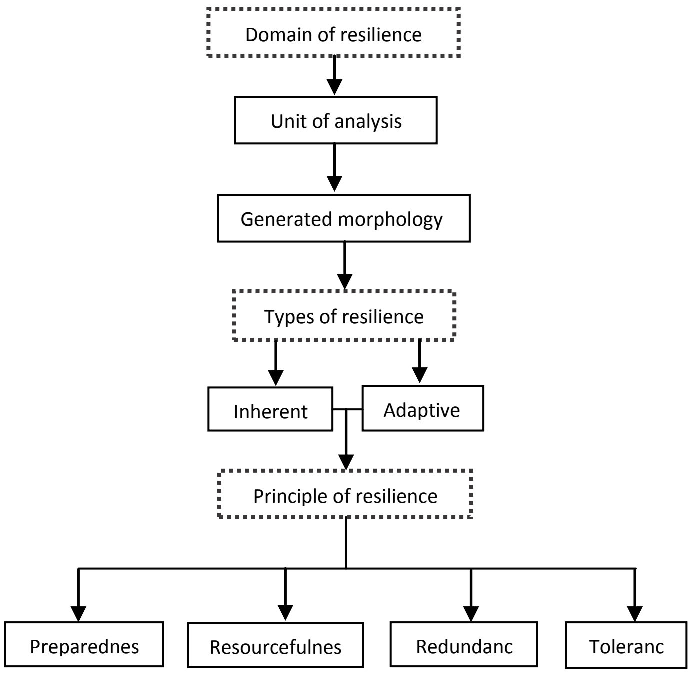


Figure 22: Resilience theoretical framework

2.9 Summary

Across this chapter, the research carried out an in depth theoretical investigation into the concept of resilience. The window through which resilience was addressed considers the pure physical dimension of the urban form. The role of resilient urban design to flood is closely linked to the vital commodity of accessibility. This is due to its association with flood consequences, identified earlier as; indirect losses and secondary impacts, where the indirect losses are the cost of goods that will not be produced and services that will not be provided during the event and in the aftermath.

Comparisons between the different perspectives of resilience, and the way they engage with urban design characteristics, yields different level of correspondence. Such comparisons moved from the static approach of engineering resilience, to the more systemically flexible ecological resilience, and ended with the absolute dynamic regime shift-based evolutionary resilience. It was found also that the level to which urban design is inclined transforms from the rigid approach of infrastructure resistance to the three resilience perspectives; this relates to the dynamics of each perspective. This was explained by understanding the systemic conflict between urban form inertia or rigidity and any transformational change. The more dynamic the resilience perspective, the more time an urban form requires to achieve resilience. Thus, two key deliverables are arrived at in this chapter. The first is the hybrid set of resilience principles achieved throughout the process of three 'turn-rounds' of the Delphi technique. The second is the initial resilience theoretical framework, which is going to guide the rest of the qualitative enquiry in this research.

Chapter 3: Urban-ecological paradigms, a cohesive physical approach.

3.1 Introduction

This is the second of two literature review chapters. It will convey an overview of the concept of the urban form morphology. This has been achieved by examining the principle urban morphological schools. The focus on the physical character of the urban form will be traced across the examined morphological schools. The chapter also discusses the ecological dimension in the urban context. Two paradigms of urban ecology will be examined to determine the best one for adoption in this research. The resulting ecological and morphological paradigms, along with the final resilience theoretical framework, are going to be discussed at the end of the chapter.

3.2 Urban design within urban planning discipline

Urban design is concerned with the design of urban places as physical/aesthetic entities and as behavioural settings concerning the 'hard city' of building and spaces, and the 'soft city' of people and activities (Carmona, 2010). Bayer, Frank and Valerius (2010) asserted that urban planning focuses on shaping the nature of a place, including the built environment and the natural environment. Ewing (2011) mentioned that urban design differs from planning in the scale, orientation, and treatment of space. Its scale is primarily that of the street, park, and up to larger regions. Its orientation is both aesthetic and functional, which places it somewhere between arts, whose object is beauty, and planning, whose object is utility. Ewing also referred that the treatment of space in urban design as three-dimensional, with vertical elements as important as horizontal ones. Urban planning, on the other hand, is customarily a two-dimensional activity, with most plans visually represented in plain view, not model, section, or elevation. In the same respect, Bayer et al. (2010) drew the attention to urban design as the crafter and shaper of the streets, blocks and lots within the development area, paying interest to the third dimension of height as well as location and character of buildings. Bayer et al. argues that urban designers manipulate these variables to give form to public places.

“Cities have always adapted to changing environmental conditions through autonomous adaptation. The dynamics of climate change may warrant the adaptation of the building stock to better cope with the increasing flood risk, through planned retrofitting and/or redesigning its structure during its life time” (Zevenbergen, 2011, p.15). Moreover, engineers and planners focus on designing facilities and services in urban environments with the goal of reducing environmental impacts and creating sustainable cities (Deelstra 1998; Pickett et al. 2001). Urban design can maintain effectiveness against pluvial flood in many physical aspects, Donald (2011, p.9) argued that “Sustainable Urban Drainage Systems (SUDS), surface water management plans, and flood proofing developments have the potential to limit the increase or even decrease the number of people and properties at risk”.

If urban planning and design are truly innovative and adaptive in their pursuit of sustainability and resilience, they have an inherent potential to fail. To reduce the risk of failure, innovations can be ‘piloted’ as ‘safe-to-fail’ design experiments (Lister, 2007). Building on the discussion on resilience and urban design, a resilient urban design to pluvial flood is more concerned with safe-to-fail scenarios, which is about managing and minimising the catastrophic effect, rather than implementing fail-safe scenarios that account more for management and control of the disturbance.

3.3 Urban Morphology

Urban morphology – the study of the form of human settlements and the process of their formation and transformation – entails the spatial analysis of urban structures, land use, street patterns, buildings, and open spaces (Barau, 2014, p.307). Larice and Macdonald (2007) define urban morphology as the study of larger urban structures, patterns and for issues, it is the study of the form of human settlements and the process of their formation and transformation. The study seeks to identify the physical structure component and the character of the urban area, and then examining the patterns of its component parts to the process of the natural event. Meanwhile the English definition for urban design is “the art of making places for people, it includes the way places work and involves matters, such as community safety, as well as how places look. It concerns the connections between people and places, movement and urban form, nature and the built fabric, and the processes of ensuring a successful village, town and city” (Liao, 2012, p.3).

The emergence of typological and morphological practice in the late 1950s provided urban designers with a research avenue that was suited to exploring urban spatial form. Typology refers to the study of categorised form types in architecture, and increasingly in urban design and landscape architecture as well. Morphology, on the other hand, is the study of large urban structures, patterns and form issues (Larice & Macdonald, 2007). In his neo-traditional design and planning principles, Krier (1984) also referred to the importance of morphological studies in designing the city advocating that typological and morphological study should guide the design process.

In urban morphology, there are three distinctive schools of thought, which are Muratorian, Conzenian and Versailles. Muratorian emerged from the thoughts and works of the Italian architect Saverio Muratori in the 1940's. A new school of thought emerged in the 1960's influenced by the Conzen approach when studying urban morphology. Finally, in the late 1960's, a French school draw its path between the two former schools (Moudon, 1997). The two aforementioned antecedents influenced the morphological analysis of the Versailles school. Moudon (1994) concurs that the Versailles School stands between the Italian and the British schools, and addresses issues of both design and the city-building process. It has its own print by demonstrating its social and behavioural traits, in this sense Moudon (1997) states that the Versailles school surpassed pure architecture to also engage the opinions of powerful sociologists, like Henri Lefebvre. The English expression 'urban design' is sometimes used in France to mean the formal conception of the city in its physical form. The closest French equivalent is the composition urbaine, or urban composition. The word urbanisme is more frequently used and it is concerned with both the urban form and its function (Loew, 2012).

The Muratorian School, represented by the works of Saverio Muratori and his follower Gianfranco Caniggia, analysed the city building process in traditional Italian towns. Their analyses rest on their extensive classifications of buildings and related open spaces extending from their state to their various mutations over time (Moudon, 1994). A specific urban design definition does not exist in Italy; instead, expressions like progettazione urbana, progetto urbano, translated as 'urban project', are used. This can explains the fact that the practice was influenced by the empirical approach, which addresses the viability of projects and includes both economical and morphological features. Urban design is a relatively new discipline in Italy although its establishment can be traced to early 1990s (Loew, 2012).

M.R.G. Conzen went deeper in his morphological analysis, down to the smallest components of the urban form, and demonstrated urban morphological analysis on three levels. The first level was the town plan or ground plan (comprising streets, plots and blocks plans of buildings); the secondly level was the building fabric, and the third was the land and building utilisation. The concept that he developed concerning the process of urban development stimulated a school of thought that was founded in his work (Whitehand, 2001, p.2). As the third dimension in the Conzen tripartite represents the functional dimension, one can trace the three main physical components of streets, plots and buildings which altogether comprise the urban form (as shown Figure 23).

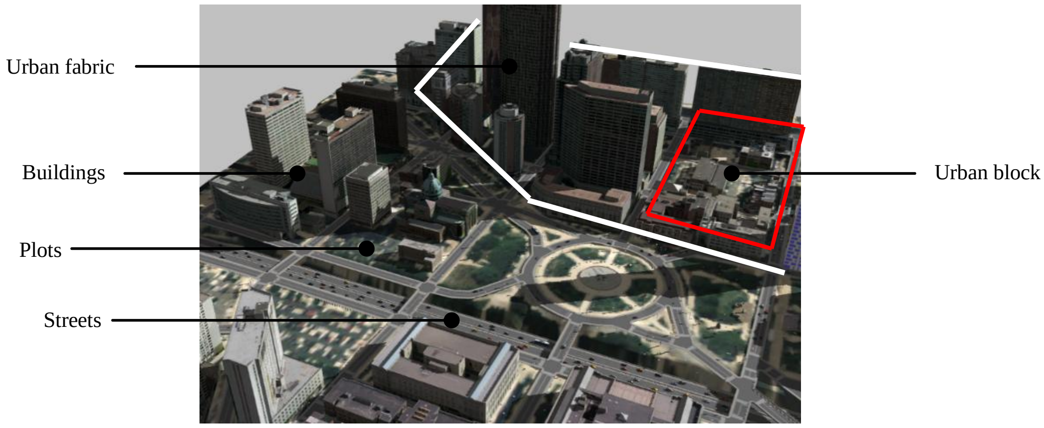


Figure 23: Conzenian morphological analysis

It is possible, however, to claim priority for the town plan on the grounds that it forms the inescapable framework for the other man-made features and provides the physical link between these, on the one hand, and the physical site as well as the town's past existence, on the other (Conzen, 1960, p.3-4). Conzen refers more specifically to the elements of urban morphology in his analysis of the plan of Alnwick town, when he defined the townscape as a combination of town plan, pattern of building forms, and pattern of urban land use. Again, he indicates his tripartite division of the townscape of town plan, building form and land use. Figure 24 shows the urban components used in Conzen's morphological analysis and the importance of emphasising the first aspect in this research.

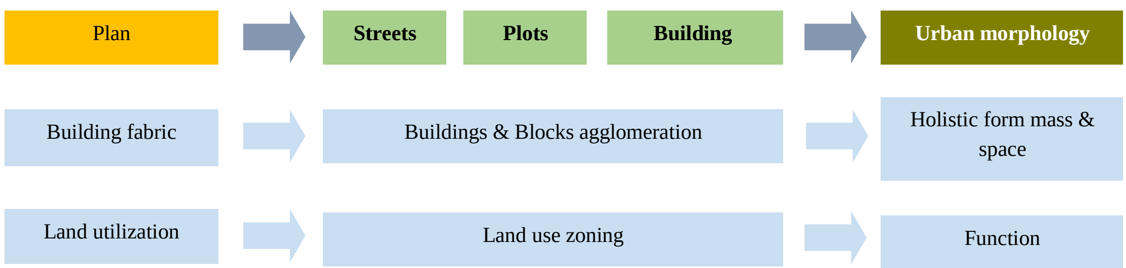


Figure 24: Urban morphological components (adopted from Conzen, 1960)

Addressing the issue of pluvial flood from a morphological perspective will consistently aid the objective of this study where the physical dimensions of both the urban context and the adjacent ecology will be explored. This is also confirmed by Larice and Macdonald (2007), who stated that morphologists are primarily interested in the tangible, physical world of objects and less interested in subjective experience or the social use of space.

3.4 Geomorphology

Leemans (2013) defined landscape ecology as the science and art of studying and improving the relationship between spatial patterns and ecological process on a multitude of scales and organisational levels. RIBA, (2009) referred to the possibility of making a very basic appraisal of the potential of a site to flood by simply looking at the context and topography within which the land is set. Wood (1996) clarified that topographical features can generally be classified into six simple specific types: plane, channel, ridge, pass, peak, and pit. The generalisation process can result in subsequent changes in these features. Sanders (2007) confirmed that data are crucial for flood inundation modelling and it is best to use recent and highly accurate topographic data.

Some scholars consider that ecological landscapes should be restricted to a human scale on the order of 100s of meters. Others have defined landscapes as a kind of observation lens defined by spatial heterogeneity and the consequences that such heterogeneity has for the ecological processes. Landscapes, both within and containing cities, are another kind of ecological system important to urban ecology (Pickett, Cadenasso, & McGrath, 2013). Research on ecology in urban systems highlights the nature of the physical environment (Pickett, et al. 2001). In this respect, flood is defined as natural physical phenomena. Runoff and floods are themselves influenced by geomorphological, spatial and social factors; floods are associated with natural, abnormal (often referred to as extreme) events where its physical characteristics are site specific (Zevenbergen, 2011). These topographical features, known as the natural capital for the urban environment, are essential for the well-being of urban life. In this context, an urban landscape can encompass extremely diverse natural features; such components, no matter how small in size, play multiple roles in supporting a safe and satisfying living environment for urban dwellers (Bolund & Hunhammer, 1999). Human interventions in the natural landscape, coupled with potential changes in the climate, might contribute to an increasing numbers of flooding incidents in the future (Zevenbergeb, 2011).

Cities evolve as an outcome of myriad interactions between choices of human agents and biophysical agents such as local geomorphology, climate and natural disturbance regimes (Alberti et al, 2003). In urban environments, the connectivity of built systems is generally robust, but in natural systems it is typically greatly reduced, often resulting in fragmentation, which means the separation and isolation of urban landscape elements with significant impacts on specific ecological processes that require connectivity (Ahern, 2011). The previous discussion discussed the terrestrial ecology, specifically the landscape topography, so, to conclude, Douglas and James (2015) confirmed that good urban planning requires a sound understanding of the ground on which a city is built. Likewise, RIBA, (2009) stated that landscape architects have a great deal to offer in the control of flood risk and the mitigation of its effect through the design of the public and private urban spaces.

3.5 Generated morphology

Campanella & Vale (2005, p.347) noted Lynch's opinions on the survival of cities, stating that, 'persistent and perpetuity value the physical assets of the city by stating that: a city is hard to kill, in part because of its strategic geographic location, it's concentrated, persisting stock of physical capital, and even more because of the memories, motives, and skills of its inhabitants'. Thus, one can conclude that the unique identity of a place emerges from the interactions between manmade structures and the natural landscape features along with human activities. Li and Ding (2014) referred to the two parts that constitute the urban morphology of entire city areas or the built environment, which are: generated form and planned form, in terms of their growing processes and morphological characteristics. In classic urban morphological theories, three morphological elements - street, plot and building - have perfectly defined the urban physical form. Generated morphology integrates a natural landscape with built solutions; it can be developed to protect human life and physical assets in a way that reduces cost (Aecom, 2015).

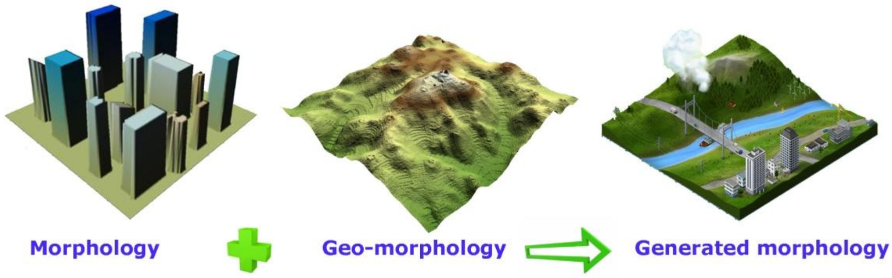


Figure 25: Urban generated morphology

Within the perspective of flood management, O'Neill and Scott (2011) call for a transformation in urban design that entails a holistic reassessment of the relationship between the built and non-built components of urban environments. In this way, a transformation demands seeing the urban environment as a hydrological unit embedded within a larger, or series of larger, hydrological units, rather than as a collection of various built elements adversely affected by flood.

Topographic features and streets crossing patterns, for instant, can give identification to the morphological features of generated forms. In conclusion, the generated form can be defined by integrating new factors into the existing morphological elements. It also shows the value of urban morphological research for the urban design method (Li & Ding, 2014). Generated morphology manifested in the coexistence between topography and man-made physical components, through a systemic perspective. Although a system consists of parts, a system is also characterised by properties that emerge from the interaction of its parts. Identifying component parts in an inclusive system yields a model for any ecological subject. Once the components enter into an interaction that generates a system, their function in the system may be different than their function as independent entities (Pickett, et al, 2013). The hydrological unit, as called by O'Neill and Scott (2011), will be addressed as the generated morphology (see Figure 25). It represents the unit of analysis for this research.

3.6 The position of the research within spatial planning discipline

According to Healy (1997), spatial planning considers three main lines of planning foci: economic planning, physical development planning and the policy analysis planning. Figure 26 specifies the position of this research within the spatial planning disciplines:

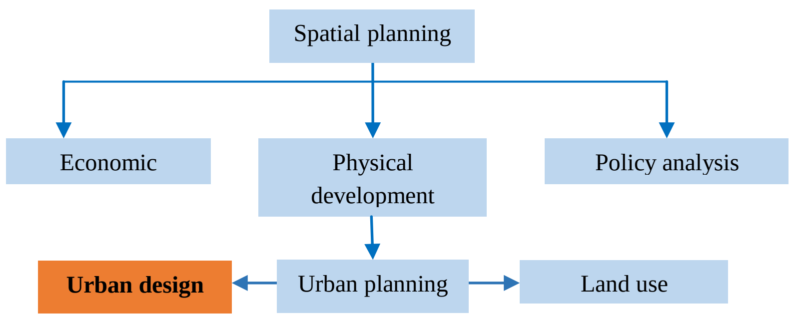


Figure 26: Position within the spatial planning discipline (adapted from Healy, 1997)

3.7 Levels of intervention

In its 2009 report, RIBA asserts that the city is a multi-disciplinary collection of systems and sub-systems interacting in the dimensions of the physical place; and achieving its resilience requires multi-levelled precautionary procedures and measurements. The report continues to clarify, for instance, that the assessment of risk and the hydraulic modelling of flood requires: the inputs of specialist consultants using sophisticated software; the design of flood defences; barriers; and an underground drainage system that requires civil and structural engineers. Previous arguments reflect the tangled atmosphere of the urban context with its interacting systems on different spatial levels. In this sense, Zevenbergen, (2011, p.16) affirmed that flood exposure is directly related to the physical mechanism underlying flood propagation through the catchment system. The propagation of a flood wave to lower spatial levels is buffered by thresholds that are set at each level.

Wilson (2006, p.23) stated that any natural phenomenon involves a spatial context that can be scaled into three hierarchal benches. The crucial aspect in urban and regional theory is the interdependence of the phenomena at different scales: Macro, Meso and Micro levels. The **Macro** level is: concerned with the population and economy for the whole region. The **Meso** level is where the space is differentiated by zonal units, where sectorial conditions will be added to the spatial one. Meanwhile, the **Micro** level is where individual or firms are identified; this involves a fine spatial level of resolution (land use plans).

Accordingly, and with respect to the magnitude of the natural event that can affect an urban block, blocks or a wider city region, the urban design role in this research will influence the spatial context on the Meso level, as shown in Figure 27. This is due to the size of the study area and the nature of flood phenomena, characterised as a site specific phenomena as previously categorised by Zevenbergen (2011).

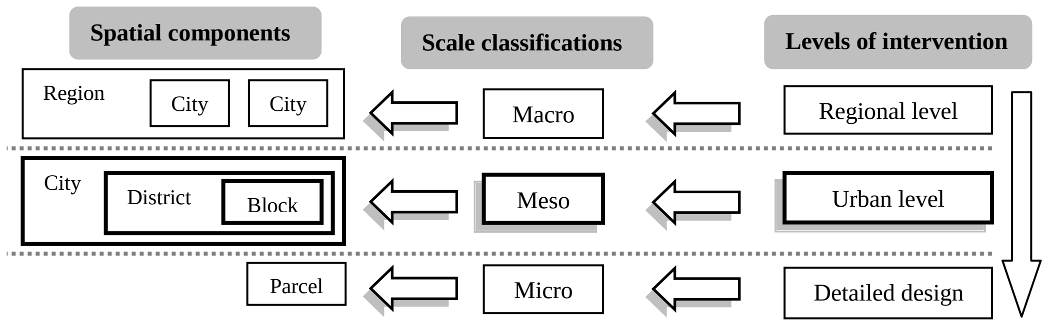


Figure 27: Spatial levels context

Thus, Zevenbergen (2011, p.16) stated that urban flood resilience involves multiple spatial levels and resilient approaches are based upon an understanding of their interaction and taking advantage of the interventions at these different levels.

3.8 Scale of intervention

Mapping flood prone areas within urban realm means defining the boundaries of flood impact zones connected to the scale of intervention (Seyoum, 2013). In a similar sense, Zevenbergen (2011) asserted that the nature of the context considered in flood mitigation study can determine the scale upon which the intervention will take place. In the prospect of large and relatively small urban areas, Vale and Campanella (2005) argue that larger scale urban patterns are not easily or readily altered. In comparison, although flooding is described, in many respects, as a local problem, the solution potentially crosses the boundaries of occurrence to downstream areas. ‘In conclusion, urban flood resilience involves multiple spatial levels and resilient approaches are based upon understanding of their interactions and taking advantage of the interventions at these different levels' (Zevenbergen, 2011, p.16).

The scale issue been commonly considered within urban design as the intermediate scale between planning (the settlement) and architecture (individual buildings) (Carmona, 2010). There are three different scales considered in urban design (McGrath, 2012, p.21):

(1) The scale of street, including the built areas and empty spaces that surround it,

(2) The scale of the district, consisting of a group of blocks with common characteristics,

(3) The scale of entire city, considered as a group of districts.

Urban design typically operates at and across a variety of spatial scales. Considering urban design at a particular scale might often be a convenient device; urban designers need to be constantly aware of scales above and below that at which they are working, and also the relationship of the parts to the whole, and the whole to the parts (Carmona, 2010).

Niemczynowicz (1999) mentioned that it is generally accepted that storm water should be attenuated locally. New methods are based on small-scale, environmentally sound technologies that involve natural or constructed biological systems for storm water treatment. To such methods belong: several kinds of ponds, plant filters, surface flow through natural or constructed ecosystems, wetlands, root-zone systems, percolation facilities, soil infiltration, permeable asphalt, and many combinations of thereof. Niemczynowicz also stated that new ideas in storm water management suggest that the process should already begin on the level of a single house, one parking lot, one street, or a part of large highway system. It is considered to be more effective to act on storm water sources, namely small units of impermeable surfaces where urban runoff is initially generated.

Adger (2005) also argued that adaptation cross scale in ecological systems adds complexity, since different ecosystem processes dominate at different levels. Likewise, Pickett et al. (2001) denoted that the boundaries of an ecosystem are drawn to answer a particular question. Thus, there is no set scale or way to bind an ecosystem. Rather, the choice of scale and boundary for defining any ecosystem depends upon the question asked and remains the choice of the investigator.

The previous discussion, specifically Pickett's comments, concludes the stance on the scale at which required interventions are going to be placed. The issue of scale depends on the effective merging between urban morphology and geomorphology, the scale of physical interventions can be stretched larger than the scale of the urban design unit to the scale of an urban block or even to the extent of an urban district. The scale can also be set depending on one distinctive natural feature. Ultimately, this is going to be realised after developing the instrumental framework from which intervention scenarios will be developed.

3.9 The ecological dimension in urban discipline

Ecology, as a scientific discipline, has really taken an approach that is historically focused on pristine natural environments where humans were viewed outside the system and not part of its internal dynamics (McPherson, 2013). Likens (1992) defined the ecosystem with reference to the interacting bio systems as the scientific study of the processes influencing the distribution and abundance of organism, and the interaction between organism and the transformation and flux of energy and matters. Meanwhile, urban ecology is defined as the study of structure, dynamics, and process in urban ecological systems (Leemans, 2013, p.6). According to Pickett, et al., (2001), ecosystems are those in which people live at high densities, or where the built infrastructure covers a large proportion of the land surface.

Historically, the term **human ecology** was associated with the Chicago School of Social Science when they first used the term to describe their work in the 1920s and 1930s (Pickett, 2013). Research questions and methods developed by the Chicago School were central to the development of the discipline of human ecology (Rees, 1997; Steiner & Nauser 1993). Ecological scientists made a giant leap forward when they began to build linkages among the following entities: ecosystem, community, population, evolutionary, and landscape ecological specialties. Indeed, landscape ecology, the discipline that examines the role of spatial heterogeneity in all kinds of ecological systems at all spatial scales, was not widely recognised until the late 1970s and 1980s (Forman & Godron, 1986). Similarly, Niemela et al. (2011) also agreed that urban ecology, as a discipline, arose in the early 1970s, while, Leemans (2013) stated that **landscape ecology** became an internationally recognised field of study in the 1980s. Despite this, ‘’ecology has not provided a new theoretical framework to fully integrate the human into ecosystem studies’’ (Alberti et al, 2003, p.1170).

Pickett et al, (2013) stated that it is useful to consider that urban ecology consists of biological components, asocial components, a physical component and a built component. Each of these components is itself a complex collection of: (1) species and their products (the biological), (2) social institutions and norms (the social), (3) soil, water, topography and air (the physical), and (4) building and infrastructure (the built), respectively. Meanwhile, Wilkinson (2011) stated that resilience in the context of city complexity can potentially reframe and reintegrate ecology, urban planning, and urban design.

McPherson (2013) exhibits the difference between conventional ecology and urban ecology where urban ecology focused explicitly on human dominated landscapes, whereby the focus on humans as fundamental elements within the system directly includes humans as final components and interacting elements within the system. Pickett et, al (2013) signify this change as the third phase of urban ecology, which is now engaging the interest of an ever growing number of researchers in many disciplines, bringing the dynamic, spatial, and integrative interests of contemporary ecological science into alignment with the concerns of urban geographers and urban sociologists, among others, to fashion a new kind of synthetic science. Thus, to summarise, Niemela, (2011, p.13) stated that ‘’**urban ecology** is at the forefront of creating the knowledge base, conceptual frameworks, and tools that are crucial for building and maintaining sustainable and resilient cities and towns in the future’’.

3.9.1 Research position in urban ecology discipline

There are two distinctive branches of urban ecology; the first is the ecology-in-cities, the second is described as a holistic ecological approach, which is ecology-of-cities (McPherson, 2013; Niemela et al., 2011; Pickett, et, al, 2013). 'The study of ecology-in-cities is typically single discipline, small scale and located within a city' (Niemela, 2011, p.11). Ecology-in-cities is the initial approach that applied traditional ecology methods to urban system services; it may study interactions between two system components, like urban soils and how they affect plant community structure and function but in the context of a city (McPherson, 2013). Pickett, et al. (2001) mentioned that the discipline of ecology-in-cities has focused on the physical environment, soil, plants and vegetation, and animals and wildlife. These studies are the foundation for understanding urban ecosystems. The literature in this area has taken a case study approach and unifying themes are still to emerge.

Douglas and James (2015) clarified the distinction between the two paradigms of urban ecology, namely ecology-in-city and ecology-of-city. Studies of ecology-in-city are typically within one discipline, small scale, and located within specific city, whereas ecology-of-city tends to be interdisciplinary and multi-scale, incorporating both ecological and human dimension of urban ecosystem. McPherson (2013) described the ecology-of-cities as a systems approach that combines interactions between multiple components, like the social, the built all, and the biophysical. This comprehensive systems approach views the city as an urban system and it takes systems thinking to focus not so much on what's happening within a particular component but rather the ecology of the entire city as an ecosystem.

Alberti, et al (2003) mentioned that the greatest challenge for ecology in the coming decades is to fully and productively integrate the complexity and global scale of human activity into ecological research. Likewise, Zevenbergen (2011) referred to the complexities associated with this comprehensive approach by declaring that our incomplete understanding of complex natural systems, and the uncertainties associated with human behaviour, organisations, and social systems make it extremely difficult to predict future vulnerability of cities to flooding.

Desouza and Flanery, (2013) commented on the complexity associated with integrating human-ecological systems; cities are best conceptualised as complex adaptive systems. Despite this complexity, it is possible to reduce a city into its basic elements for analytical purposes. The reduction of a city into components can help to better handle issues of designing, planning, and managing for resilience. The benefit of simplifying and segregating the components of a flood system is also noted by Hall et al. (2003) who stated that the fragmented approaches that prevailed in the past can be seen as an attempt to reduce the complexity of the problem by subdividing it into manageable roles and allocating them to different individuals or organisations.

Building on the definitions mentioned previously for the two ecological disciplines, the research will address the event of a pluvial flood within the approach of ecology-of-cities. This is due to the following reasons, firstly: the research incorporates the physical dimension of both the natural (topography) and the built (urban morphology). This will be guided by the human experience (as the social) that will shape the orientation of the physical solutions across the qualitative analysis in this research. Secondly: there is a current gap in this field, addressed above by Zevenbergen (2011), and there are challenges associated with researching in this multi-dimensional approach, as stated by Alberti, et al (2003). Thirdly, this study initially sets an objective to examine mutual interaction between two of the urban ecology components addressed by Pickett et al. (2013, p.48) namely, the urban design unit (as the built) and the topography (as the physical). These are combined in this research as the generated morphology, which is guided by the social experience in studying flood phenomena. Figure 28 shows research position in ecology discipline.

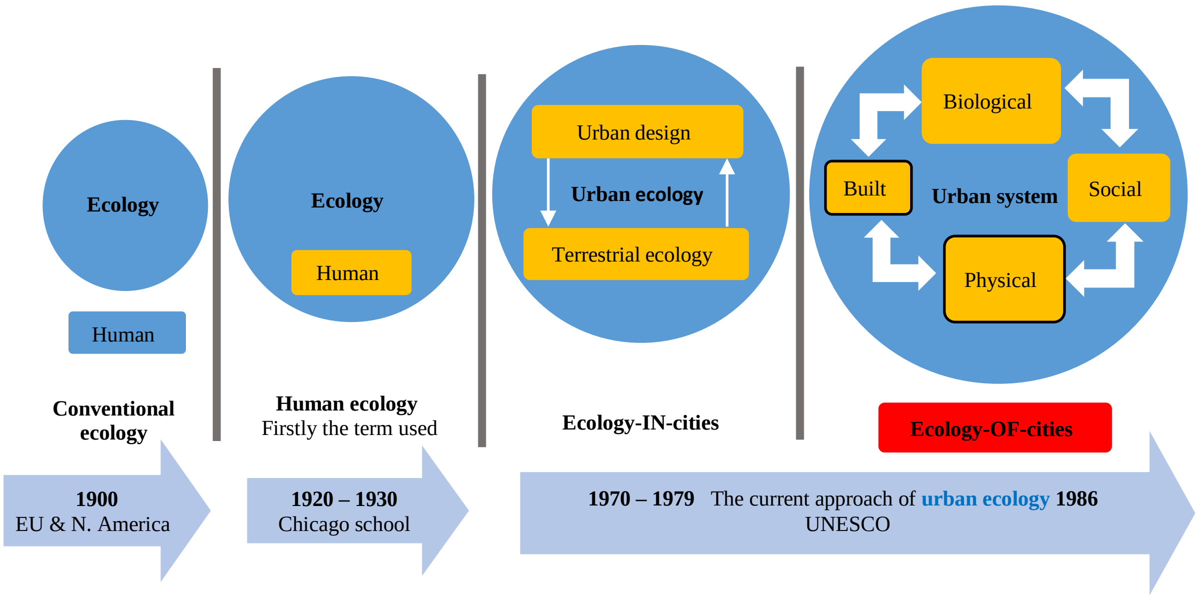


Figure 28: Research position within ecological paradigms

In addition to the justifications mentioned above, Bozza, Asprone and Fabbrocino, (2017) confirmed that when addressing resilience, methodologies in research literature can be divided in two categories: (a) the physical resilience approach; and (b) the social-economic resilience approach. In the approach to physical resilience, attention is focused on the physical systems' performances, e.g., single buildings, Sustainability urban lifelines, transportation systems. In this circumstance, resilience is measured as the capability of the physical systems to effectively function and to recover their functionality in the case of disruption. Mainly, these methods are developed and proposed within the engineering community conversely, according to the approach to the social-economic resilience, attention is focused on social systems and resilience is measured as the capability of communities to recover a good life quality level. Despite the complexity associated with addressing urban ecology within the approach of ecology-of-cities, the research will rely on Desouza and Flanery, (2013) and Hall et al. (2003) in terms of overcoming the problem of complexity by following a simplified approach of reducing the city's urban and ecological settings into its fundamental components.

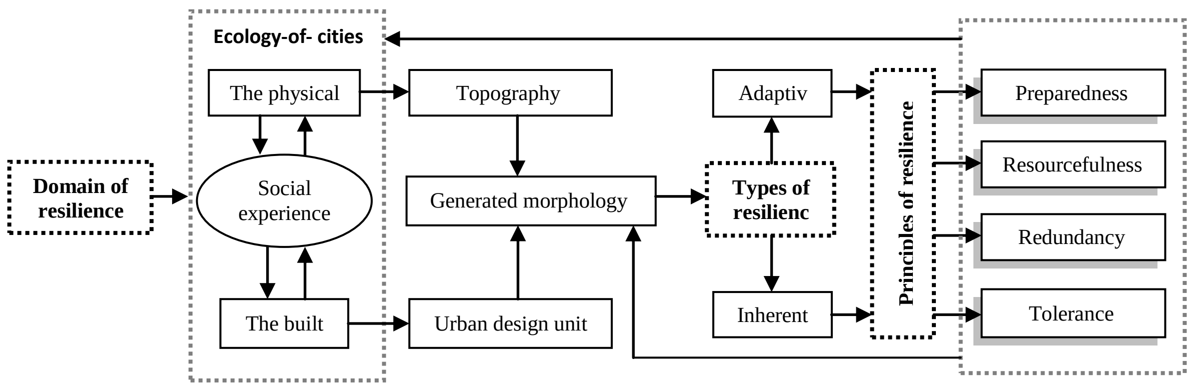


Figure 29: Final resilience theoretical framework

Figure 29 shows the resilience theoretical framework developed to test the ecological resilient response of urban design to pluvial floods. It was developed in consideration of the position of the research within the ecological paradigms shown in Figure 28, the urban design unit, and the research position within resilience perspectives. This framework will lead the qualitative enquiry in this research. Starting from the domains of resilience, identifying the ecological paradigm followed in the research, moving forward to the types of resilience and ending with resilience principles that will associate directly with the interview questions.

3.10 Floods

Urban flooding occurs when rain overwhelms drainage systems and waterways and makes its way into the basements, backyards, and streets with homes, businesses, and other properties. There are several ways in which stormwater can cause the flooding of a property: overflow from rivers and streams, sewage pipe backup into buildings, seepage through building wall and floors, and the accumulation of stormwater on property and in public rights-of-way (CNT, 2014). Nevertheless, throughout history, floods have been part of human destiny. They are widely discussed today as a result of increased public awareness and greater research activity on the part of both physical and social scientists. Floods continue to be not only a problem but in some respects an increasing problem, catching individuals and communities by surprise in a repeatedly exasperating way and causing disruption, damage and even death (Smith & Ward, 1998, p.3). Figure 30 shows the historical acceleration of flood events during the last 50 years.

“Floods kill more people and damage more property than any other natural phenomenon known to mankind” (Doe, 2006, p.1). Zevenbergen, (2011) mentioned that floods are the result of the rise of water level in main land areas due to heavy rainfall, which can influence the water levels in water courses, like rivers or lakes, tidal floods can happen in coastal areas, other factors can cause floods, like tropical storms or massive avalanches. Gustin (2004, p.73) referred to floods as the most common and widespread of all natural disasters, except for fire. In fact, more than half of all presidential disaster declarations over the past 40 years resulted from natural phenomenon in which flooding was major component.

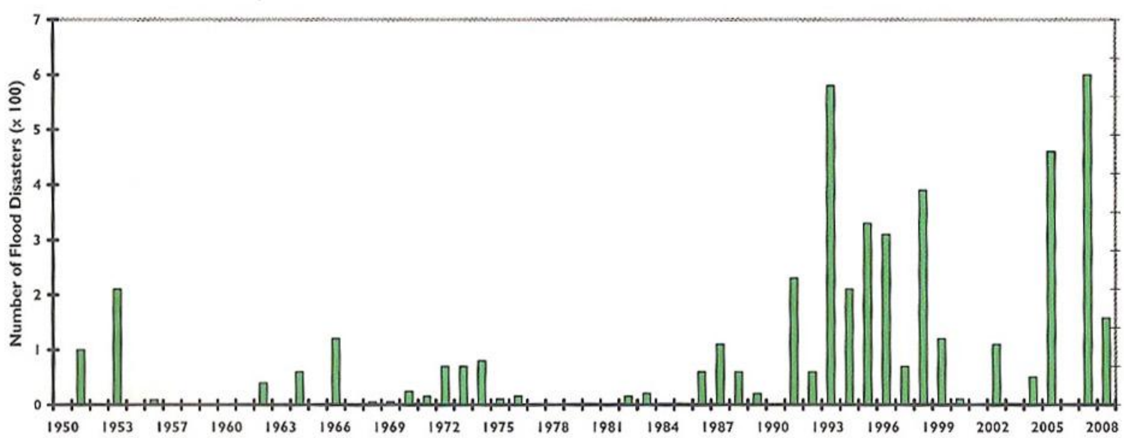


Figure 30: Historical layout for flood disasters worldwide (Zevenbergen, 2011)

Floods may affect all aspect of our lives, particularly in the case of cities; cities are the most vulnerable because of the concentration of people and their possessions, and economic activities (Zevenbergen, 2011, p.1). Smith & Ward (1998, p.19) explained that natural floodplains can be drastically changed - but not damaged - by the events which create them. Indeed most floodplain ecosystems are geared to periodic inundation and terms, such as flood risk and flood losses, are, therefore, essentially human interpretations of the negative economic and social consequences of the natural events. When White, (1945) stated that "floods are acts of God, but flood losses are largely an act of man", he transformed the way people looked to natural events as disaster direct drivers.. However, they are part of a natural process embodied within the natural system for millions of years, whereby, extreme natural events can stimulate an inverse hazard-threatened reaction in built up areas due to developments facing critical exposure to the natural process territories.

The effect of floods may range in scale from local to larger impact depending on the magnitude of the event that can affect either a neighbourhood or vast areas to a regional level. Flood occurrence in the area of study, can vary in nature from intense to a moderately manageable flood. This is dependent on the catchment natural settings and the urban developments. It can sometimes take the mode of flash floods that develop within a short period of time and without a previous sign of rain, as the rain fall takes place on the foothills and mountain areas elsewhere up stream and eventually find their way through urban areas downstream; this is very common in the study area.

3.10.1Types of floods

The terms floods and flooding cover a very wide range of phenomena, and each require a different type of management (Smith& Ward, 1998, p.19). Donald (2011, p.7) argued that the most common source of flooding is when water levels in rivers rise so that the rivers overtop their banks (‘fluvial’ flooding). Donald (2011) also referred to another familiar source of flooding along coasts that result from a combination of high tides and stormy conditions. Less well known by the general public, and less well understood, are pluvial (rain-related) floods which occur following short intense downpours that cannot be quickly enough evacuated by the drainage system or infiltrated to the ground. Pluvial floods often occur with little warning in areas not obviously prone to flooding; hence, they are categorised as an ‘invisible hazard’. Zevenbergen (2011) refers to two basic types of flooding in relation to their origins and geographic location, detailed in Figure 31:

1. Inland flooding, mainly driven by rainfall (pluvial).

2. River basin flooding, driven from river water rise due to rain or snow melt (fluvial).

2. Sea front area flooding, driven by a combination of sea tide and/or rainfall (tidal).

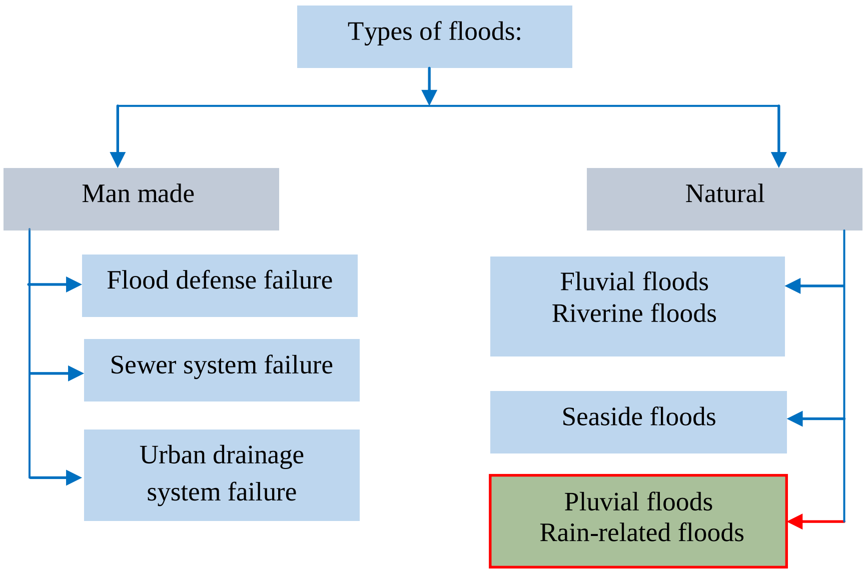


Figure 31: Types of flooding (adapted from Zevenbergen, et al, 2011)

3.10.1.1 Pluvial floods

Pluvial floods are less well known and understood. These floods occur after short, intense downpours that cannot be evacuated quickly enough by the drainage system or infiltrated to the ground. Pluvial floods often occur with little warning in areas not prone to flooding – hence they are labelled an 'invisible hazard' (Donald, 2011). They result out from intense localised and often short durations of rainfall events and consequent surface water runoff over impermeable surfaces, which overload the hydraulic capacity of the urban drainage system (Zevenbergen, et al, 2011. p. 41).

Smith & Ward (1998, p.72) mentioned that, in defining pluvial flood, it cannot be expressed simply in terms of the amount of intensity of rainfall but must also take into account the condition of the catchment upon which the rain falls. Accordingly, heavy rainfall can stimulate floods in urban areas conditional to nature, coupled the physical and social contexts of the event area.

Pluvial flooding occurs when rainfall that is usually converted into run-off, which can be evacuated by the drainage system, remains on impermeable surfaces and flows overland or into local depressions and topographic lows to create temporary ponds. Pluvial flooding only occurs when the rainfall rate exceeds the capacity of storm water drains to evacuate the water and the capacity of the ground to absorb water (Donald, 2011, p.15). 'It occurs in poorly drained or impermeable basins, influenced by the degree of urbanization, the remaining percentage of the natural surface, and the dimension and distribution of building that affect the runoff-damming ratio' (Zevenbergen et al., 2011, p. 41). Gad-el-Hak, (2008) classified pluvial floods as topological disasters, the same as landslide, avalanches and mudflows. This is one of the reasons why the research draws studies pluvial floods within its contextual topological settings in areas of occurrence.

3.10.2 Flood risk

Before determining flood risks, a definition of risk was provided by the UNISDR (2009) who stated that it was the combination of the probability of an event and its negative consequences. Two factors should be considered when assessing the flood risk; firstly, the likelihood of a flood occurring, and secondly the potential consequences that it might have upon the various receptors in its path (RIBA, 2009, p.6). Figure 32 outlines the flood risk factors.

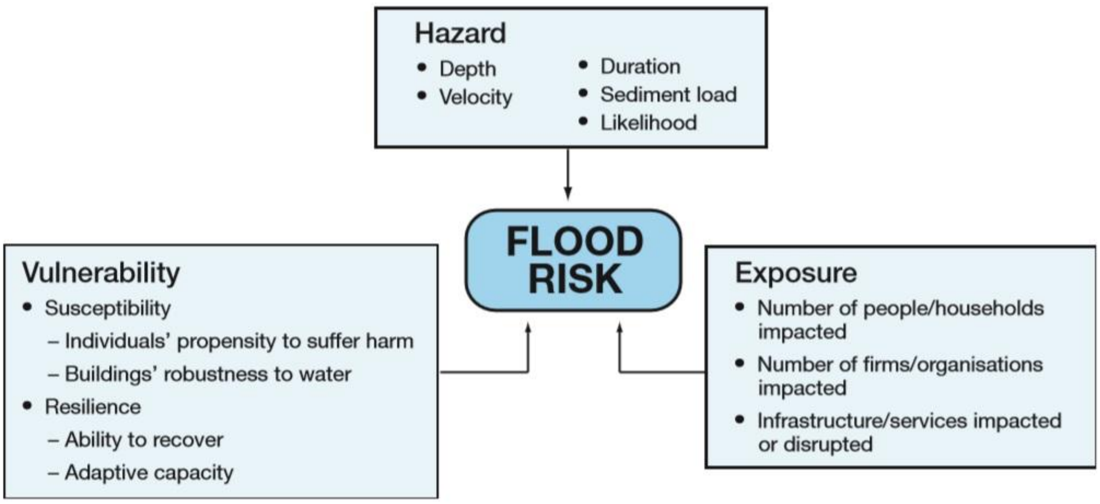


Figure 32: The influences of flood risk (adapted from McLaughlin, 2011)

The flooding system processes and the relationships among them can be represented as the causal linkage between the source of risk, exposed receptors and the pathways linking them (Zevenbergen, 2011, p.28). A flood risk results from a combination of physical exposure and human vulnerability to the geophysical process. Physical exposure reflects the type of flood events that can occur and their statistical patterns (Smith & Ward, 1998). These statistical patterns constitute that factors that determine the impact of a flood on the physical environment, and these factors are illustrated in Table 9:

Factors	Description
The level of predictability	This affects timing, accuracy and communication of a warning given before a flood.
The rate of onset of the flood	How quickly the water arrives and the speed at which it rises will govern the opportunity for people to prepare and respond effectively for flood.
The **speed** and **depth** of the water	This dictates the level of exposure of people and property to flood. It is difficult to stand or wade through even relatively shallow water that is moving. Flood water often carries debris, including trees, and water over 1metre in depth can carry objects the size of a car. Fast flowing water can apply devastating force to property and other receptors.
The duration of the flood	This is another important factor in determining the extent of its impact, particularly on individuals and affected communities.

Table 9: Factors which determine the effects of flooding (RIBA, 2009)

Taylor (2004) specified two types of systemic losses associated with natural disasters, like floods; the first is the indirect losses and the second is the secondary effects. Indirect losses are the cost of goods that will not be produced and services that will not be provided, while the secondary effects are the consequences on the macro economy. Zevenbergen et al (2011) also referred to how cities' economic vulnerabilities to flooding have an indirect impact on economic sectors where changes in productive capacities are affected by the change in resource productivity or market demand. Likewise, Grosvenor (2015) mentioned that cities are resilient if they absorb shocks, maintain their output of goods and services, and continue to provide their inhabitants with a good quality of life according to the standard of the time.

Zevenbergen et al, (2011) also differentiated between direct and indirect flood related losses; indirect losses include a disruption of physical and economic linkages, emergency costs and other flood prevention measurements. These indirect effects of flood can be suffered by productive and emergency activities, both within and beyond the area of immediate direct physical flood impact.

3.10.3 Flood parameters

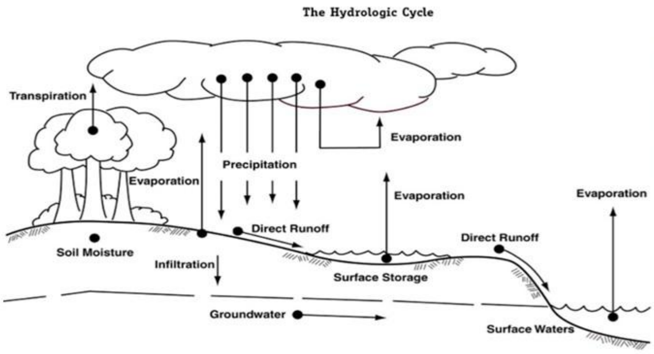
Pluvial floods are caused principally by rain water precipitation of any intensity and duration that exceeds the infiltration (including the drainage capacity) interception and evaporation capacity of the affected area to absorb that rainfall. This can be intensified in urban areas because of an increase in runoff compared to filtration (Zevenbergen, 2011.p.40). Due to the increasing areas of paved surfaces, the permeability of soil and infiltration decreases, and surface runoff accelerates. The channeling of natural streams results in fast runoff with high peak flows. Such changes in the natural regime in a comparatively small area of a city bring significant and often disastrous effects on the whole river basin downstream of the city. (Niemczynowicz, 1999)

3.10.3.1 Surface runoff

In the urban area, the management of surface runoff has been highlighted as a key driver for flood risk; surface runoff is not only generated by flow that is in excess of the rate of infiltration, but also on saturated topsoil layers of the surface (Zevenbergen, 2011). Ning, (2006) stated that excessive rainfall exceeding the local drainage and infiltration capacity lead to water logging disasters. The increased runoff in urban areas changes the morphology of the urban streams, which become deeply engraved in their floodplains (Pickett, et al. 2001).

The physical characteristics of the runoff flow are subject to translation and retention. Translation corresponds to the travel time of the water, which is dependent on the flow velocity and the length of the watercourse. The flow velocity is influenced by the gradient of the bed of the water course, the water depth and the flow resistance, as shown in Figure 34 (Zevenbergen, 2011). The surface runoff is affected in three ways:

- Increased runoff due to a reduced infiltration and evapotranspiration rate, (Figure 33).
- Increased the velocity of runoff due to the hydraulic improvements of conveyance channels.
- Reducing the catchment response time by restricting the absorption and interception, and thereby increasing the maximum rainfall intensity causing peak discharge.



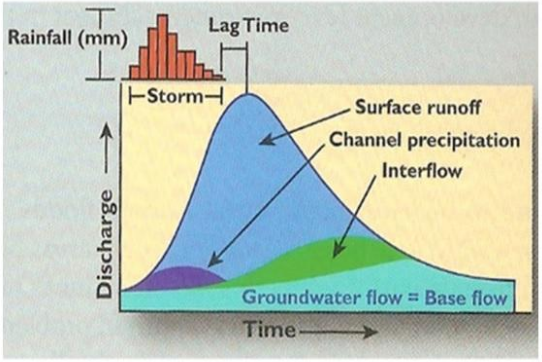


Figure 33: The Hydrologic cycle (New Jersey S.B.P.M, 2004)

Figure 34: Stream hydrograph (Zevenbergen, 2011)

As cities, towns, and suburbs have developed to accommodate increasing populations, more impermeable surfaces (roads, roofs, parking lots, driveways, alleys, sidewalks, and patios) have led to increased storm water runoff, and natural drainage systems have been replaced with man-made sewer and storm water infrastructure (CNT, 2014).

As far as urban storm water modeling is concerned, and despite the constant development of new methods and techniques, the inherently complex nature of the physical process involved in rainfall runoff transformation mechanisms are still not very well understood and many problems remain unsolved. Therefore, seeking innovative modeling tools and exploring new alternative approaches to storm water management modeling is still considered a priority in ongoing research (Chen & Adams, 2007).

3.10.3.2 Flood depth and velocity

Buildings are liable to structural failure if subjected to the combined effects of deep flooding and high velocity flood water. Such cases are rare but can occur with extreme floods, either under natural conditions, or as a result of a dam failure's inundation at a critical depth and velocity for residential buildings (shown in Figure 35) (Smith, 1994). The base flood elevation is the computed elevation to which floodwater is expected to rise or that it is expected to exceed during a (1%) annual chance of flood; it forms the basis for setting flood insurance premiums and structure elevation regulations (US. & NRC, 2009).

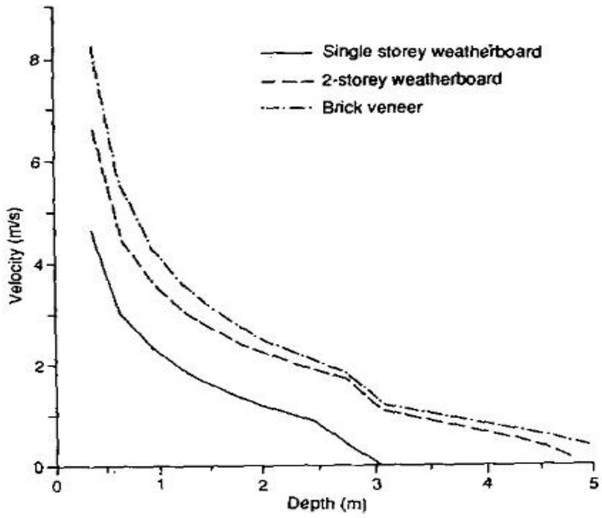


Figure 35: Critical velocity and depth for building failure for differing depth of inundation and residential building types. (Smith, 1994)

In order to make living and transportation possible, large impervious areas are constructed; this results in a change of hydrological cycle. Infiltration and groundwater recharge decreases, the pattern of surface and river runoff is changed imposing high peak flows, large runoff volumes and accelerated transport of pollutants and sediment from urban areas. Thus the city influences the runoff pattern and the state of the ecological systems (Niemczynowicz, 1999).

In their study in 1977, Penning-Rowsell and Chatterton were the first to associate flood depth and velocity to losses in residential and commercial properties in the UK. Their method was to classify the urban area into morphological groups depending on the type and age of the buildings, dwelling units that vary in type between detached and semi-detached to terraced and ages from pre-1918, 1918 to 1935, 1935 to 1965 and post 1965.

They also introduced further social class subdivisions to end up with 48 types of dwelling unit. Flood characteristics are usually driven from hydrodynamic models, which provide information about the flood flow over time and provide insights into flood characteristics, such as water depth figure (shown in Figure 36), flow velocity and the rate at which water levels rise. All these characteristics can be depicted on maps. (Zevenbergen, et al, 2011)

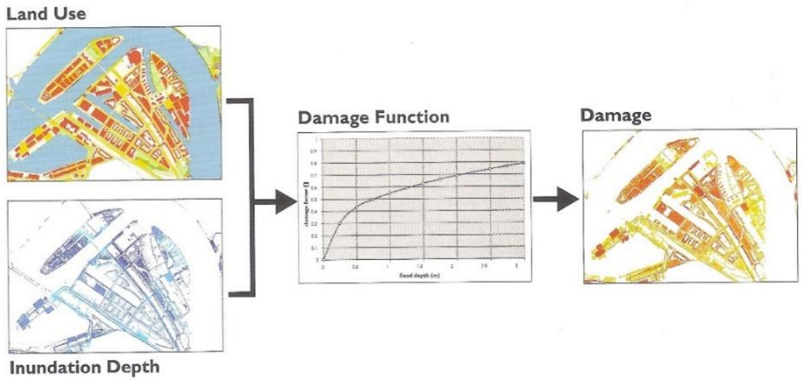


Figure 36: Flood characteristics (depth) (Zevenbergen, 2011)

Among the different classifications for flood factors, this research found three major factors, which are: depth, velocity, and direction (DVD). Correspondingly, and according to the researcher's experience and direct observations in the study area, flood runoff depth and direction were of prominent importance. Hence, the research will pay them primary attention through the analysis process. Other less effective factors, like runoff velocity, will be monitored all the way through the analysis process as well. Nevertheless, inputs of all characteristics, key and insignificant, will be equally introduced to the flood simulation platform to draw the flood wave propagation; results will be displayed before and after the introduction of physical intervention scenarios.

3.10.4 Flood management and urban design

Malmquist and Bennerstedt's (1997) made one of the early calls to shift thinking in storm water management from the conventional flood protection infrastructure to more adaptive and creative solutions. They stated that; for the moment, we are forced to take temporary measures but the real challenge in storm water management is to find more environmentally sound materials and technologies. In the long-term, it will be necessary to change also our habits and life style. Ning (2006) also referred to this essential shift in thinking when he asserted that fostering the concept of transferring from *flood control* to *flood management* and promoting the harmonious coexistence between man and flood is an important action to carry out scientific development and new water management concepts, and has vital and far-reaching significance in both theory and practice. Likewise, Hall and Rowsell (2011) mentioned that a major shift in approaches to the management of flooding is now underway in many countries worldwide.

in the context of the study area, the consultancy services for Muscat area drainage study (2011, p.14) confirmed that; “It is absolutely fundamental to highlight that the main urgent and important actions to carry out after the achievement of the Master Plan are in the urban planning field”.

Urban areas can be flooded by rivers, costal floods, pluvial and artificial system failure, although urban floods resulting from metrological and hydrological extremes, such as extensive precipitation and flow, they also occur as a result of human activities, including: unplanned growth and development in floodplains, urbanisation increasing the magnitude and frequency of floods by increasing impermeable surfaces, an increase in the speed of drainage collection, reducing the carrying capacity of land, and, overwhelming sewer systems (Seyoum, 2013). The flooding system processes and the relationship among them can be represented as the casual linkages between the source of risk, exposed receptors and the pathways linking them (Zevenbergen, 2011). The rainfall is a driving force of all hydrological processes and it constitutes the most important input to any runoff calculations and modeling procedures (Niemczynowicz, 1999). There are two types of rainfall events, convective and advective, and the characteristics of these two types of rainfall in terms of time scale and intensities are remarkably altered; nevertheless, this research will investigate the flood generated from convective rainfall.

Convective events have a small spatial extension (not more than few tens of square kilometers), they are also of limited duration (a few hours) but involve high rainfall intensities. Meanwhile, advective events result in large regions being affected by the rain over a long period of time with relatively smaller rainfall intensities (Niehoff, Fritsch & Bronstert, 2002). They also stipulated that convective rainfall is usually driven from a thunderstorm with dry antecedent catchment conditions. Thus, advective rainfall occurs in late autumn, winter and early spring with usually wet antecedent catchment conditions.

Niemczynowicz, (1999) argued that any construction of urban water-related infrastructure, including channels, pipes, conduits and even the shaping of streets must be based on good knowledge of what will be the effect of these structures on water flows in the city and what is necessary to avoid damage to man-made constructions. Even more important is the fact that the increasing imperviousness of the city area with the generation of storm water flows may significantly influence the flow regime in the entire river downstream.

All these influences must be quantified by the analysis of hydrological data and calculations before any construction is built. In other words, adaptation should become an element in urban renewal schemes and life cycle assessments, which in turn calls for planning ahead for up to 100 years. The capacity to adapt to changing conditions depends on their substitution rates of the built environment components, as shown in Figure 37 (Zevenbergen, 2011).

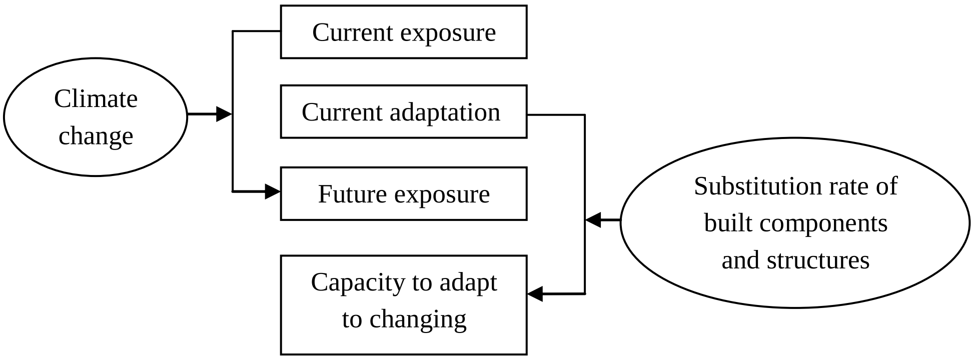


Figure 37: Substitution of built components and structures (Zevenbergen, 2011)

Zevenbergen referred to the substitution rate as when the urban system is provided with a sufficient amount of redundant components it can switch from one component to another. Interventions to reduce sensitivity at a certain level may enhance the system’s redundancy. Zevenbergen also refers to how the possibility of building options into the design of engineering systems offers a means to introduce flexibility to manage uncertainties; it enhances the ability to preserve alternative options without having to abandon existing arrangements. Embedding options in the design creates flexibility, which can be used in the future to accommodate a range of other possibilities. Similarly, AECOME (2015) referred to flood resilient design by considering reasonable probabilities and anticipated changes in the behavior of the system in which our cities and population exist. Moreover, in urban design, Zevenbergen (2011) referred to flood damage as a function of the location of the urban area and the characteristics of the urban features.

3.11 Summary

This chapter exhibits a theoretical investigation of two major domains, urban design and urban ecology, as they both represent the internal and external contexts of this study. This was achieved by identifying flood factors as change agents. The two major domains mentioned above were approached from the perspective of the pure physical dimension. These two domains were analysed in cohesion with relevant resilience conceptions that were explored to best fit the current physical approach of the urban form. Three key deliverables were arrived at from these domains, which are: the urban design unit as the physical intervention that will take place, the ecological paradigm which will govern the context boundary, and the resilience framework that will guide the rest of the enquiry in the research.

The role of resilient urban designs to flood was linked to the vital element of accessibility. This is due to its association with flood consequences, identified earlier as; indirect losses and secondary impacts, where indirect losses are the cost of goods that will not be produced and services that will not be provided during and aftermath. Comparisons between resilience perspectives, and the way they engage with urban design characteristics, yields different levels of correspondence. These levels move from the static approach of engineering resilience to a more systemically flexible ecological resilience, and ends with the absolute dynamic regime shift-based evolutionary resilience. The level to which urban design transforms from the rigid approach of infrastructure resistance to the three resilience perspectives very much relates to the dynamics of each perspective. This can be explained further by understanding the systemic conflict between urban form inertia, or rigidity, and any transformational change. The more dynamic the resilience perspective, the more time the urban form requires achieving.

The difficulty of addressing city resilience as a whole living complex system stemmed from the differences between interacted acting systems functioning within the city. Hence, this research adopts the ecological paradigm of ecology in cities. This will facilitate in return the arrival at solid conclusions for the adopted paradigm and highlight the required physical dimension of the built environment targeted in this research.

Chapter 4: Research methodology

4.1 Introduction

This section will outline the research strategy and methodology followed in the study that answered the research questions and met the research objectives. A brief discussion will reveal the study's methodological position concerning the relevant research philosophy, which is followed by a further discussion on the research approach and strategy undertaken.

4.2 Research philosophy

The focus of the research inquiry is underpinned by a philosophical concept (resilience); this concept influences the philosophical approach of the urban design discipline, and also this study in terms of its theoretical and philosophical nature. The research will follow an exploratory quest that will rely on the theoretical concepts to develop an interpretive and conceptual framework. It is intended that this framework can guide urban design to achieve resilience to flood in pluvial flood prone areas. The concept of resilience itself is still changing, across different disciplines, and touching on social, economic, and ecology concerns. Accordingly, the research will contribute to the current evolving knowledge about the implications and manifestations of the term within the urban design discipline. It aims to achieve this by developing an interpretive framework concerning the implications and potential contribution to urban design to withstand pluvial floods.

"In their choice of qualitative research, inquirers make certain assumptions. These philosophical assumptions consist of their stance toward the nature of reality (ontology), how the research knows what they know (epistemology), and the role of values in the research (axiology)" (Creswell, 2007, p.16). Sexton (2003) also referred to the same context, that research philosophy can be pursued form three distinct assumptions of epistemology, ontology and axiology. Epistemology describes the reality and the assumptions in the field of study, ontology address the nature of the reality, while axiology is about assumptions of the value system.

4.2.1 Epistemology:

Positivism and interpretivism (social constructivism) are the main research philosophies and are positioned at the extreme ends of the scale (Easterby-Smith, 2008). According to positivism, 'the world exists externally and its properties should be measured objectively rather than being inferred subjectively through reflection or intuition' (Easterby-Smith, 2008, p.56). While in interpretivism, reality is determined by people rather than external factors. Moreover, Baxter (2008) purports that constructivism claims that truth is relative and that it is dependent on one's perspective. This paradigm, recognises the importance of the subjective human creation of meaning, but does not outright reject some notion of objectivity.

In the case of this research, the intention is to explore the capacity of urban design to mitigate pluvial flood impacts from within-this study developed notion-of resilience. Also, it is intended that the study will produce an instrumental framework or contribute to theory building instead of theory testing. Garson (2001, p.11) explained that, 'when the emphasis of the study is to seek out meaning and understanding of the phenomena, so theory building is positioned under interpretivism/relativism'. Meanwhile positivists begin with a theory, and then collect data that either support or refute a theory (Creswell, 2009). In this research, no well-established theory was found in the literature to govern resilience in urban design to flood. Instead, the data analysis will inductively develop from particular observations to generate themes and build meanings.

When distinguishing between positivism and interpretivism, Moudon (1997) mentioned that architecture and urban planning have not followed other professions in developing systemic, empirical approaches to learning and building a knowledge base. Moudon stated that "the justification for this lies in the amount of artistic approaches to decision-making in architecture and planning. She argues that 'urban morphologists 'will have to catch their attention, to demonstrate the validity and effectiveness of the morphological approach in identifying cause and effect relationships" (Moudon, 1997, p.9). In addition to Moudon's (1997) argument about urban planning and design, Desouza and Flanery (2013) referred to the same consideration in studying resilience, stating that resilience is a normative concept, which is not easy to present in quantitative terms. Lynch (1981) referred to interpretivism when describing urban design as encompassing a wide range of concerns across different spatial scales; urban planners may seek to protect neighbourhood streets, revitalise a public square, set a regulation for conservation or development, or build a participatory process by writing an interpretive guide. The RCEP, (2002, p.75) also stated that, 'planning is inherently political in nature, and can never be a completely quantitative or technocratic process'. While, Bozza, Asprone and Fabbrocino, (2017) stated that resilience is assessed according to two main approaches: qualitative and quantitative.

The stances of Moudon, Desouza & Flanery, Lynch, and the RCEP appear to favour the interpretive approach for research mainly located in architecture, urban planning and resilience thinking. This approach to research heavily dominates these fields. Therefore, due to reasons mentioned above, this study follows the interpretive research orientation in exploring phenomena with no clear boundaries or well established governing theory. Thus, this approach will underpin the mixed method approach used in the research, which will be subsequently followed by a positivism approach.

Qualitative research begins with assumptions, a worldview possible use through a theoretical lens, and the study of research problems inquiring into the meaning individuals or groups reflect on a human problem. Qualitative research uses an emerging qualitative approach to inquiry; this means the collection of data in a natural setting sensitive to the people and places under study. Moreover, the data analysis that is inductive establishes a pattern or themes (Creswell, 2007). Accordingly, the study will essentially adopt a qualitative inquiry although; the study will be strengthened with a subsequent quantitative method.

4.2.2 Ontology

Sayer, (2000) stated that ontology is concerned with nature of reality where a number of researchers seek to investigate their studies. The two ontological assumptions are defined as realist and idealist. Sexton (2004) states that an ontological assumption involves the researcher in considering whether the world is external to the researcher or constructed by examining human perceptions. Meanwhile, realists believe that the natural world exists with a predominant nature and structure. Idealists believe that different observers may have different viewpoints because the world is realised in different ways. It is experienced and perceived by individuals differently (Sayer, 2000).

Creswell (2007, p.18) also mentioned that 'qualitative researchers conduct a study with the intent of reporting multiple realities. Evidence of multiple realities includes the use of multiple quotes based on the actual words of different individuals'. From a similar perspective, Willis (2007, p.9) referred to the idealist ontological stance as “relativist ontology-realities existing in the form of multiple mental constructions, socially and experientially based, local and specific, dependent on their form and content on the person who holds them”.

This research will develop a resilience framework through which an overarching understanding of ecology and urban design will be established. This is going to be based on qualitative data taken from experts in the field of the phenomenon. The research does not propose to govern the research field by using statistical models; hence, it is based more within the ontological assumption of idealism.

4.2.3 Axiology

All researchers bring value to the study, but qualitative researchers like to make those values explicit (Creswell, 2007). Axiology considers whether the reality is value free or value driven. In value free (neutral) research, what to study and how to study can be determined by objective criteria, whilst in value driven research, it may be determined by human belief and experience (Easterby-Smith, et al. 2008). Likewise, Nagel, (1961) agreed with the arguments that social sciences cannot be value free.

Meanwhile, Denzin and Lincoln (2011) mentioned that the ways in which value feeds the inquiry can be through; the choice of the problem, the choice of paradigm to guide the problem, the choice of theoretical framework and the choice of the major data-gathering and data-analytic methods. They also referred to the contribution of Max Weber, when he distinguished between value freedom and value relevance, arguing that choosing between these two elements must serve the purposefulness and rationality of value relevance. Since 1917, Weber mentioned that the problems of social sciences are selected by the value relevance of the phenomena under study; the expression of the 'relevance to values' simply refers to the philosophical interpretation of that specifically scientific interest which determines the selection of a given subject matter and the problems of empirical analysis (Weber, 1917, cited in Denzin & Lincolin, 2011).

In this research, value relevance is not represented on the level of problem selection, as Weber suggested, but on the significance of the key characteristics of the physical components influencing the phenomena under investigation. The 'problem choosing' is almost free from subjective considerations, as flooding is a highly evident problem and affects the entire urban context in the area of the study. Even with the research inclination to apply a mixed method approach, the qualitative nature will be of greater dominance. Accordingly, the research philosophical assumptions are interpretivism epistemologically, idealism ontologically, and value driven in terms of axiological orientation.

4.3 Research approach

Although this research leans towards the interpretive stance epistemologically, yet a subsequent quantitative approach from the positivist paradigm strengthens the qualitative approach. By using mixed method, the research will demonstrate better outcomes, including consistency and solidity; this is a more limited when using one paradigm.

Brown (2001, p. 253) divides the research design into four parts, which are, 'purely statistical, statistical with some qualitative, qualitative with some statistics, and purely qualitative.' Correspondingly, qualitative and quantitative approaches, when used together, produce the more complete knowledge necessary to inform theory and practice (Migiro & Magangi, 2011). The mixed method integrates or links two forms of data in a parallel order by combining them; this can mean merging them, or integrating them sequentially by having one build on the other. The weighing of the two methods can be of equal importance, or the priority is for one approach over the other, which frames the procedures within the philosophical worldview and a theoretical lens (Creswell, 2011).

The current difference in thinking about mixed method design can be seen in Patton's and Sieber's approaches. Patton (1980) often presented the mixed method when qualitative data is transformed into counting (data transformation process) (Patton, 1980, cited in Patton, 2002). Meanwhile, Sieber (1973) discussed the interplay of fieldwork and survey methods, and identifies the procedures for combining the two methods, a method building on the other process.

In considering paradigms, Guba and Lincoln stated that elements of paradigms might be blended in a study, while Creswell suggested that multiple paradigms related to different phases of a research design, thus linking paradigms to research design (Creswell, 2011). Meanwhile, Teddlie and Tashakkori (2011) stated that mixed method research offers a third alternative based on pragmatism, which argues that two methodological approaches are compatible and can be fruitfully used in conjunction with one another.

In this research, inductive reasoning will dominate the qualitative enquiry, within a interpretivism paradigm. The qualitative approach will dominate the data collection and analysis throughout the two case studies. The analysis shall generate a pattern leading to a tentative hypothesis and ending up with developing an instrumental framework for resilient urban design in the face of pluvial flood. Findings from the qualitative part of the enquiry will inform the quantitative part, and the findings will thus be put forward for numerical testing. This aims to maintain robust findings and examined for confirmations in a sequentially mixed method.

4.3.1 Mixing strategy

Designing a mixed methods study involves a number of steps, many of which are similar to those taken in traditional research methods. These include dealing with the purpose of the study, the research questions and the type of data to collect. Designing mixed methods, however, also involves at least three additional steps. These include: deciding whether to use an explicit theoretical lens; identifying the data, data collection procedures and identifying the data analysis; and the integration procedures (Migiro & Magangi, 2011).

The first step involves whether to use an explicit theoretical lens (philosophical basis or paradigm) that underlies a researcher's study and subsequent methodological choices (Crotty, 1998). Creswell (2009) also referred to the theoretical lens used in mixed method approaches, confirming that all researchers bring theories, frameworks, and hunches to their inquiries and these theories maybe made explicit or implicit. Theories are found to be in the beginning sections that serve as an orientating lens that shapes the type of questions asked. The second step involves deciding how data collection will be implemented and prioritised. Implementation refers to the order in which the quantitative and qualitative data are collected, whether concurrently or subsequently, and, the priority refers to the weight, or relative emphasis given to the two types of data, namely equal or unequal (Creswell, 2003). The third step involves deciding the point at which data analysis and integration will occur. In mixed method studies, the data analysis and integration may occur by analysing the data separately, by transforming them, or by connecting the analyses in some way (Tashakkori & Teddlie, 1998). These three steps in mixed method approach are clearly identified and classified by Creswell who is one of the most prominent writers on this topic; this is one of the reasons why the researcher was comfortable with adopting this approach for the study.

Creswell described the three steps mentioned above as timing, weighing and mixing, where, timing is about which one comes first and which one follows, qualitative or quantitative. Weighing refers to the importance paid more towards which form of inquiry. In this sense, Brown (2001, p. 259) cautions that, 'you may need to decide whether it is primarily a statistical study or mainly qualitative in nature'. Finally, mixing means that either both qualitative and quantitative data are merged at the end of study or kept separate. These two cases are extremes and in between they might combine in some way (Creswell, 2009).

Creswell, (2011) identified three different designs for mixed method studies, and they are; convergent design, explanatory sequential design, and exploratory sequential design. Briefly, the convergent design tends to merge the results of the quantitative and qualitative data analyses. Meanwhile, an exploratory design is often used for studying a problem, which begins with a quantitative and then a qualitative phase. Finally, the intent of exploratory sequential design is to study a problem by first exploring it through qualitative data collection and analysis. The following face is to develop a new instrument or interventions for a new experiment. In the case of this research, and according to the epistemological and ontological assumptions that mainly rely on constructivism and idealism, the research explores the phenomena through a qualitative approach following deductive reasoning (bottom-up). The sequential exploratory design will fit the case of this research and Table 10 showcases the research mixed method choice and the three steps of mixed methods (timing-weighing-mixing) adopted from Morse (1991).

Design type	Variants	Timing	Weighing	Mixing	Notation
Exploratory	Instrument development	Sequential	Usually Qual.	Connect the data between the two phases	Qual. >> Quan.
	Taxonomy development	Qual. Followed by Quan.			

Table10 : Sequential exploratory mixed method research design (Morse, 1991)

4.4 Research reasoning

There are two broad methods of reasoning used in research, known as deduction and induction. There is also a mix of both, known as abduction reasoning. Deductive reasoning is mainly adopted in quantitative research and works from the more general to the more specific. It is sometimes informally called the top-down approach, which means the researcher begins with a theory about the topic of interest and then narrows that down to a more specific hypothesis that can be tested. Meanwhile, inductive reasoning is mainly used in qualitative research when a phenomenon is observed and certain conclusions are drawn regarding broader generalisations and theories. This is sometimes informally called the bottom-up approach (Knowledge-base, 2006). Figure 38 exhibits the logic of inductive reasoning.

Saunders, Lewis, and Thornhill (2012) stated that deductive reasoning is criticised for the lack of clarity in terms of how to select theory to be tested via hypotheses. Inductive reasoning, on other hand, is criticised because no amount of empirical data will necessarily enable theory-building. Abductive reasoning, as a third alternative, overcomes these weaknesses by adopting a pragmatist perspective.

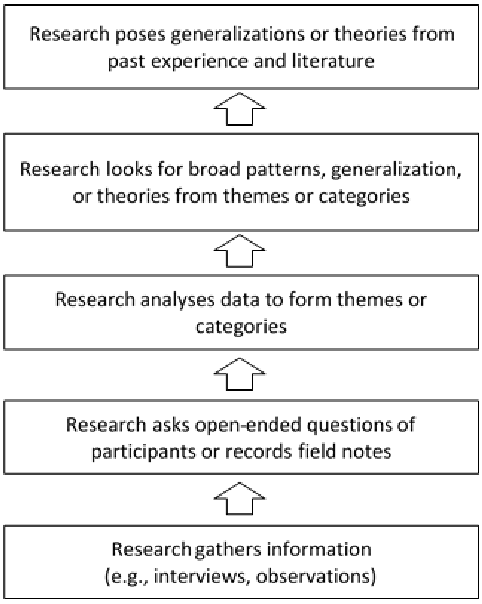


Figure 38: The inductive reasoning in qualitative study (Creswell 2009)

In considering flood management, Niemczynowicz (1999) stated that it is generally accepted that storm water should be attenuated locally. He also confirmed that the process of storm water management should begin on the level of single urban features, like houses, lots, and single streets or one part of large highway system. It is considered more effective to act on storm water sources on the smallest units of urban form where the storm water runoff is first generated. Zevenbergen (2011) referred to the same meaning when he described the association of floods with natural, abnormal, often referred to as extreme, events where its physical characteristics are site specific.

At the same time, it has to be clarified that abductive reasoning is similar to deductive and inductive approaches in the way that it is applied to make logical inferences and construct theories. In an abductive approach, the research process starts with ‘surprising facts’ or ‘puzzles’ and the research process is devoted their explanation. ‘Surprising facts’ or ‘puzzles’ may emerge when a researcher encounters empirical phenomena that cannot be explained by the existing range of theories (Bryman & Bell, 2015). Charles Sanders Peirce, the founder of American pragmatism, was the first philosopher to give to abduction a logical form (Aliseda-LLera, 1997). His discussion of abduction is typically cited as the first attempt to argue that our willingness to infer that hypothesis H is true is based on the judgment that H qualifies as a good explanation of the data that supports it (Campos, 2011). In abductive reasoning, the results of scientific reasoning vary in their degree of novelty and complexity; some discoveries are simple empirical generalisations from observed phenomena, and others are complex scientific theories introducing sweeping new notions (Aliseda-LLera, 1997). Sebeok and Eco, (1983) stated that Peirce showed the differences and relationship between the three reasoning patterns, Table 11. Figure, 39 shows Peirce's triangle.

Deduction	Induction	Abduction
Case: All serious knife wounds result in bleeding.	**Case**: This was a serious knife wound.	**Rule**: All serious knife wounds result in bleeding.
Result: This was a serious knife wound.	**Result**: There was a bleeding.	**Result**: There was a bleeding.
Rule: There was a bleeding.	**Rule**: All serious knife wounds result in bleeding.	**Case**: This was a serious knife wound.

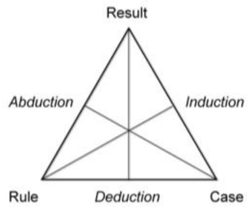


Table 11: Pierce's abduction logic (adapted from Sebeok & Eco, 1983)

Figure39 : Pirrce's triangle

In this research, and according to the nature of the problem, inductive reasoning will be given greater attention in reaching the research objectives. As described in the literature above, a flood is a site specific problem and the best approach to it is to follow a bottom-up trail starting from the smallest observations and ending up with building explanations for the phenomena. Yet, to overcome the drawbacks of applying only inductive reasoning, as mentioned by Saunders, Lewis, and Thornhill (2012), mixed reasoning, or the abduction approach, will be adopted for the research reasoning.

4.5 Research strategy

There are a number of research strategies available, and different authors have classified these strategies in different ways, as follows: experiments, ethnography, case study, survey, and action research. A case study is an in depth analysis of a phenomenon under investigation; case studies are appropriate where the objective is to study the contemporary and where it is not necessary to control behavioural events (Yin, 2009). A case study design should be considered when: (1) the focus of the study is to answer "how" and "why" questions; (2) it is not possible to manipulate the behaviour of those involved in the study; (3) the researcher wants to cover contextual conditions because they believe they are relevant to the phenomenon under study; or (4) the boundaries are not clear between the phenomenon and context (Yin, 2003).

Case studies are a strategy of inquiry in which a researcher explores a program, event, activity or process in depth. Researchers collect detailed information using a variety of data collection procedures over a sustained period of time (Stake, 1995). Merriam (1988) defines case study as an examination of a specific phenomenon, such as an event, person, process, institution, or social group. Creswell (2007, p.73) stated that 'case study research involves the study of an issue, explored through one or more cases within a bounded system'. Flooding disasters tend to be swift and violent. Furthermore, each flooding disaster usually has its own particular features, is non-repetitive, and needs specific measures that correspond to the real situation (Ning, 2006, p 249).

Stake, (1995, p.8) mentioned that 'the real business of a case study is particularisation, not generalisation. A particular case is adopted and the researcher gets to know it well, not primarily as to how it is different from others but what it is, and what it does. There is an emphasis on uniqueness, and that implies knowledge of others that the case is different from; nevertheless, the first emphasis is on understanding the case itself'. Building on the contemporary nature of the flood phenomena described above, and considering the unpredictable nature of its occurrence, flood shape and size is not easily identified, nor bounded with the context of the prone areas. These are the reasons why a case study has been chosen as a research strategy to explore research questions and meet the objectives.

To support this perspective, the research refers to the case study definition as a research strategy. Established by Yin (2009, p.18), a 'case study is an empirical enquiry that investigates a contemporary occurrence within its real life context, especially when boundaries between phenomenon and context are not clearly evident'. Meanwhile, Patton (2003, p.67) defines it as, "the ultimate goal of a case study approach is to uncover pattern, determine meaning, construct conclusion and build a theory".

In order to choose the right strategy, two approaches can be applied to determine the right research strategy; Yin's (2003) three conditions and Sexton's (2004) research philosophical dimension. Yin (2003) establish three conditions that the researcher needs to consider in relation to the research questions, which are: first, the type of research question, second, the extent of control a researcher has over the actual behavioural events, and third, the degree of focus on the contemporary events, as described in Table 12:

Strategy	Form of research question	Requires control of behavioural events?	Focus on contemporary events?
Experiment	**How**, why?	Yes	Yes
Survey	Who, **what**, where, how many, how much?	No	Yes
Archival record	Who, **what**, where, how many, how much?	No	Yes/No
History	**How**, why?	No	No
Case study	**How**, why?	No	Yes

Table 12: Sense of research question (Yin, 2003)

According to the research's (what and how) questions, surveys enriched by a literature review can be used in synthesising the conceptual framework by answering the (what) question, to a stage where the (how) questions can test the conceptual framework into a selective case study. Sexton (2004) explained in his diagram (shown in Figure 40), the relationship between the research philosophy and the research strategies. According the philosophical stance of this research, interpretivism, idealism and value driven denote the study's philosophical position. Hence, experiment and survey are not likely to be applied as long as they are mostly positioned with positivism and realism.

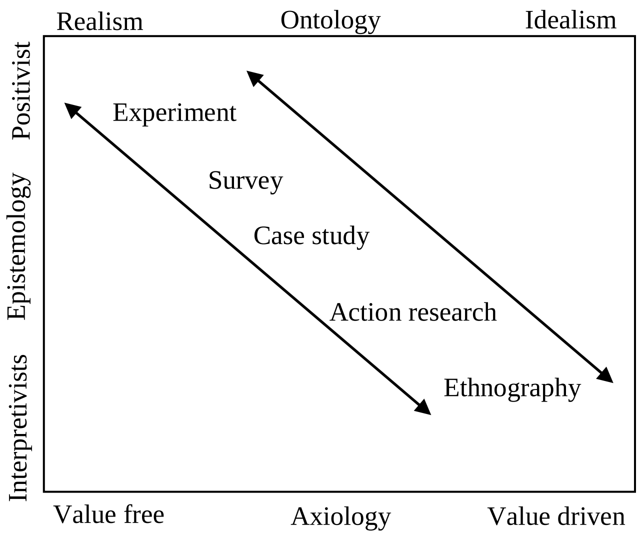


Figure 40: Research philosophical dimension (Sexton, 2004)

The research does not intend to apply changes to the study area, thus, action research will not be an appropriate research strategy. Moreover, ethnography is not appropriate as it involves investigating behaviours, languages and beliefs (Creswell, 2007). Therefore, a case study was determined as the most appropriate research strategy for this study.

4.5.1 Case study design

Yin (2009) defined research design as the logic that links data to be collected to the initial questions of the study. The design consists of components of questions, propositions, units of analysis, linking data to propositions, and the criteria for interpreting the results. Creswell (2009, p.3) also defined research design as plans and procedures that span the decisions from broad assumptions to detailed methods of data collection and analysis. Yin (2003) asserted that case study can be classified into four types: single or multiple, and in terms of the unit of analysis, holistic or embedded. A single case study is conducted if the case under consideration is: (1) a critical case, (2) representing extreme or unique phenomena, (3) a revelatory case.

Baxter (2008, p.550) asserts that, 'in a multiple case study, we are examining several cases to understand the similarities and differences between the cases'. Multiple case studies can be used to either, '(1) predict similar results (a literal replication) or (2) predict contrasting results but for predictable reasons (a theoretical replication)' (Yin, 2003, p.47). Creswell (2007) answered the question of 'how many cases' with the response that there is not a set number; typically, however, the researcher chooses no more than four or five. Often the inquirer purposefully selects multiple cases to show different perspectives on the issue.

Stake, (1995) differentiates also, according to design, between three types of case study, namely: single instrumental, collective and intrinsic case study. In the single instrumental case, the researcher focuses on one issue of concern in a bounded context, while in the collective case study there is one issue of concern but the inquirer selects multiple case studies to illustrate the issue. The intrinsic case is a unique manifestation and can only be studied in its context. In this research, the choice will be a multiple holistic case study, (shown in Figure 41). This is because the phenomena of pluvial flooding in urban area is not a critical or unique situation, and there is only one unit of analysis that will be investigated in order to reveal the role of urban design in mitigating the pluvial flooding impact. Also, from the perspective of Stake (1995), the case can be seen as a collective case study.

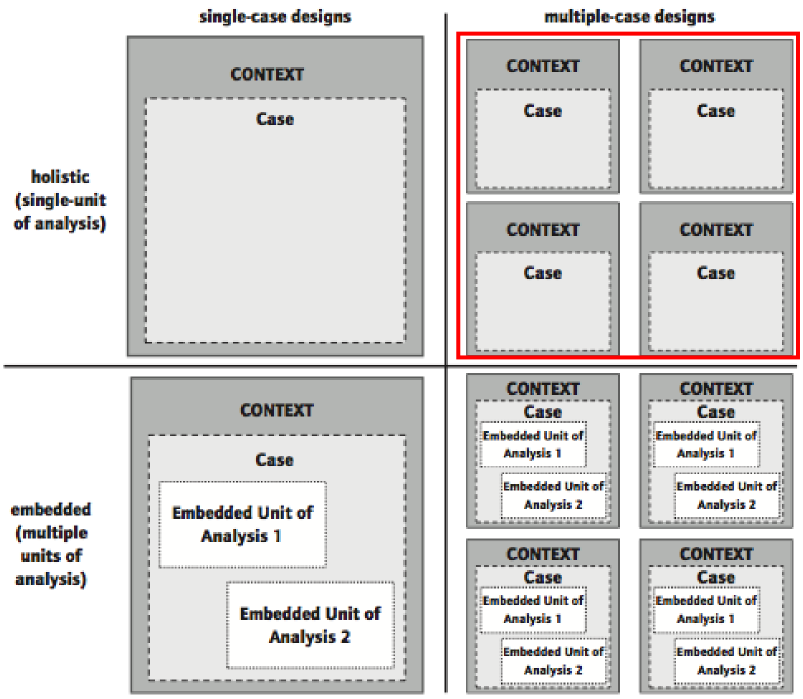


Figure 41: Basic types of design for case studies (Yin, 2009)

There are two distinctive manifestations of terrestrial ecology in the study area (Muscat city) upon which pluvial floods have produced different courses of occurrence. Accordingly, there will be two areas to be investigated as multiple holistic cases in respect to the two dominant ecological features in the study area represented. These areas are mountainous ecology and hilly ecology.

4.5.2 Unit of analysis

Baxter (2008) argues that, while considering what a research question will be, a researcher must also consider what the case is, and determining the unit of analysis (case) can be a challenge. The case is defined by Miles and Huberman (1994, p.25) as ‘a phenomenon of some sort of occurring in a bounded context. The case is, “in effect, your unit of analysis’. Yin (2009) asserts that unit of analysis is governed by the research question in a study and it is advisable to define the unit of analysis as similar to the previous studies, in the context of cases, or when it serves a revelatory or longitudinal purpose.

According to Creswell (2007, p.78) “the unit of analysis is studying an event, a program, an activity, more than one individual”. Patton (2002, p.447) asserted that “cases are units of analysis, what constitute a case or unit of analysis, is usually determined during the design stage and become the basis for purposeful sampling in qualitative inquiry”. The unit of analysis in this research will be the (resilient generated morphology), as the research will carry on a holistic multiple case study design. Data will be collected about the generated morphology in the two cases under investigation identifying the resilient status; moreover, data will be analysed and interpreted to examine the cohesion between the ecological and the built on influencing a resilient urban design to pluvial floods.

4.5.3 Case study selection

The study will investigate the case of pluvial floods in Muscat city, where the researcher has lived and worked in the field of urban infrastructure for ten years. The researcher has thus closely watched the recurrence of this phenomena in Muscat city specifically and whole regions of Oman in general, having day by day experience with the merely effective effort spent to govern the consequences of pluvial floods through the engineered solutions of flood control.

Sandelowski (1986) observed that subjects in qualitative studies are initially selected because they can illuminate the phenomenon being studied. The two case study areas were selected purposefully. Patton (2002) explained that the reason why purposeful sampling is chosen is to ensure the selection of information-rich cases whose study will illuminate the research questions. Selecting purposefully allow the inquiry to build an in depth understanding of the phenomena. Indeed, information-rich cases are those from which one can learn a great deal about issues of central importance. Stake (1995) listed the criteria upon which a case study selection will lead to maximum knowledge gain; this includes: the understanding, the modifying of generalisations, the hospitality of the case to the designed inquiry, the actors willing to comment on the case, and also the uniqueness and the context of the alternative selection, which should be well thought-out. As previously mentioned, there are two distinctive manifestations of terrestrial ecology in the study area (Muscat city) upon which pluvial floods produce different courses of occurrence in the event of heavy rain fall. Accordingly, two areas with distinctive ecological features will be investigated as multiple holistic cases, characterising them as follows, Figure 42.

1- Wadi Adi: catchment as a mountainous ecology, blue boundary.

2- Bowsher: catchment as semi-flat ecology, red boundary.

Figure 42: The two selected case study areas (SCP)

4.6 Data collection

Creswell, (2007) argued that qualitatively oriented research tends to collect data in the field at the site where participants' experience the issue or problem under study. In the natural setting, the researcher has face-to-face interaction over time. This up-close information gathered from participants in their actual context is a major characteristic of qualitative research. Richards (2010) mentioned that the situation in qualitative study is likely to be complex, and the complexity of the record cannot be reduced until researcher recognises that valuable information is about to be lost by simplification. The situation has to be understood in its context so the record must retain the context. Otherwise, there will be a risk of losing some understanding of the issue under study. Qualitative data are records of observations or interactions that are complex and contextual, and they are not easily reduced to numbers.

As interpretive paradigms cuts across a number of disciplines and areas of application, there is also plenty of room to use many different research methods (Willis, 2007). Creswell (2007) also stated that quantitative data is not exclusive to quantitative research; qualitative researchers might use quantitative data, as can be the case for quantitative research. In the same context, Patton (2002) confirmed that qualitative data can be collected in experimental design; likewise, some quantitative data may be collected in naturalistic inquiry approaches. In the same perspective, Willis (2007) stated that quantitative research use numbers as data, whereas qualitative research does not. In fact, this is not true, as number-based research methods often are used by qualitative researchers, and a growing number of quantitative researchers used qualitative data.

Accordingly, both qualitative and quantitative forms of data will be collected in this research, although the research is not following an abduction approach. Quantitative data will be used in one of the methods to validate qualitative findings (details in the validation section). Figure 43 exhibits how the data are generally analysed in the qualitative enquiry.

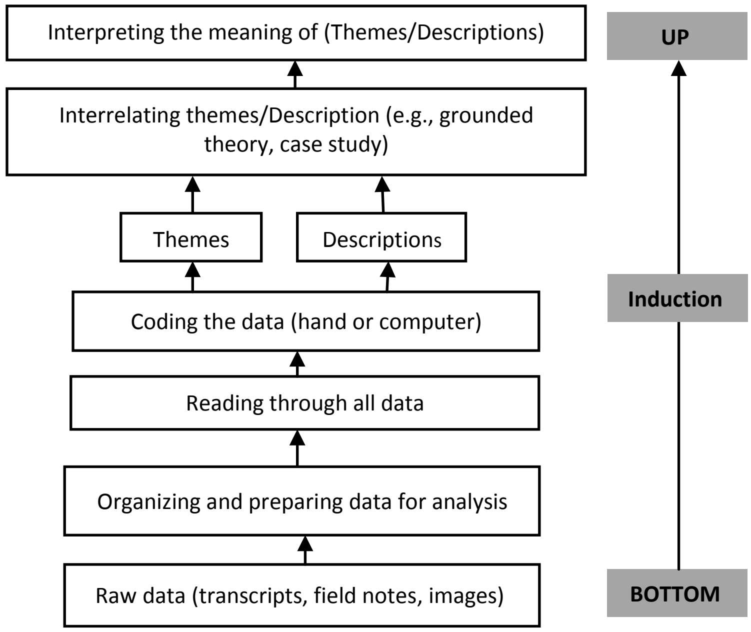


Figure 43: Data analysis in qualitative research (adapted from Creswell, 2009)

4.6.1 Maintaining access to data

In the data collection phase, a researcher must not consider all data about the case, but rather what they have access to (Gamseon, 2016). Although individuals often immediately comply if a superior has granted permission, a brief written description of the intended casework should be offered (Stake, 1995). Moreover, Creswell (2007) referred to the challenges associated with gaining access to organisations, sites, and individuals to study. Convincing individuals to participate in the study, building trust and credibility at the field site, and getting people from a site to respond are all important access challenges. Stake (1995, p.59) also mentioned that; "an opportunity should be taken early to get acquainted with the people, the space, the schedules and the problems of the case. With most studies, there is a hurry to get started, yet a quiet entry is highly desirable". The process of getting access to research data with the experienced challenges explained in detail in appendix-1.

4.6.2 Primary Data collection

Willis (2007) described interviews and questioning as the primary means of obtaining data to achieve the understanding of a meaning a conscious person has developed and not necessarily about an external reality itself. The interview coordinates a conversation aimed at obtaining required information. It is about promoting dialogue rather than interrogation (Gubrium & Holstein, 2003). Stake (1995) referred to the importance of collecting live experience from actors in the field, and hearing their stories; researchers are usually interested in those actors for both their uniqueness and commonality. Researchers must approach them with a sincere interest in learning how they function in their ordinary pursuits and put aside many presumptions. Patton (2002) also referred to this fact when describing qualitative data by capturing and communicating someone else's experience of the world in the participant's own words. Creswell (2007, p.173) confirmed that “the researcher role in an interview is to record meaning that the participants hold about the problem not the other way around”.

According to Yin (2003), data for case studies may come from many sources, but Yin identifies six important sources of data collection that are widely used: Documentation, archival records, interviews, direct observations, participant observations, and physical artefacts. Willis (2007, p.125) stated that; “an interpretive approach, could involve data such as diaries, journals, debriefings, interviews, textual analysis, reflections, and much more”. However, Creswell (2007) relies on four basic types of information in qualitative research, and they are: interviews, observations, documents, and audio visual materials. Meanwhile, Stake, (1995, p.64) also drew attention to the significance of the interview by saying; “there are two principal uses of case study are to obtain the descriptions and interpretations of others. Qualitative researchers take pride in discovering and portraying the multiple views of the case as the interview is the main road to multiple realities”. Hence, semi-structured interviews will be conducted and transcribed as the research primary data.

4.6.2.1 Potential interviewees

With respect to the philosophical stance of this study, namely interpretivism, and its engagement with a contextual inductive approach as its dominated methodological choice, this study will interview experts to collect primary data. Becker, (2012) argued that; how many qualitative interviews is enough? Every experienced researcher knows this question has no reasonable answer, no magic number you can do and then you’re out of danger. The only possible answer is to have enough interviews to say what you think is true and not to say things you don't have that number for. The kinds of things you might want to say take a lot of forms and so require varying numbers of interviews. Baker and Edwards (2012, p.5) stated that; "there is no ideal number of interviews determined and it depends on what one wants to obtain". Some authors determine an adequate number of interviews; for example, Adler and Adler, (2012) advice graduate students to sample between 12 and 60, with 30 being the mean. Ragin and Becker, (1992) suggested that a glib answer is '20 for an M.A. thesis and 50 for a Ph.D. dissertation.

This study is seeking qualitative information about efficient measurements in the urban design discipline to address the problem of pluvial floods. Hence, a group of experts that have around 15 years experience in the field will be approached. Hierarchically speaking, those experts were informing decision makers and been informed by other consultants, junior staff, analytical tools and software on their institutions. An initial supposition was made to address public and private bodies to seek relevant expertise. Those bodies were distributed between four Ministries and two private consultancy companies.

Discussions with the team formed to assist the researcher emphasised that the participants selection process should built on their years of experience, and the specialisation that requires enough knowledge of planning and disaster management.

4.6.2.2 Reviewing and revising the total population of potential interviewees.

Further discussion with the supporting team work (mentioned in Appendix-2) yielded special attention to the importance of diversifying the population of interviewees, having the selection based on different professional orientations, the classification of the interviewees was broadened to include academia along with the predetermined governmental and private sectors. Suggestion to include the main university was made to check for relevant experts' availability to the research topic. However, when approaching the suggested bodies, a total of 16 candidates were found to have relevant experience to take part in the research. They were distributed as; six from the public sector, six from the private sector and four from the university. Accordingly, the total population of 16 candidates originated from three major orientations, Table 13, was chosen and their consents were taken. Eight candidates were interviewed on each case study. Tables 16 and 18 (Chapter-5) shows the orientation, qualification and job titles of the interviewed candidates.

	Governmental sector	Private sector	Academia
1	Supreme Counsel of Planning	Consultancy company (Infrastructure)	University of Sultan Qaboos
2	Muscat Municipality	Consultancy company (rods, bridges & dams)	
3	Ministry Of Regional Municipalities And Water Resources		
4	Ministry Of Housing		

Table 13: Interviewees' orientations

4.6.2.3 Managing semi structured interviews

This part of data collection concerns real time primary data taken about the phenomena from the field through interviewing key candidates with relevant experience in flood management and planning. This section will explain the interview protocol, construction and analysis along with the potential interviewees and their profiles. Most qualitative research is based on interviews. There are good reasons for this; the researcher can reach areas of reality that would otherwise remain inaccessible, such as people's subjective experiences and attitudes. The interview is also a convenient way of overcoming distances, both in space and time; past events or faraway experiences can be studied by interviewing people who took part in them (Perakyla & Ruusuvuori, 2011, p.529).

Creswell (2007) referred to one-on-one interviewing, stating that the researcher needs individuals who are not hesitant to speak and share ideas, and needs to determine a setting in which this is possible. Likewise, Willis (2007, p.139) confirmed that, 'the method used in interpretive research may be structured, very open, or semi-structured'. Creswell (2007) confirmed that the 'researcher in [a] qualitative study tries to minimize the "distance" or the "objective separateness" from the case being studied and the more he prolongs staying in the field, the better. Also, language [is] used [to] become personal, literary, and based on definitions that evolve during a study rather than being defined by the researcher. Seldom does one see an extensive "definition of terms" section in [a] qualitative study, because the terms, as defined by participants, are of primary importance.

Patton, (2002, p.353) confirmed that qualitative inquiry, strategically, philosophically, and therefore methodologically, aims to minimise the imposition of predetermined responses when gathering data. Thus, it follows that the questions should be asked in a truly open-ended fashion so people can respond in their own words. In the entire qualitative research process, researchers keep a focus on learning the meaning that the participants hold about the problem under study, not the meaning that the researcher brings to the research (Creswell, 2007). Language used in interviews, is a little more than a medium or transparent system which conveys messages from one mind to another (Willis, 2007).

An interview process should follow a certain protocol; Creswell (2009) addressed the protocol to include the following component: A heading (date, place, interviewer, and interviewee) / Instruction for the interviewer to follow so that standard procedures are used from one interview to another / The questions (typically an ice-breaking question at the beginning followed by 4-5 questions that are often the sub-questions in a qualitative research plan, followed by some concluding statement or a question, such as, ‘Who should I visit with to learn more about my questions / Probes for the 4-5 questions to follow up and ask individuals to explain their ideas in more details or to elaborate on what they have said / Space between the questions to record responses /A final thank-you statement to acknowledge the time the interviewee spend during the interview. The interview transcript will be made available for participant to review, comment on and to decide whether to remove some answers due to liability or inconsistency. This reflects on the rigour of the collected data and adds value to the overall validity of data collection process.

4.6.3 Secondary and quantitative data collection

May, (2011) stated that documents allow comparisons to be made between the observer’s interpretations of events and those recorded in documents relating to those events. They can tell us a lot about the way in which events are constructed. Patton (2002) argued that governments, nonprofit agencies, and private organisations produce massive amounts of files and reports; there are some challenges in analysing documents, including the following:

- Getting access to documents.
- Understanding how and why the document was produced.
- Determining the accuracy of the documents.
- Linking the documents with other sources, including interviews and observations.
- Deconstructing and demystifying institutional text.

Applying the quality check proposed by Scott (1990) helped to eliminate some of Patton’s concerns. This aims to check the quality of secondary source of data, including the government documents and reports (addressed in table 30, Chapter 7).

Documents, like archival data, government reports consultancy studies and metrological data bases among other forms of documentation will be used to support the primary data gained from the interviews. During the researcher’s second visit to the study area (Appendix-2), some of the secondary and other quantitative data in the form of government reports, consultancy studies, maps and geo-referenced images, were obtained from different authorities. These data sets include, but not limited to, the following:

- Consultancy services for Muscat area drainage study-2011-Final Report.
- Al-Amerat heights Flood Protection Dam-In Case study-1.
- Approved governmental plans and programs for urban water drainage networks.
- A total of (91) Governmental report, damage-repair projects by type and cost, cyclone Gonu 2007.
- A total of (51) Governmental report, damage-repair projects by type and cost, cyclone Fiet 2010.
- Muscat natural stream map, scale 1:1200.
- Consultancy study for the national strategic master plan.
- Digital elevation module (DEM) files for the two studies area catchments of 0.5m horizontal accuracy and 0.2m vertical accuracy.
- Air born Aerial photo of 0.5m horizontal accuracy.

4.7 Data analysis

Qualitative researchers make an interpretation of what they find; this is an interpretation shaped by their own experience and background. The researcher's intent, then, is to make sense (or interpret) the meanings others have about the world. This is why qualitative research is often called 'interpretive' research (Creswell, 2007). Interpretivists believe an understanding of the context in which any form of research conducted is critical to the interpretation of the data gathered (Willis, 2007, p.97).

Stake (1995) stated that qualitative researchers emphasise placing an interpreter in the field to observe the workings of the case, one who records objectively what is happening, examines its meaning and redirects observations to refine or substantiate meanings. Initial research questions may be modified or even replaced mid-study by the researcher. If early questions are not working, or if new issues become apparent, the design is changed. Parlett and Hamilton, (1972) called this process progressive focusing, during the data analysis; the researcher follows a path of analysing the data to develop an increasingly detailed knowledge of the topic being studied. This question of interpreting data in context highlights the concern that interpretivists have about the "situatedness" of knowledge. Thus, the goal of interpretive research is an understanding of a particular situation or context much more than the discovery of universal laws or rules (Willis, 2007, p.99). Similarly, Denzin and Lincoln, (2013) stated that; behind and within the phases of a qualitative study, stands the biographically "situated" researcher.

Erickson claimed that the primary characteristic of qualitative research is the centrality of interpretation (Erickson, 1986). Qualitative researchers build their patterns, categories, and themes from the "bottom-up", by organising the data into increasingly more abstract units of information. This inductive process involves a researcher working back and forth between the themes and the database until they establish a comprehensive set of themes. It may also involve collaborating with the participants, so that they have a chance to shape the themes or abstractions that emerge from the process (Creswell, 2007). Patton (2002) also confirmed this when stating: 'Qualitative interpretation begins with elucidating meanings. The analyst examines a story, case study, a set of interviews, or a collection of field notes and asks, what does this mean? What does this tell me about the nature of the phenomena of interest? In asking these questions, the analyst works back and forth between the data and his own perspective or understanding to make sense of the evidence.' Representing data in qualitative research can be partly based on a researcher's perspective and partly based on researcher's interpretation, never clearly escaping researcher personal stamp on a study (Creswell, 2007).

In this research, two distinguished case studies in two characteristically different sites have been purposefully selected; the aim of this is to better represent the diverse contexts of the pluvial flood problem in the area of interest, and the analysis of these case studies will follow the two strategies, verified by Creswell (2007) as: *within-case-analysis*, where a detailed description of each case will be presented, followed by *cross-case-analysis*, which is a thematic analysis across the cases, as well as assertions or an interpretation of the meaning of the case. Yin (2003) asserted that the cross-case synthesis is an analytical technique when the researcher studies two or more cases.

4.7.1 Coding

Coding is the process of organising the material into chunks or segments of text before bringing meaning to information. The interpretation will start with a coding process, and in all qualitative research, the goal of coding is to gather everything about a topic or analytical concept, in order to review and refine thinking about this category (Richards, 2010, p.107). Richards distinguished between three types of coding;

- Descriptive codes.
- Topic codes, and
- Analytical codes.

Richards (2010) also argued that most studies use all three, and two are qualitative tools in the sense that they are an interpretive process. Descriptive coding is more like quantitative coding, whilst topic and analytical coding are more qualitative. Topic coding occurs at the start of qualitative coding, labelling text according to its subject; it can be automated with software. Analytical coding is central to qualitative inquiry; it is difficult to be automated with software as it is more about interpretation. Richards also mentioned that, while topic coding may be a first step to more interpretive work, well-handled analytical coding is a prime way of creating conceptual categories and gathering the data needed to explore them.

Goetz and Le Compte (1984) described the conceptual basis for reducing and condensing data in this ongoing style as the study progresses. They stated that researchers compare, aggregate, contrast, sort, and order data. They describe the analytic procedures researchers use to determine what the data mean. These procedures involve looking for patterns, links, and relationships. A qualitative researcher engages in speculation while looking for meaning in data, and look more deeply for new patterns in this "recursive" process.

Bogdan and Biklen (1992) describe in detail the practical approaches to writing up field notes; one of the main forms that qualitative data take is "words”. They recommend writing field notes with large margins in order to write later notes when analysing the data, and also to write codes for these data. They also listed a possible set of codes:

- Setting and context codes.
- Perspectives held by subjects.
- Subjects’ ways of thinking about people and objects.
- Process codes.
- Activity codes.
- Strategy codes.
- Relationship and social structure codes.
- Pre-assigned coding scheme.

Creswell (2009) encouraged researchers to analyse their data for material that addresses the following codes:

- Codes on topics that readers would expect to find, based on the past literature and common sense.
- Codes those are surprising and not anticipated at the beginning of the study.
- Codes that are unusual and of conceptual interest to readers.
- Codes that address a larger theoretical perspective in the research.

Even though all the coding ways mentioned might seem plausible, the research was yet to properly collect the data for coding from the interviews. At this stage, it was early to decide before having the rich material of interviews transcripts; nevertheless, the author developed a classification for the way codes will be looked at from different perspectives, as shown in Table 14:

Types of codes	**Types of coding**	**Interpretive power**	**Spontaneity**	**Processing**
Expected	Open coding	Topical	Emerged	Software-aided coding
Surprising	Axial coding			
Unusual	Selective coding	Analytical	Predetermined	manual coding
Of higher philosophical influence				

Table 14: Codes classification

One further issue about coding that Creswell (2009, p.187) mentioned was whether the researcher should: (a) develop codes only on the basis of emerging information collected from participants, (b) use predetermined codes and then fit the data to them, or (c) use a combination of predetermined and emerging codes. In multiple case studies, and to illustrate the pre-code specification, for each case, codes exist for the context and description of the case. Also, codes can be advanced for themes within each case, and for themes that are similar and different in the cross-case analysis. Finally, codes will be included for assertion and generalisation across all cases. The process is explained in the template in Figure 44 (Creswell, 2007, p. 173).

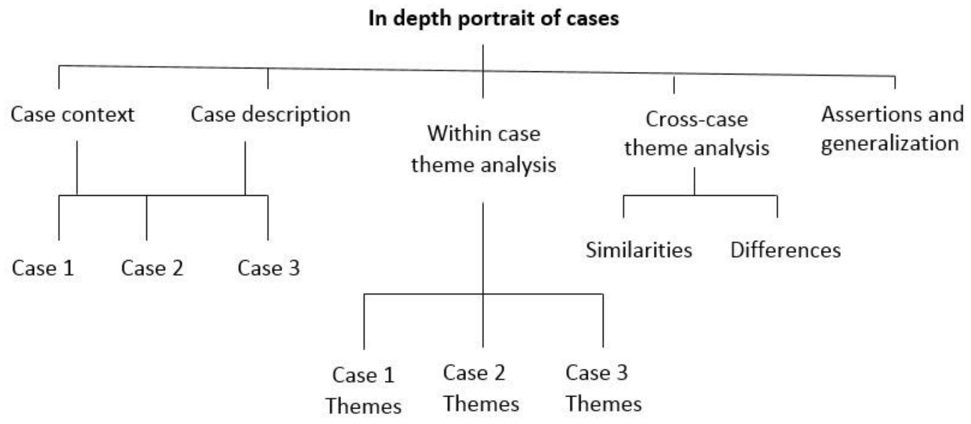


Figure 44: within & cross-case analysis   (Creswell, 2007)

4.7.2 Software coding

The software does not reflect on the meaning of the text, it is searching for the words mathematically (Richards, 2010). Software coding locates common passages or segments that relate to two or more codes labels. It also compares between code labels and helps the researcher to conceptualise different levels of abstraction in qualitative data analysis (Creswell, 2007). Computers and software are tools that assist analysis; however, software does not really analyse qualitative data. Software facilitates data storage, coding, comparing, retrieval, and linking, while the analysis is a human construct (Patton, 2002).

Auto coding will inevitably will make some weird errors, and as such, researchers must always keep a note that this coding was done mechanically. While it is common to conduct topic coding through software, analytical coding is central to qualitative inquiry; it is difficult to automate with software as it is more about interpretation. Coding was always a trap to researcher, but its danger is far greater with software (Richards, 2010). In general, some researchers have found it useful to hand-code qualitative transcripts or information, sometimes using a colour code scheme and cutting and pasting text segments onto note cards (Creswell, 2009). Patton (2002) confirmed that the analysis of qualitative data involves creativity, intellectual discipline, analytical rigor, and great deal of hard work. Accordingly, in this research, the use of software coding will be conducted to extract topic coding and for other comparison purposes, analytical codes will emerge following author’s experience and creativity and/or with respect to peer review.

4.8 Pilot study and initial findings

Three pilot interviews were conducted to test the clarity of research question and construct a preliminary content analysis. Pilot interviews were audio recorded and transcribed and the full texts were analysed and coded through the qualitative analysis software QSR Nvivo 10. A number of themes were identified from the research six questions. These themes yielded a set of codes and sub-themes that yielded in return a set of sub-codes (child codes). Two of these three pilot interviews were analysed. The full content analysis for the two interviews is displayed in Appendix 6, whilst the Table 14 shows the brief coding results derived from interview 1. Although three pilot interviews were conduct out of which two were analysed, yet it was a very beneficial process to experience the interview process with candidates, get feedback on the research questions, conduct the preliminary content analyses, and experience software coding through the SQR Nvivo 10 software.

As experienced in the literature, the code recurrence in the interview transcriptions were starting after having analysed 30 to 40% of the collected data, while the data richness will not be achieved until 60 to 70% of the interviews' transcriptions are analysed. In this case, the conducted analysis will not be taken to the level of final code list realisation or cross case synthesis, but its usefulness will reveal the potential process to be followed to conduct the full interview analysis and yield an initial list of codes. Table 15 briefly outlines the initial coding analysis findings for candidate A1. In the Table, the flow of the analysis starts from the major themes determined from the research questions to the code elicitation from interviewees' responses. The recurrence of some concepts, identified as sub-themes, and further coding for those sub-themes in Nvivo software yields some sub-codes (child codes).

Theme	Codes	Sub-theme	Sub-Codes	Candidates Quotes
Theme 1 Urban design unit	Space-Mass ratio			If we allow sufficient urban space appropriate with surrounding topography at the end this space will accommodate the flow of people, vehicles and even surface water runoff resulted from rain fall.
	people, vehicles & water flow			
	urban space-water flow direction			
	building, plot & street elevations			
	linking safe spaces			
	land use-occupants allocation			
Theme 2 Physical nexus urban-natural features	elevations variation			
	consider distinctive topography			
	delineation of inundation areas			
	Flow directions			
	delineation dry-well drained areas			
		Low-lands	space-mass ratio	It comes to mind that it is probable to consider vertical expansion rather than horizontal to reduce the intensity of the building mass for the favor of the urban space to allow safe transfer for the surface water to lower areas or to water channels and to accumulate within the urban areas and gain height.
			vertical expansion	
			mass intensity	
			surface sealing	
Theme 3 Accessibility	elevation's design-urban unit			We can consider linking elevated areas in a way that constitutes a network of pathways for people and even small vehicles to function somehow like emergency network for accessibility during surface runoff circumstances.
	elevation's variation-safer levels			
	linking safe places			
	pathways network			
	emergency pathway network			
	linking safely elevated featured			
Theme 4 Redundancy	feature's occupancy nature			In normal cases all places occupied with permanent residents like residential areas or hospitals are more prone to danger in cases of natural events, and these should be prioritize in considering safer urban design.
	permanent occupancy			
	alternating occupancy-impermanent			
	evacuation difficulty-permanent occupancy			
	priority for land use			
	allocating vulnerable occupant			
	vast areas-low occupancy rate			
	reconsidering multi functionality for redunded features			
		Inundated areas	runoff transfer	urban features can act as part of the drainage infrastructure but on contemporary basis, also a civil design might considered in these features to support this purpose, I think this going to be extraordinarily helpful in mitigating the runoff consequences.
			function as temporal urban drainage system	
			function as temporal runoff pathways	
			linkages with wetlands	
			ease the discharge of surface drainage network	
			shift function	
		Vast areas-low occupancy rate	minimum accessibility by adjusting elevations	activities that required vast areas of land and relatively less numbers of users like for instant storage buildings and can be protected from surface runoff by elevating entrances levels and floors to higher than the expected levels of runoff.
Theme 5 Tolerance	land use type			And like that the more the space is tolerable to the minimum level of accessibility the more it will be resilient to runoff exposure in terms of depth and the period.
	vast areas-low occupancy rate			
	minimum required accessibility			
	minimum required accessibility			

Table 15: Content analysis - Candidate A1

4.9 Summary

This chapter presented the research methodology adopted, which involved a mixed method approach where qualitative and quantitative methods were used sequentially. The quantitative complements and strengthens the dominant qualitative approach. The position of research on the epistemological, ontological and toxicological philosophies was also explained; the study adopted abduction reasoning, which was linked to the mixed method research approach where both induction and deduction is followed across the exploratory, sequential mixed method approach.

Data collection sources were varied from semi-structured interviews to focus groups and the Delphi study as primary source of data, whilst other (secondary) data included government documents and consultancy studies. These came together with the quantitative data collection of geo-data sets that include geo-referenced images, urban characteristic shape files, digital elevation models, and rain gage readings and natural stream flows.

The content analysis and coding were also explained, and a pilot study carried out at earlier stages during the research journey to explore participants' initial reflection on the research questions. It was also a convenient opportunity to practice the content analysis and develop an initial set of themes, codes and sub codes. Those were developed in the final analysis into themes, areas, factors and influential variables.

Chapter 5: Data analysis and findings

5.1 Section 1: Within-case analysis: CS-1 Wadi Adi catchment

5.1.1 Introduction:

This section displays the primary data analysis gained from the insights of face-to-face semi-structured interviews. The section will introduce the within-case analysis of the first case study within the Wadi-Adi catchment, which will be referred to as CS-1. After this introduction, a brief description of the data sources will be presented, a description of the catchment area under study will follow, and finally, the content analysis and findings from the interviews will be provided. This will be followed by case study two's within case analysis, and a cross case synthesis; finally, the instrumental framework will be presented.

A number of themes were developed from the interview questions. These themes formed the basis for the discussions during the interviews. The themes represented the broader areas developed from the literature review, earlier addressed in chapter-3 as resilience theoretical framework that guides the inquiry. Meanwhile, the lead questions and sub questions ordered so to obtain specific information within these broader areas. The interview questions were developed after carrying out an in-depth literature review and further discussion with the researcher's supervisory panel.

5.1.2 Explaining the data

All the participants were categorised according to their professional orientation, and the three main domains explained all participants' backgrounds; Government sector (G), private sector (P) and the academic sector (A), shown in Table 16. A total of sixteen participants were interviewed across the two case studies, eight for each case study, three from the government sector, three from the private sector, and two from the academic sector.

No.	Candidates	Orientation	Qualifications	Job title
1	G1	Government	BSc. Surveying. MSc. Urban planning. PhD. Urban planning	Urban planning consultant
2	P1	Private	BSc. Architecture. MSc. Architecture. PhD. Urban planning	Urban planning consultant
3	G2	Government	BSc. Civil engineering. MSc. Project management	Land use management & compensations consultant
4	G3	Government	BSc. Urban spatial data management	Ministry advisor
5	A1	Academia	BSc. Civil engineering. MSc. Project management. PhD. Flood risk management	University Professor
6	A2	Academia	BSc. Architecture. MSc. Architecture. PhD. Urban planning	University Professor
7	P2	Private	BSc. Hydraulic engineering	Urban hydrologist
8	P3	Private	BSc. Civil engineering. MSc. project management	Project manager

Table16 : participants list

5.1.3 Case study area – Wadi Adi catchment-CS-1

In CS-1, the research will investigate the case of pluvial floods, where the researcher had lived and worked in the field of urban infrastructure for ten years. The researcher closely watched the recurrence of this phenomenon in Muscat city specifically and the whole region of Oman in general. The researcher's experience of effort spent in governing pluvial floods helped a lot in shaping a better understanding of the problem. Sandelowski (1986) observed that subjects in qualitative studies are initially selected because they can illuminate the phenomenon being studied. Patton (2002) explained that the reason why purposeful sampling is chosen is to select information-rich cases whose study will illuminate the questions under investigation. This means selecting purposefully, and authorising the inquiry into an in depth understanding of the phenomena. Information-rich cases are those from which one can learn a great deal about issues of central importance.

Stake (1995) listed the criteria upon which a case study selection will lead to the maximum knowledge gained from the case under investigation, and these are; the understanding, modifying of generalisations, the hospitality of the case to the designed inquiry, actors willing to comment on the case, and the uniqueness and context of the alternative selection, which should be well thought out. Hence, for reasons discussed above, the two case study areas were selected. As mentioned earlier, there are two distinctive manifestations of terrestrial ecology in the study area (Muscat city) upon which pluvial floods produce different courses of occurrence. These two dominating geo-morphological settings are mountainous ecology and the semi-flat hilly areas. Therefore, the two ecological settings were investigated as multiple holistic cases.

The second reason for the implementation of purposeful sampling of the two case study areas is that; the two selected locations are flood-prone zones. They witness at least one flood inundation event each year, which is affected by short intense rain fall. The first case study area studied in this chapter is the Wadi-Adi catchment, shown in Figure 45. This area has suffered from frequent floods over the last fifteen years, and many infrastructure projects were started in the area to prevent flood consequences, but the problem reoccurred as no adequate solution was presented. Most of the participants interviewed for this case were well aware of the area and the public sector infrastructure projects implemented to overcome the associated flood problems.

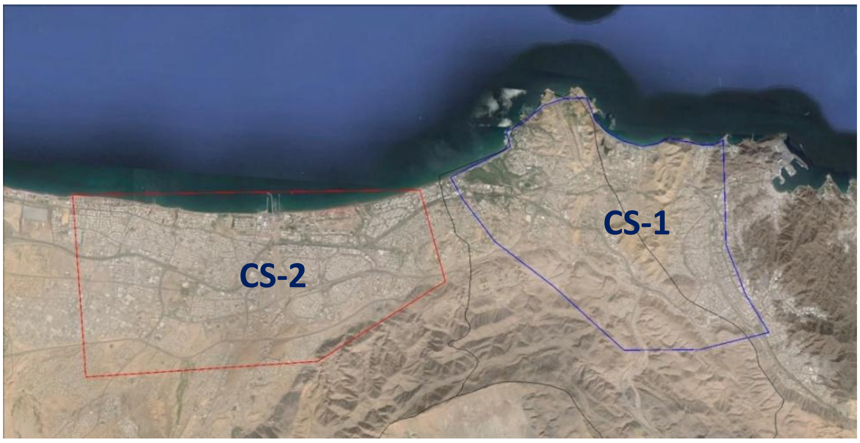


Figure 45: Wadi Adi catchment

5.1.4 Data analysis

5.1.4.1Theme 1: Urban design unit

This theme explores the first question, and a number of sub questions emerged from the discussion with the interviewees. It was set to identify the role and involvement of the urban design morphological unit in mitigating runoff. The main and sub questions were asked in order to gain an understanding of the level of engagement of the physical aspect of urban design in the long term process of realising a resilient urban form to pluvial floods, by moving inductively bottom-up from the smallest component of the urban form.

The level of awareness reflected from the initial participants' insights was good. This was experienced due to the fact that there was a common dissatisfaction about the conventional measures of flood control, and other inappropriately urban expansions. Most of the participants gave their insights on the three morphological levels of (plot, building and street) two of whom believed that there is a little to be done on the plot-building level.

5.1.4.2 Plot idealisation

The concern of plot idealisation was raised by most participants, and the first thing that the participants drew attention to was the plot area, dimension and plot cluster in forming the final, two-dimensional space-building boundary relationship, the participants referred to the area allocated for residential uses. It was recommended that 60% of the plot area - according to current planning rules - should be left open, to be under the *municipality authorisation* in terms of the type of *fencing* and *surface sealing*. These two factors, along with the type of *plot cluster*, will recalibrate the ratio of the open space and allow for more water to penetrate the ground and evaporate. It will also allow water to flow in each area to the urban drainage network or to the natural streams without generating a considerable runoff in terms of depth and velocity. These two aspects were referred to by one of the participants as the *vertical permeability* and the *horizontal permeability* of rain water. One of the participants stated:

In your area you can go further in eliminating the barriers by leaving the ground floor for the parking spaces only this can make the city structure more hollow like and penetrable for the water and its better than contain water between building and fences, consequently increasing its depth and speed of flow in some cases.

5.1.4.3 Building - space ratio

The allocation of the *building mass within the plot boundaries* was the first issue identified by most of the participants; this is the building allocation inside the plot, the physical setup in which the plot-building relate to the street, and will all construct the overall building-space configuration on the urban block and on the broader image of the city as whole. The configuration of the urban space driven from the single unit of plot, building and street will create *paths of flow*, not only for water, but for ventilation pedestrian and automobiles.

The *building mass-space ratio* yields three important factors, firstly, the *within plot ratio* stimulated from the location and the percentage of the building within the plot area and how this is going to be reflected on the general scene of an urban block or a city sector,; secondly, the *within block ratio,* which is dependent on the lower previous level of the plot ratio. The third factor is the *building space order,* namely the way building-open spaces relate to each other creating a certain form - typology - of open spaces that allow the flow of not only the runoff water, but, also people, resources and automobiles.

5.1.4.4 Level enabled design

The general consensus on this character was obtained, specifically, in the way it influences the general performance of the urban form in mitigating surface runoff. Most of the participants referred to one mode of physical setup for this characteristic when the street will be the lowest point and the right of way has to be a little higher moving up to the plot level and the building entrance to reach the highest level in this *micro level*. One participant suggested another setting where the *right of way* and the *separate island* between the two directions of the dual carriage way are at the lowest point, or even the service roads on both sides of the main road.

This setting exemplifies the area to have those segments, which function like huge ducts on both sides to facilitate the flow of water in circumstances of heavy rain fall in the form of gradient-parallel related design, reflected on the *meso level*. One of the participants referred to how inappropriate practice in this matter had worsened the situation, commenting on the development of the main road in the study area in early 2011:

Ok, I think lifting up the street is not necessarily the right practice, as you might notice that two years after the protection project was done, AlNahda hospital was flooded again. Sacrificing the adjacent areas to secure the main street is what should inversely [be] accomplished in safeguarding the surrounding areas for the street to be the lowest point, then the right of way and finally the plots and buildings.

5.1.5. Theme 2: Runoff-sensitive Generated morphology:

The discussion on this theme yields a variety of insights as this character was merely practiced systemically in urban design schemes, where the typical practice was to design the area layout, street open spaces and building zones upfront, and then incorporate infrastructural modes of protection. As the variety of insights exhibited at the initial analysis, the axial coding for the interviews shows pattern of similarities, and the researcher was cautious about the surprising codes, and their unique valuable insights. The discussion on this theme diverged into *natural* and *manmade measurements* as follows:

5.1.5.1 Natural characteristics:

Most of the participants engaged with the distinctive characteristics of each *water shade* and how the achieved *harmony* between the natural features and physical dimension of the design can benefit the *surface runoff reduction*. The local scale of considering the *within water shade characteristics* was broadened by other two participants by looking at the relations between adjacent water shades, coded as *cross water shade qualities.* One of the participants referred to the importance of an *ecological index* which should be made available for urban planners, enabling them to have the natural characteristics of each area clear ahead of any urban development. The *location of the water shade* with respect to the *up-stream/down-*

stream direction was also noted. Also, the restoration of the ecological services that originally dominated the surface of the area is one of the initiatives of the natural-man made reconcilement.

One participant describes how the urban sprawl in the Al-Himreya area-within the case study boundaries, reflects on water shade interdependencies, saying:

In your case study area, water mounts up in the entrance of the Al-Himreya area where the new mosque is. Originally, in the early eighties, it flowed to the stream in the Wadi Kabeer area but the development changed the natural link between two watersheds Wadi-Adi and Wadi Kabeer. In 2008 as I recall we proposed a project of dual carriage way linking between Al-Himreya area and Wadi Kabeer to ease the problem of traffic congestion in the area. The project was hindered with huge compensation amounts in the Al Walja area, but I believe that if we look at it over a strategic long term perspective it will add value to the whole area of Wadi Adi in terms of runoff mitigation, as it will be one massive corridor linking two watersheds efficiently to the final downstream at the sea, close to Al-Fahal marine port.

Other specific characters that were agreed to be of prominence in this sense were: *natural elevations*, *overall surface gradients* and *within location surface gradients, historical rainfall readings* and *natural streams*. One participant referred to the surface gradient (mentioned above as inter-intra surface gradient), referring to the *within water shade and cross water shade surface gradient* and how that can be reflected effectively on the local and wider scales. The researcher is more comfortable with using the last description of this character in terms of terminological convenience. Three participants referred to this character in further detail mentioning its implications for design from the level of a single plot to the wider image of an urban block. One participant put it in a hierarchical order of single unit, or plot-neighborhood, unit-city block. This can be conceived in a way that natural gradients incorporated with design and associated with overall water shade characteristics benefit from surface runoff mitigation.

Most of the participants mentioned the inevitability of the occurrence of surface runoff in the study area. Two participants presented an advance description of this phenomena discriminating between *good flow* and *bad flow*, and explaining how differences between the two can reflect on the degree to which remedial alterations can range from *reliable interventions* to costly retrofitting to more financially-liable evacuation measures.

5.1.5.2 Man-made measurements

Submission to nature, rather than resisting it, was one of the frequent codes that repeatedly manifested in most of the participants' responses, referred to also as ecological compliance. One participant's description was as follows:

I understand that when you introduced your research project you were seeking resilience rather than resistance, and resilience is very much about walking with – walking by nature rather than confronting it.

Three participants thought that the enablement of surface water runoff on a smaller scale, even from between two buildings units or plots boundaries, could lead to a *fragmentation* of the flow and reducing the *aggregate impact* of wider surface flow wave. This can effectively help to manage retrofits and evacuation techniques to harness the physical benefits of surface gradients and the *direction of flow*.

The researcher's understanding of this specific character, is that it leads to a mass-space ratio character, as presented in theme one. This is in the sense of a pre-recognised space-mass pattern that can lead to the creation of a *spatial order* that facilitates the flow of people and water. This character was discussed solely in theme one within the morphological level and referred to as the *horizontal permeability*, whereby in this theme it is represented participants' responses in connection with the surface geo-morphological features of *surface gradient* and *direction of flow* in the overarching generated morphological sense.

5.1.6 Theme 3: Accessible generated-morphology

In this theme, the main question stimulated the discussion, followed by two-to-three sub questions and probes to ensure the ultimate knowledge gained from participants. This theme discussed the mutual relationship between the two areas; the urban morphology and the geomorphology. These areas were examined to expand a deeper understanding of their involvement in facilitating accessibility to the flood prone case study area.

5.1.6.1 Gradient dependent route alignment

Most of the participants emphasised safeguarding the *main traffic routes* with respect to the natural topography. The characters of *gradient* and *elevation* drew most attention. The focus was on the *alignment* of the traffic route to run *beside the gradient* of the surface, and this being safer than intersecting it in certain points. Also, the elevation character was considered in a way that the main traffic routes safely allocated in *higher elevations* were they less likely to be waterlogged. Two participants referred to character of the traffic alignment route as either parallel or perpendicular to the surface gradient and flow direction. One of these participants detailed the issue in the example of the Al-Hail area (a flood prone area to the north of Muscat city) in which the main transportation route crosses two natural streams:

You know the development in Al-Hail area, the authority had responded to the destruction that took place there after cyclone Gonu in 2007 immediately by safeguarding the whole route from Al-Maualeh round about til the Al-Kudh roundabout. The next heavy rainfall events, I think 2010, the water was passing safely towards the sea taking underpass channels and ducts. Well, in Hell area the street alignment was perpendicular to the flow path accordingly there was nothing to negotiate there but the street level. In Wadi Adi, the story is different as the street resembles the main flow path; this why lifting it, in the case of Wadi Adi, was not much of a successful treatment as the surrounding areas suffered inundation on so many occasions after that.

Another important consideration raised in this perspective was the decision where to allocate the main transportation route according to the surface topography; the main route will assign for the whole underneath hierarchal order of the road network and the urban areas serviced by them.

5.1.6.2 Connectedness

As accessibility is the main character discussed in this theme, participants denoted the larger scale to be considered in achieving this characteristic as accessibility is a cross-boundary character linking between different areas that might be *prone and non-prone* to flood. One participant mentioned:

For achieving this character in the study area, we should consider the broader image of the cross water shade boundaries to incorporate the physical characters of both the natural and built up areas.

Most of the participant commented on the special design that considers two levels of intervention: the first is the effective *linkages* between the *safely elevated areas*. The second is to consider linking *safely elevated areas* to the adjacent prone areas in ways beyond conventional roads, but in terms of *open spaces connectedness*, pathways between buildings to reinforce accessibility alternatives.

5.1.6.3 Urban design typology

In terms of urban typology, two participants referred to the implications of using different urban types in prone areas. This was representing the convenience of using the grid iron type of urban development where an intersecting road network offers accessibility options. Meanwhile, the longitudinal layout - which mostly fits the area of the study - provides the convenience of fitting in the strain of rough topography where the accessibility options are limited, yet the variation in surface elevations tolerates other design characteristics like level enabled design and path dependency.

5.1.7 Theme 4: Urban form redundancy factors

The area explored in this theme is the redundancy of the urban form; this was initiated on the level of urban form features (building-street-urban block-open space) and carried on to the wider level of an urban context as a whole. All responses shared an understanding of this character as the effectiveness of an urban feature to lose its function or to shift function in favor of other parts of the city in times of flood.

All participants believed that this character is a key issue in achieving resilient urban form to floods. Three factors were attributed to urban form redundancy; firstly the *land use*, secondly the *type of occupants and occupation mode* and finally, the *economic value of land*.

5.1.7.1 Land use

The first factor focused on is the type of the urban land use, as varied from residential, commercial, industrial, leisure and other cultural, historical or mixed uses. The degree to which a part of the urban context can be safely desolated depends on the nature of the land use, which determines its redundancy or susceptibility to be redunded. This factor was referred to in the analysis as area *dispensability*.

Dispensability is best represented in recreational and leisure areas, mostly in vast open green areas like public parks which are likely to have the greater share of the natural disturbance resulting from flood without having a significant impact on other functioning systems in the city. In the study area, there are no open parks or even vast vacant lands; hence, in the event of runoff generation, the area's urban structures, buildings and roads are the first to receive the stress. However, two participants added the importance of the car parking areas and schools outdoor yards as potential spaces that are possible to negotiate the surface runoff, and *absorb* a sufficient amount of surface runoff. As with early warning systems, such places will be evacuated early enough before the natural event. In Muscat area and Oman generally, authorities tend to give the day or two days of a storm event as a day off to schools and in some cases to public sector employees.

One participant referred to the two vacant lands that are left in their natural setting without any change in the study area. These two vacant lands are not as vacant as they seem; they are both ancient cemeteries. If an appropriate authorisation is carried out to relocate these sites to the Al-Amerat cemetery which is only four kilometers away, then the natural areas claimed from the *evacuation process* will add a significant ecological value to the study area.

Aside from the comments mentioned above, there is a little potential in the specific area of land use. The nature of the prevailing land use in the area is of mixed used where the commercial activities dominate the ground levels of the buildings, while residential use is above. Sensitive areas, like Al-Nahdah hospital and the royal services compound are also one of the important land uses in the area. All these restraints make it difficult for the land use dimension to be a redundancy reliable domain of intervention.

5.1.7.2 Occupants

The second key factor is the occupants of the place, and this was pointed out on two different levels; the *nature of occupants* and the *occupation mode*. This represents the type of people that reside in a place and how fragile they might be in circumstances of flood, whether elderly, disabled or children. Several participants also referred to the occupation mode expressing that occupants may stay in a place depending on its land use. The occupation mode came into two categories, *permanent* and *temporal* residents who leave the place after finishing their work hours, for instance. To conclude, places with temporal occupants are more likely to be redunded in favor of other adjacent places with permanent occupants, like residential areas. One participant comments:

In an industrial area, it is of course less likely to have considerable losses like a residential one. Take the industrial area in Wadi Kabeer, though it is ironically safe compared with residential areas around it, but still have not much to lose, all care fixing garages do not *have valuable assets compared to residential areas, and the occupants are not permanent and all mid aged technicians who can manage to get themselves to safer areas compared to the permanent fragile residential area occupants.*

Other participants commented on both the land use and the nature of occupants:

Sometimes it is a mix of both land use and occupants as in the case of Al-Nahdah Hospital in your study area. It is an important facility and at the same time the occupants are fragile patients.

5.1.7.3: Economic value

The third factor is the economic value of an urban area; this owes, in a great sense, to the type and size of the physical assets in a specific urban area. It is associated with other non-physical variables, which are the economic losses resulting from floods or the required cost for restoration of similar places. Thus, the higher the cost, the less redundant the place and more liable to surface runoff.

However, very few participants answered the questions related to this theme from different perspectives, referring to the gradual tendency of an urban area with frequent inundation incidents to lose its economic vale, as the land uses tend to be *marginal* after a while. The areas lose their economic significance over time, shifting to more water logged tolerated uses. The emphasis here is on multiple events over time and their impact on the economic value on an area to be redundant to less important or less valuable activities.

Two participants refereed to the historical cultural values of the urban area, aside from emphasising the economic value. One participant actually linked the two emerging aspects above with the economic value. The reason was that areas of such character are potentially locations of city tourism and spectator attractive. Hence, this factor was coded as economic value.

5.1.8 Theme 5: Redundancy-runoff mitigation

The questions that were explored under this theme included the ability of the safely redunded urban features to support surface runoff mitigation, as well the diversity of the technical solutions that can be placed. This theme was well supported by the participants, indicating the innovation associated with the inverse thinking of the surface runoff impact in trying to recruit it as a benefit, thus considering the urban context as one unit. In general, participants pointed out that spatially integrated design meant the adjacent prone/non-prone areas are effectively connected either by conventional roads or by spatially integrated design. The non-prone areas are considered safe reach zones for the adjacent prone areas.

Diverse responses were experienced in this theme, in considering the potential of turning prone areas from a scene of a catastrophe to solution-added areas. However, participants discriminate between two main aspects depending on the location of the prone area on the runoff pathways.

5.1.8.1 Downstream prone areas

Areas that are like low lands on the runoff pathways or at the lowest point in the topography will represent pond-like areas were the water is finally collected and locked in. In this case, the solution mainly stimulated from the mode of land use - *water logged desensitised land use* - is more reliable for such areas. Participants referred to suitable land uses that fit such areas; land uses are characterised with vast open areas and *low occupancy rates*, like public parks, parking areas, or sports and leisure facilities.

One participant referred to the importance of eliminating horizontal *permanent obstacles* in, for example, fences to facilitate water flow avoiding the escalation of the water depth and velocity. He also referred to the *temporal obstacles*, which are moving objects like cars, which can exacerbate the impact of debris in runoff circumstances.

5.1.8.2 On stream prone areas

The other type of prone area that the participants assigned another kind of solution was the prone area located on the runoff pathway, but not at the lowest point. In this case, participants denoted different types of technical-design-based and planning-decision-based solutions, designing the road or the urban feature to facilitate water runoff to the desired directions either entirely or partially. A *flow enabled design*, where streets' cross sections and alignment will be considered as flow facilitating members enabling water flow to its natural downstream destinations.

Buildings that are within on stream prone areas are also calculated to be waterlogged - *desensitized* - on the ground floor. Less water sensitive activities to be planned for the ground floors, and the entrances protection, will increase the reliability of the area by being less sensitive to surface runoff.

5.1.9 Theme 6: Inundation-tolerated generated morphology

In this theme, tolerance was discussed; this is the limit to which an urban area can live with a certain level of inundation. Important characteristics share the very level of attention through participants' responses.

5.1.9.1 Occupants

An agreement on two factors was expressed in most participants' responses. The first factor was the *nature of occupants* as *vulnerable* or *manageable,* and their *occupancy mode* being either *permanent* or *temporal* residents of the space. This factor captured the prime attention, as people are the first priority - as one of the participants commented. The second factor is maintaining the daily needs of food, potable water and *access* to health care and rescue services for vulnerable occupants, like elderly or children, affected by the circumstances of a flood.

5.1.9.2 Sensitive land use

A third (less emphasised) factor was the sensitivity of the area in terms of the essential services linked with it. In times of flood, hospital and law and security enforced institutions should not be affected by inundation in a way that blocks their functions. However, two participants also pointed out the issue of the surface water contamination associated with the failure of the sewer network.

In the study area, this consideration is of lesser significance as the sewer network is not yet accomplished, due to the tough topography. Most of the building units operate with septic tanks aside from small local sewer networks with lifting substations in some areas. Even though the government plans to have the whole area served by one integrated sewer network, the current sewer service in the area reduces the impact of this consideration compared with a fully integrated sewer network. Aside from the agreement on the aforementioned factors, two participants commented thematically on this question. One had ethical-professional considerations, which were as follows:

Being urban planners, we should not take this question as a given fact, dealing with the problem of inundation from the prospect of tolerating it; the ideal thinking is to plan pre-actively in order not to get to this situation. However, this can be plausible with solving the status quo problems as a temporal setting for the final subtle solutions to be established.

The second participant, interestingly, drew attention to a political dimension that - in their point of view - might associate with raising this question in government sectors, stating:

Well, this can have a political dimension, as no city governor, for example, accepts to compromise that even if the situation is so difficult to tackle, I know you are asking from a realistic technical point of view, and you are asking an expert, but I knew also that you still have scheduled interviews to be made with decision makers like D.G's in ministries. Those executives might give you sort of enthusiastic propositions on how the prone areas are subject to ambitious plans that are eventually going to solve the problem. You need to lay your question with caution in an environment like that.

5.1.9.3 Accessibility

To conclude, *accessibility* was presented as a function of all these three factors mentioned above; hence, in terms of certain prone areas, the more the accessible the more the tolerated. Also, with the ethical considerations raised, tolerance should be looked at as an event based character; whereas, is in similar future events the area that receives a proper responsive design should be less exposed and hence have less need to be tolerated. This, on the philosophical level, reflects the dynamics of adaptive resilience.

5.1.10 Summary

This chapter presented the key research findings from the CS-1, Wadi Adi catchment. This was driven by the face-to-face interviews with experts. The main questions were followed by emergent questions, and then probes that led into deeper discussion, and enriched the level of knowledge acquired about the research unit of analysis, and the resilient generated morphology. Findings represented the detailed level of information gained in the analysis and are shown in the cognitive model, Figure 46, derived from the software added tool, Nvivo. Table 17 outlines the CS-1 code index in a hierarchal order where *themes* close down to specific *areas*, yielding to *factors* that generate the final influential *variables*. Physical solutions will be drawn upon also.

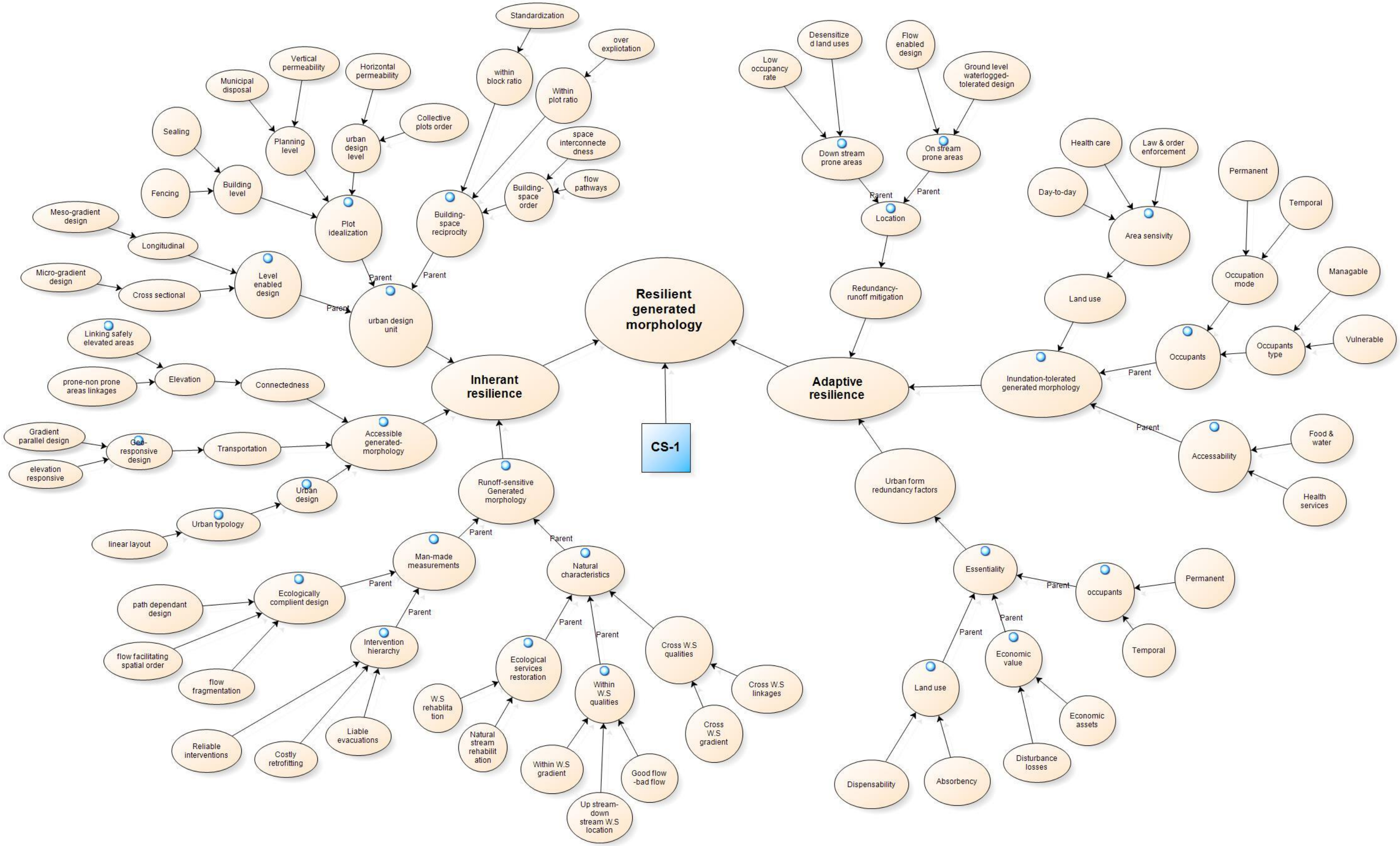


Figure 46: Cognitive model for CS-1

Themes	Areas	Factors	Variables	Description
Urban design unit	Building – space reciprocity	Within plot building-space ratio	Over exploitation prohibition	Legislative dimension
		Within block building-space ratio	Space interconnectedness	Allow for sufficient open space.
		Building-space order	Flow pathways	Organise building-space order to create pathways
			Space interconnectedness	Design for effective, flow enabling space linkages
	Plot idealisation	Urban design level	Horizontal space flow	Design in compliance with natural flow pathways
			Collective plot order	Consider the overall plot cluster geometry
		Building level	Fencing	Horizontal permeability on the plot level
			sealing	
	Level enabled design	Longitudinal (breadth)	Meso gradient design	Gradient based design – block level
		Cross sectional (depth)	Micro gradient design	Gradient based design-building- plot-street level
Accessible generated morphology	Connectedness	Elevation	Prone-non prone areas linkages	Enrich accessibility surrogates within prone - non-prone areas for emergent use
			Safely elevated areas linkages	Broaden the zone of waterlogged-safe areas to increase reliability of allocating vital uses
	Urban design	Urban typology	Linear layout	Topographically compliant Linear layout
	Transportation	Geo-responsive design	Gradient-parallel	Transportation routes runs gradient-parallel
			Elevation responsive	Route alignment ultimately trails higher elevation
Runoff-sensitive generated morphology	Man-made measurements	Eco-compliant design	Path dependency	Design to avoid or comply with natural pathways
			Flow facilitating spatial order	Design to facilitate flow between natural points
			Flow fragmentation	Design to facilitate local flow generations
		Intervention hierarchy	Reliable intervention	Geometric alteration on single urban unit shape, direction and/or elevation
			Costly retrofitting	Remedial building- space creation/alteration
			Liable evacuation	Prone buildings clearance- land use shifting
	Natural characteristics	Within W.S qualities	Upstream-downstream location	Early flow generation locations versus final flow accumulation locations
			Within W.S gradient	Within W.S contour lines index
		Cross W.S qualities	Cross W.S gradient	Overall natural gradient connecting watersheds
			Cross W.S linkages	Natural Accessibility points between watersheds
		Eco-services restoration	W.S rehabilitation	
			Natural stream rehab.	
Inundation-tolerated generated morphology	Land use	Sensitive services	Health care	Planning dimension
			Law& order enforcement	
			Day-to-day supplies	
	Occupants	Occupants type	Vulnerable	Planning dimension
			Manageable	
		Occupants mode	Permanent	
			Temporal	
	Accessibility	Emergent needs	Food & water	Logistic aspect
			Health services	
Redundancy-runoff mitigation	Location	On stream prone areas	Flow enabled design	Flow compliant structures
			Ground level waterlogged-tolerated design	Water insensitive ground level land uses
		Downstream prone areas	Desensitized uses	Planning dimension
			Low occupancy rate	Land use related variable
Urban form redundancy factors	Essentiality	Land use	Redundancy	Planning dimension
			Absorbency	Water retention enabled design
		Economic value	Physical assets	Planning dimension
			Disturbance related loses	Economic aspect
		Occupants	Permanent occupants	Planning dimension
			Temporal occupants	

Table17 : Table 16: Code index-CS-1

5.2 Section 2: Within-case analysis: CS-2 AlKuwair catchment

5.2.1 Introduction

This section displays the primary data analysis gained from insights from the face-to-face semi-structured interviews. The section will introduce the within-case analysis of the second case study, Al-Kuwair catchment, which will be referred to as CS-2. After this introduction, a brief description of the data sources will be presented, a description of the catchment area under study will follow, and the content analysis and findings from the interviews will be provided. This will be followed by a cross case synthesis for CS-1 and CS-2.

A number of themes were developed from the interview questions. These themes formed the basis for the discussions during the interviews. The themes represented the broader areas developed from the literature review, earlier addressed in chapter-3 as resilience theoretical framework that guides the inquiry. Meanwhile, the main questions and sub questions were posed to obtain specific information within these broader areas. These themes and questions were developed after carrying out an in depth literature review and further discussions with the research supervisory panel.

5.2.1.1 Explaining the data

All the participants were categorised and labeled according to their profiles; there were three main domains according to which all participants were sampled; they were the government sector (G), private sector (P) and the academic sector (A), shown in Table 18. A total of sixteen participants were interviewed across the two case studies, eight for each case study. They were explained as follows; three from the government sector, three from the private sector and two from the academic sector.

No.	Candidates	Orientation	Qualification	Job title
1	G1	Government	BSc. Surveying. MSc. Urban planning. PhD. Urban planning	Urban planning consultant
2	P1	Private	BSc. Architecture. MSc. Architecture. PhD. Urban planning	Urban planning consultant
3	G2	Government	BSc. Civil engineering. MSc. Project management	Land use management & compensations consultant
4	G3	Government	BSc. Urban spatial data management	Ministry advisor
5	A1	Academia	BSc. Civil engineering. MSc. Project management. PhD. Flood risk management	University Professor
6	A2	Academia	BSc. Architecture. MSc. Architecture. PhD. Urban planning	University Professor
7	P2	Private	BSc. Hydraulic engineering	Urban hydrologist
8	P3	Private	BSc. Civil engineering. MSc. project management	Infrastructure planner

Table 18: Participants' overview

5.2.1.2 Case study area – Alkuwair catchment

Reasons for the purposeful sampling and the choice of the two selected area was explained in the introduction of the first case study CS-1. In this section the second area of interest, CS-2, which represents the Alkuwair catchment, (shown in Figure 47) will be closely studied and analysed according to insights from the face-to-face interview with the participants.

Almost all of the participants in this case were well aware of the persistent problem of this area, which manifested in considerable runoff and inundation accompanied by heavy rainfall events throughout the last few years. Participants were also mindful of the significant ecological character of the study area represented in its natural streams and clear topographic gradient from the upstream down to the coastline.

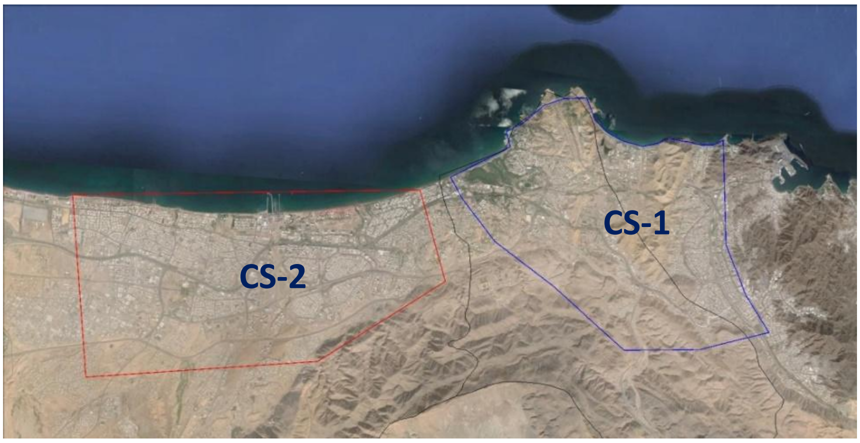


Figure 47: Alkuwair catchment

The area is highly specialised and clearly clustered in terms of land use. Moving from the mountain foot where the Muscat Southern Express Way delineates the upstream side of the area down to the sea coast line, there are three apparent types of land uses (residential, mixed-commercial, and administrative-governmental) dominating the area. They also outline four adjacent corridors lying perpendicularly on the main topographic gradient, Figure 48.

The first urban expansion created at the mountainside was the residential area developed in the early 1980 and served by the Sultan Qaboos Street (SQS) as the main traffic route at that time. The area developed constantly towards the seaside; a commercial and mixed used corridor adjacent to the SQS was created, and was later dominated by the main state ministry buildings to form another corridor, known later as the ministry district. The final urban expansion at the down streamside right, adjacent to the sea coast line was made by scattered embassy buildings, forming the embassy district.

Figure 48: Urban corridors in Alkuwair catchment

5.2.3 Data analysis

5.2.3.1 Urban design unit

As the first question set to explore the potential response of the urban form, in examining the smallest level of the urban design unit, participants responded slightly differently. Some participants account for the contribution of the smallest urban design unit and refer to a slim physical role played on this level. Other responses departed to a larger level from urban blocks as the more flexible physical boundary in introducing some changes to benefit flood mitigation. Three of the participants referred to relying less on the smallest urban design unit, but in various ways. Many reasons were experienced and summarised as follows:

- The area is heavily developed and there were few spaces left to negotiate physical interventions on the plot level,
- Relatively high land value,
- Multiplicity of property ownerships,
- Land use variety.

Despite the low expected physical contribution of the urban design unit, and technical complications associated with implementing measures on the smaller level, fairly equivalent insights were obtained on the three morphological levels; plot, building and street.

5.2.3.2 Urban block optimisation

The clarity of the urban morphology was captured by most of the participants. The hierarchal order of the transport route was also referred to as clear. Sound land use classifications in a way; guide most of the responses on the level of the urban design unit. The four functional corridors, shown in Figure 4, with their different functional requirements informed the participants` feedback.

For the four reasons mentioned above (topic 5.6.1), some responses came with less interest, showing possible solutions on the plot level, instead of looking at the larger scale of the urban block. Aspects like the relationship between the urban block and open space, and urban block/blocks layout was what most of the responses were grouped around.

Three of the responses referred to the land use clarity in a specific way; this was reflected in the possibly of ***regrouping and redesigning supportive outdoor services*** like parking, loading areas, and the backward approach roads for similar blocks (blocks with similar requirements) instead of having each building with stand-alone services. Theses grouped services will help to ***re-establish larger urban spaces*** between dense multi-story buildings through ***re-clustering larger urban blocks*** in each corridor. These can be efficiently used during inundation conditions as ***assembly evacuation points***, not to mention that paving them with proper permeable materials - on the technical level - will increase the overall surface retention and absorption capacity.

An ***open space orientation to slop*** was referred to by two participants; they drew attention to the layout of the open space whether ***parallel*** to the main topographic slop or ***perpendicular***. An open space perpendicular to the overall slop direction can act as ***runoff retention and absorption*** member as it gets the maximum exposure; meanwhile a space that runs longitudinally with the slop direction can be used as a ***conveyance space***.

One participant states that:

Addressing interventions on this level, to establish the described physical changes can only be done by effective retrofitting, led and commenced by government traits.

5.2.2.3 Urban space re-productivity

Among the most important things, the ability of urban space to contribute to mitigating the problem of runoff was the first thing to refer to. This started with the spaces between buildings which could be considered as ***connection routes*** for pedestrians; furthermore, redesigning larger urban spaces to have as much absorption as possible; providing ***spaces of absorption***, and establishing linkages between adjacent spaces to create bigger ***connected open spaces*** by clearing out boundaries and eliminating less-important physical barriers, like fences and surface types of sealing.

Two participants referred to one building type that has recently dominated the area due to the relatively high land value. This is a multi storey type where the buildings have the first two or three storeys designed as parking areas. The repercussions of this ***urban typology*** contribute to urban space degradation, where instead of having the free open spaces to serve as recreational spaces or even car parking; the over exploitation of multi-story buildings end up with disturbed overall ***building-space ratios***.

In this theme, three important factors were addressed, a near consensus on the urban space organisation, ***urban space orientation to natural gradients***, ***urban space connectedness*** and the ***urban space re-establishment*** through an effective infill in the area. One of the participants termed this, **i***nfill to evacuate*. These factors are associated with the principle of preparedness on the level of aggregate plot areas and urban block levels.

5.2.4 Runoff-sensitive generated morphology

Most of the participants' feedback on this theme pays considerable attention to the ecological significance of the study area. Noticeable topographic gradients, natural streams and terrain features diversity represented in the mountainous area at the upstream, moving by the hilly and flat areas deeper towards the downstream and ending with the flat sea front. Discussion on this theme is delivered via two sub themes, as follows:

5.2.4.1 Eco-oriented urban reform

Participants on this theme focused on how urban designers use the natural characteristics of the area in favor of runoff impact reduction. One important widely agreed issue was the clear land gradient from the upstream to the downstream. One participant comments, ‘‘*with the* *clear gradient in the area, we shouldn't have the inundation we had each year in the ministry district on each occasion of heavy rain fall''*

Urban design insights circulate around making full benefit of natural terrain characteristics to reduce runoff, using the area's natural terrain to ***preserve existing terrain quality*** and restore ***natural discharge*** capacity, whilst also using urban design capacities to create and assist ***artificial discharge***. With the contribution less likely to be effective on the smallest morphological level, for the reasons mentioned in topic 4.1, insights focused on interventions on the scale of a whole street segment and urban block level.

On the ecological level, a specific insight linked the two main natural streams of the study area along the SQS route. It was suggested, to ease the tension of the flooded route in front of the ministries district, an artificial low-laying pathway could be developed linking the two major streams and ends up with sea. The main insights gained within this theme were based around the ***ecological reform*** of freeing out the natural stream's shoulders from densely developed areas; this is to assist the ***natural settings' performance***, and recreate diminished or faded natural features.

One participant commented on the differences between inundation and runoff,

It is important to discriminate between runoff and inundation, even though they are both two sides of the same coin; runoff is the start of the problem while inundation is a reflection of poorly-designed areas.

5.2.4.2 Retroversion urban measures

''Vigilance towards natural features is the last thing you see when you examine the urban development directions in the area''. This is one common concern rephrased by the researcher, and reflected from participants' feedback on the relationship between the built and natural in the study area. This view was put forward by one participant, as follows:

I look to your map; I see a city that turned away from the reality of existing natural settings, good and bad. This is ecological negligence.

Further discussion on that topic revealed similar opinions; one participant extended their response to this issue by classifying the area into three zones; the built up area, the natural settings, and the ***interference zones***. The participant revealed that the interference zones are the areas where the built up and natural are in close proximity; they were described as critical areas where special planning rules and regulations need to be applied.

Four participants responded to the question addressing this theme by describing the area with a clear ecological character, and clear urban layout. The clarity of both the built and the natural were focused on by participants, in terms of the potential physical solutions. Opinions referred to the homogeneity of the physical characteristics in the two, built-and-natural environments.

On the plot level, land uses with vast open spaces and relatively low coverage areas, like stadiums, car parking, and public parks can be allocated to run along the main streams natural corridors, called ***zones of interference***. This is to avoid the reversal impact of the flood water surcharging from the natural streams back to sensitive or dense surroundings; this factor is referred to as the ***land use de-intensification***. This will change the spatial order as more open-spaced land use will close in to zones of interference, while densely developed land uses, with relatively less open space on the boundary of the single plot/block area, will retreat further back from these zones. This will have a double impact, the first is that the urban context in these areas will have more room to accommodate flood water, at the same time, land uses like those listed above are normally less likely to have permanent occupants, valuable assets, and are not consistently busy most of the day.

Among the insights gained in this theme, the identification of the ecologically interfered zones is one prominent finding. These areas are functioning as safeguard zones for both natural and built up areas. The encroachment of these areas will deteriorate its ecological role of setting the flood back from the city or delaying the flood peak.

The sensitivity and responsiveness of the urban design to runoff water, addressed in this theme, seems to have much to do with the relationship between the urban morphology and geo-morphology. Factors, like natural and artificial discharge, de-intensification of land use, and preserving existing ecological services, are among the important variables that will hopefully lead to building a responsive generated morphology.

5.2.4.3 Accessible generated-morphology

This theme was stimulated from main question set to explore the mutual rapport between urban morphology and geomorphology. Interdependencies between these two areas were examined to determine their mutual influence in facilitating accessibility to the flooded area.

Insights attained, addressed key solutions and yielded several modes of physical intervention. It was widely agreed among the participants that the issue of accessibility is a key parameter for any subsequent solution. The level of awareness was good, responses were enthusiastic and promising, and responses categorise around the three urban morphological components as follows:

5.2.4.4 Street level

Feedback on this issue revealed the importance of connecting routes in the area; participants focused on a contribution that is yet to be made in this segment of the city morphology. One participant specifically referred to the ***dynamic route design***; two other participants also referred to this as flexible road design. The first design-specific parameter uncovered by the discussion considered ***multiple nodal design*** on the prone routes. These nodes will perform as interchange nodes connecting to escape and exit routes to adjacent and safer areas. A multiple nodal route design is conceived to have influence near the major stress points on the prone routes where access surrogates are essential.

The second design-specific insight was made by three participants; it was about the super elevation of the road, how potentially it can incorporate physical measures allowing and facilitating the flow of the runoff water in an efficient manner, giving way to one or two road lanes to runoff flow. This will reduce the stress on the remaining lanes to serve the connectivity in the flooded area. The third design-specific insight was made by most of the participants; they recommended the creation of alternative routes running parallel to the ground gradient and starting from the stressed areas towards upstream safer zones. These routes can be normal segments of the road network in the dry times, although its significance arises in the flood event as an escape route to the adjacent dryer areas. One participant referred to it as ***cross contours route alternatives***.

5.2.4.5 Building-block level

The organisation of each building’s services as incorporated in one facility of a group of similar-functioning buildings or blocks, gathered parking areas and the consideration of storey parking will add more outer space availability, as one participant mentioned:

Don’t forget that cars can form dangerous debris by drifting with runoff water, blocking access to some areas and increasing the depth of flood, considering two or three stories of *the buildings for parking can help eliminate the problem and allow for free space around building to be used by water and people during flood times.*

This ***storey-incorporated car parking*** within the plot boundary or even within the building will create a free space outdoors to accommodate the flow and allow a smooth and shallow runoff flow by reducing the residual impact of debris. This is can all be reflected in more accessible routes; it provides a cross benefit to both people and runoff water; the more the space for the runoff to pass through, the less the impact on the flow of people.

One participant referred to horizontal ***over ground block connectedness***, a characteristic resembled in connecting parking stories or the first floors of buildings with pedestrian routes, overcoming the flooded ground level and creating ***rescue pathways*** that end at higher safer elevations out of the prone areas. These routes are described as a spider web and can be designed easily with existing buildings, linking a few blocks to end up with building or a block safely elevated from the flood levels.

5.2.4.6 Plot level

Most of the insights gained in this sub-theme were about increasing the plot overall storage and retention capacity; this is very much owed to the technical practices in a way that it can be managed by assigning proper paving material. However, as far as the research is concerned, it is still the availability of the outer open space that governs this characteristic, meaning that when the open space is provided and organised on the plot level, this character can be successfully operated. Participants also referred to the unified level design for the outdoor spaces within the plot boundary to avoid trapping amounts of runoff water between high and low-laid ground at outdoor levels. This plot leveling is also considered an applicable physical intervention that was seen to influence the overall area performance in surface runoff conveyance.

Participants also referred to the relation of open space in a single plot with surrounding buildings and ***plot mosaics***. The consideration of an open space within one plot as a dependant to the next is a basis for a design tool that can facilitate the ***creation of a controlled and purposeful open space design***. Although this character can be useful, it is still difficult to achieve in an existing urban form, although it is not impossible with the consideration of urban renewal and the end of life of some buildings. This can open a window to consider this character on long term planning scenarios, in the slow process of a city's metabolism.

5.2.5 Urban form redundancy factors

The area examined in this question explored factors influencing the redundancy of urban form features in times of flood. Responses described insights, starting from smallest level of the urban morphological unit to the wider perspective of a city block or cross-location, natural and manmade urban features.

Participants were mindful of the area's sensitivity, represented in strategic nature of the land uses; this explains why the majority of responses showed interest and caution in the same time. Little concern was experienced in the responses about introducing direct physical interventions; this was due to reasons associated with the highly important land use and the consequences associated with any change to the urban structure. Nevertheless, some participants contributed their vision for the best valid solutions that could be effectively set in place. Insights experienced in this theme were categorised into main four sub-themes, as follows.

5.2.5.1 Land use redundancy

As there were no vulnerable types of residential land use, most of the discussion was about urban land use. The commercial and strategic land uses were what captured participants' attention; indeed, the *extent of exposure* and the *nature of land use* to which each area was labeled is what determined which part of the urban context can be safely redunded. This factor was also referred to in the analysis of CS-1 as area *dispensability*.

Land use management was experienced in many participant responses; aside from the planning and legislative-natured responses yielded in the discussion, there were specific design-based insights. Participants referred to the ***land use distribution*** and ***land use desensitisation*** to flood. This was expressed in various ways; one participant mentioned the ***multi-layering*** of commercial activities on the main route. It was seen that a significant change in responding to flood can be achieved when commercial activities are designed to occupy first and second floor with relatively less occupation on the ground floor, rather than concentrated on ground level.

This *vertical orientation* will reduce the vulnerable exposure of valuable assets to flood. This will create a separate ***dry level*** of commercial and other land uses in a building scale (positional), and these levels will be linked over the flood affected level, and thus help to create a ***floating city layer*** on the block scale (locational). Moreover, ***vertical retreating*** referred to the reduction of commercial land use occupation on the ground level. This will allow for more space to be available for ***less sensitive activities*** to flood impact, as represented in car parking and loading areas, which will effectively fit in.

Participants commented on the strategic level, that land uses, like ministries and other public service bodies with a sovereignty nature should be considered for reallocation. This is similar to what has happened throughout the last five years in moving three ministries to the airport heights new zone, in new planning measures of decentralisation that were taken by the government based upon transportation studies to reduce the traffic congestion.

5.2.5.2 Economic value-revenues

Opinions also reflected on the ***economic value*** and ***economic revenue*** thriving in the area as a hindering factor for any redundancy measures. The relatively high land value and investment potential make it difficult to neglect any part of the land to flood runoff. There is a little to be done on land redundancy, as one participant comments;

Investors and land developers normally follow commercial logic; they will not let valuable land go as a runaway goat for the flood. City dwellers conceived of cities as places of reliance; occupants, like taxpaying investors, expect safe and serviced areas for what they paid. Rather than that, effective flood control measurement is what they built on when they linked their lives with the city.

5.2.5.3 Transportation routes redundancy

Discussion also revealed that the availability of ***transportation route alternatives*** and ***vacant land availability*** can be seen as effective factors to build redundancy measures. Participants responded to the available vacant plots in the ministries district, as one participant said:

… you know the vacant plots between the ministries buildings, [a] few years ago they were so many that one can see the sea from this point (on the map SQS). Now with land over exploited there are few open spaces left between the buildings and these should be kept as they are or handled carefully.

Vacant lands can be used in various ways, starting from retention ponds to connected informal routes of conveyance to water, people and any other modes of *emergency circulation*. Meanwhile, available transport routes across the area can be seen as effective redundancy surrogates. Alternative routes could be *cross-contour or gradient parallel* to retain the ability of transfer emergent circulation from prone to non-prone areas. Participants reflect on this issue by pointing out two important circulation distribution nodes, at the beginning and the end of the prone area, with almost one kilometer separating them. Participants recommended investing in reliability by creating more connecting nodes that could be linked to new routes alternatives and assist the redundancy of the affected major route (SQS).

5.2.5.4 The natural selection

One participant referred to an interesting natural process of a flood surge, indicating the importance of the natural process of the flood wave and its propagation during flood events. The area the flood wave frequently draws should be looked at as natural boundaries. In another words, the natural setting in the area should reclaim land with frequent flooding events, as the participant stated: "*let the flood depict the boundaries"*.

The discussion concluded that claiming back lands that were frequently flooded to assist the natural setting in the area will help in mitigating the flood impact. However, this will face technical and mostly financial liabilities; instead, it may be more appropriate to address the areas, known as ***zones of interference,*** for future planning and design measures in order to consider suitable attributes when addressing any development. Reducing land use intensity by reducing the floor area ratio covered with the building would allow for more open space. Thus, ***hollow structure***s would replace *dense structures*.

Thus, the discussion on this theme revealed that there is little to be introduced as land redundancy, aside from the design-specific insights of the *vertical retreating* and *land use runoff desensitisation,* which generally reduce the occupancy rate of ground floors in prone areas. In terms of transportation alternatives, the more they were available the more redundancy measures they can tolerate, especially when considering the best alignment direction with respect to topography. Contrary to the high land value in the area, there are still some considerable vacant plots between buildings and some open spaces. These can redunded temporarily or permanently to assist in flood mitigation.

5.2.6 Redundancy-runoff mitigation

The main question and discussion within this theme was around the possible ways that safely redunded urban features could better function as flood mitigation features, rather than being an exclusive resemblance of a disaster scene. Participants, classified specific physical interventions in responding to this theme, generally, and, due to the high land value and strategic character of the area, responses were based around the flexibility of the road network and efficient alternatives to accommodate runoff water for temporal computations. Open space redundancy was also referred to, and in spite of the limitations associated with interventions within the land use, participants were able to identify direct interventions and some project-based solutions.

5.2.6.1 Temporal-redundancy oriented solutions

One participant referred to a similar problem experienced in Thailand, where the solution was to safely design one direction of the dual carriageway to function as a runoff channel during flood times. The super elevation of the road was designed to have one direction half meter higher than the other direction. This ***eco-compliant design*** solution worked very well in curbing floodwater from surging into the surrounding areas, while the two-way traffic used the three lanes in one direction as two-way traffic with a relatively slower but safer flow.

Other temporarily-based solutions addressed in this theme were the *monkey checks* phenomena; this was what one participant referred to the measures taken to improve the retention and absorption factor of the prone area, have had each single plot armed with the capacity to safely hold a certain amount of runoff water as a resemblance of *"some monkey species storing nuts in their checks*". This ***temporal storage capacity*** would enhance the overall performance of a city to flood by reducing the amount of runoff water and delays to the runoff peak. The best way of achieving this, as one participant stated, is by having small ponds each around single plots or urban blocks, which would be used as retention tanks in extreme events and for irrigation, cleaning, and recreational purposes in dry times. The participant affirms that: "*this initiative was made by the king of Thailand himself"*.

5.2.6.2 Ecologically restored redunded features

Sayings like, *"Let the flood draw the line"* and *"Let the flood depicts the boundaries"* were frequently expressed in many of responses. Participants generally felt that the area overwhelmed by flood should rather be considered as a potential redunded feature, from an *ecological reformative perspective*.

Insights referred to the linear open space separating the ministries corridor from the main street – SQS - as an area where ecological reform should take place. The area is designed to be on a slightly elevated level on the side of SQS, while the ecological sense links it with two major streams in the area to act as a problem solving/mitigating feature rather than a problem-deepening feature. Moreover, two participants suggested re-establishing the open space, known as Ministries gardens, on the level of the contour line that joins the two natural streams together and finally to the sea. This would make a sound ***ecological restoration*** and qualify the area for a higher performance to reduce/mitigate runoff impacts.

Opinions also referred to the urban rapid development and how they closed in on the natural stream corridor, not necessarily on the stream course itself, but on its shoulders and the area adjacent to its path. One participant commented;

You see this area – on the map where the small natural stream [is] stressed by a road junction and flyover columns - year after year development[s] keep violating its boundaries, and we witness a knock-on on this route each year as the runoff water strains in this bottle neck and shuts down the road with over a meter of inundation water. The ideal situation is that we should see the bare ground across this natural pathway, no manmade intervention on the course of this natural stream; all road connections should be lifted at least two meters.

5.2.7 Inundation-tolerated generated morphology

In this theme, alertness was experienced in participants' feedback; the relatively important mixed land use area influenced this. Participants were cautious in responding to the main and sub questions. Among the very well established and thriving commercial activates in the area, the ministries compound exists on the other side of the main road (SQR). The embassy corridor is right after the ministry district facing the sea from the other side at the lowest point on the downstream pathway. In such an area, tolerance to flood runoff is the last solution any urban designer would rather have; although some solution seeking insights were obtained to improve the status quo.More than half of the participants shared a common concern to secure *access* to important locations, like the ministries and embassies districts, during a flood. By doing so, the second issue is to avoid a prolonged restoration process drying out the area from runoff water. From the political side of the problem, this directly affects the state image, as one participant commented:

Ministries and embassies are sovereignty sites with a strategic and political significance; losing access to these sites can affect the order of the state, even maintaining minimum access with inundation conditions might carry a negative prestigious impact.

One participant stated that *access* is still achievable in a slow traffic mode with 25-30 cm of inundation water, especially with the non-considerable flow speed that results from many physical obstacles in the area. These limits are challenging to achieve compared to the inundation level of 50-60cm experienced after each heavy rainfall event that occurs almost twice annually. Two participants commented on the significance of *access* as the chief commodity to look at in the area. Occupants are not that vulnerable, as mixed commercial and administrative use defines the users of the area; hence inundation is not that worrying compared with other types of land use, like single unit residential areas or other vulnerable uses, like health care facilities.

Two participants reflected on the main question; they were reluctant to tolerate inundation in the area, and agreed with a temporal acceptance of the fact until full infrastructure plans are set to solve the problem completely. From their point of view, investing in efforts to build the infrastructure-based solutions of urban drainage networks and upstream protection dams should be the priority rather than investing in physical resilience measures. According to this perception, the proper image for the area and its identity requires dry city oriented solutions.

Summing up all opinions, and taking the range of thoughts into consideration, there was little disagreement about whether solutions should enable the city to cope temporarily with stress, or consider long-term plans of full flood control, which require significant time, effort and resources. In such a time, urban planners should have feasible and immediate salient solutions in place, and when considering the similarities and disparities in reflecting on the questions asked, *accessibility* was found to be a key commodity that all participants expressed views on.

5.2.8 Summary

This chapter presented the key findings from CS-2, the Al-kuwair catchment. This was driven from the face-to-face discussion with experts on the assigned themes. The main questions were followed by emergent sub-questions leading the discussion further and deeper, which enriched the level of knowledge acquired about the research unit of analysis, namely the resilient generated morphology. The general finding from this case was that the area was ecologically reliable, whereby it was liable in terms of the urban context. Important and valuable assets make it difficult to physically intervene, and this is the reason why most solution stemmed from the ecological dimension. Findings representing the detailed level of information gained from the analysis are shown in the cognitive model, in Figure 49. These are derived from the software tool, Nvivo. Table 19 reveals the CS-2 coding index in a hierarchal order where themes close down to specific *areas*, yielding *factors* that generate the designated *variables* where certain physical solution scenarios will be drawn upon.

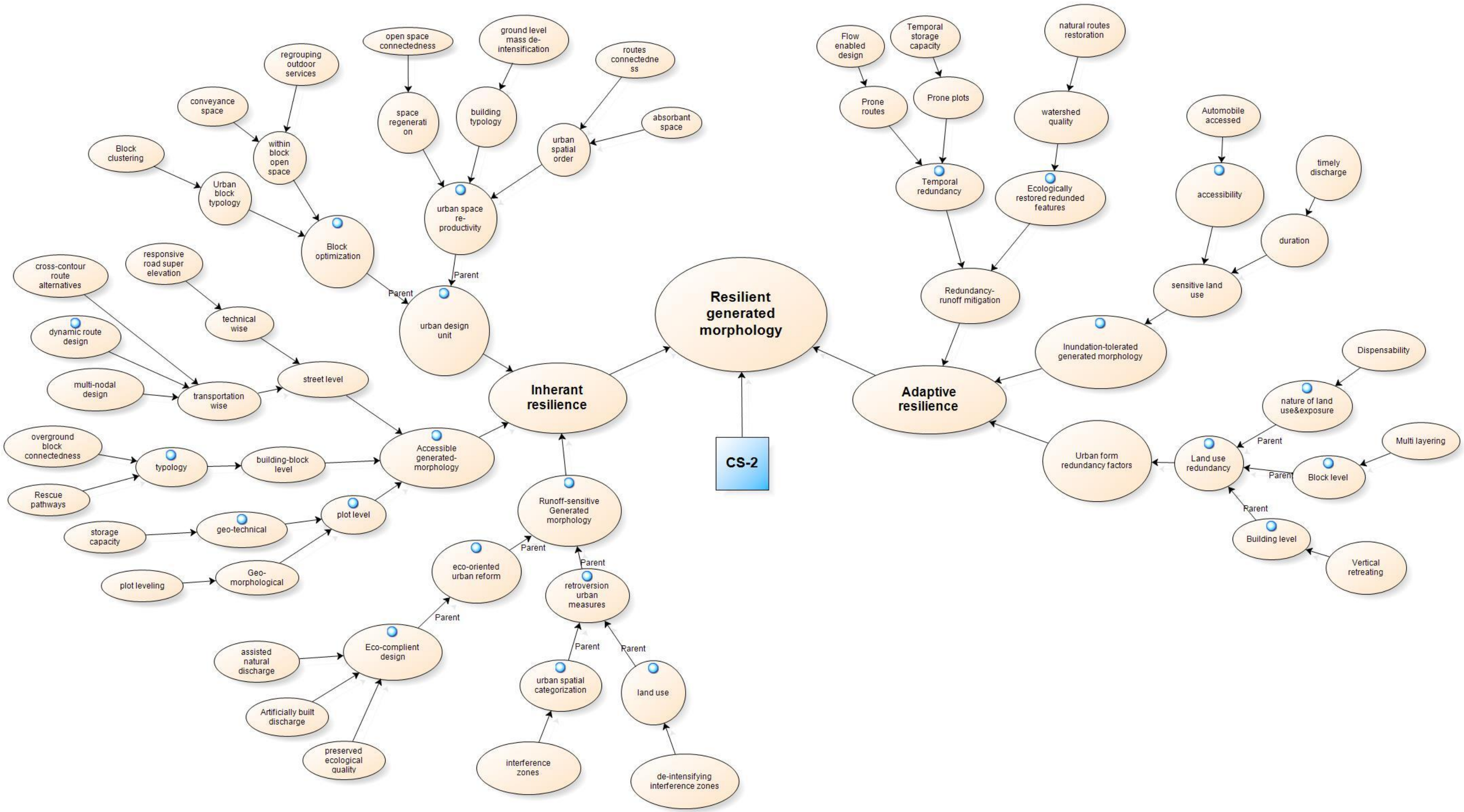


Figure 49: Cognitive model for CS-2

Themes	Areas	Factors	Variables	Description
Urban design unit	Block optimisation	Within block open space	Regrouping outdoor services	Legislative dimension
			Conveyance space	Allow for sufficient open space.
		Urban block typology	Block re-clustering	Organise building-space order to create pathways
				Design for effective, flow enabling space linkages
	Urban space re-productivity	Space regeneration	Open space connectedness	Design in compliance with natural flow pathways
			Ground mass de-intensification	Consider the overall plot cluster geometry
		Urban spatial order	Routes connectedness	
			Absorbent space	
Accessible generated morphology	Street level	Transportation wise	Dynamic route design	Enrich accessibility surrogates within prone - non-prone areas for emergent use
			Multi nodal design	
			Cross-contour routes alternatives	
		Technical wise	Responsive road's super elevation	
	Building-block level	Urban typology	Over ground block connectedness	
			Rescue pathways	
	Plot level	Geo-technical	Plots geometric adjustment	Plot overall morphology
		Geo-morphological	Plot levelling	Topographically responsive aggregate plot area
Runoff-sensitive generated morphology	Eco-oriented urban reform	Eco-compliant design	Assisted Natural discharge	Design to assist flow towards natural pathways
			Built Artificial discharge	Design to facilitate flow through urban spaces
			Preserved ecological quality	Enhance and restore existing ecological qualities
	Retroversion urban measures	Urban spatial categorization	Reconsidering interference zones	
		Land use	Interference zone de-intensification	Replacement with low plot-coverage land uses
Inundation-tolerated generated morphology	Sensitive Land use	Accessibility	Automobile accessed	Minimum level of accessibility
		Duration	Discharge rapidity	Time of surface runoff discharged
Redundancy-runoff mitigation	Temporal redundancy	Prone routes	Flow enabled design	Flow submissive transportation routes
		Prone plot	Over ground storage	
	Natural features redundancy	Watershed quality	Natural routes network restoration	
Urban form redundancy factors	Dispensability	Land use	Land use redistribution-desensitization	Land use shift inclination
			Vertical retreating	Creating floating land use level
		Economic value	Value of assets	Economic dimension
			Revenue of investment	
		Transportation routes redundancy	Gradient path dependency	
			Multi-node path design	Hazard escape nodes
		Natural selection	Flood guided natural restoration	
			Identifying zone of interference	Planning dimension

Table 19: CS-2 code index

5.3 Section 3: Cross case synthesis and conclusions

5.3.1 Introduction

Wadi Adi (CS-1) and Al-Kwuair (CS-2) catchments both are urban settings with generally similar parameters, considering the mixed land use that commonly dominates the nature of urban land use. Both areas have a distinctive ecological setting reflecting a unique ecological footprint. Both areas had a clear natural stream network, and watershed characteristics. Although Wadi Adi is a natural setting, (CS-1) is severely disrupted by urban development and comparatively fragmented.

The Al-Kwuair catchment is a less disrupted natural setting. Natural streams and watershed characteristics are less affected by urban developments, leastwise the tightening of the two major natural streams that still end up with a clear path to the sea. Watershed and natural landscape enclave urban growth, though the area still preserves its original character. Aside from the existing situation, a digital elevation model of bare ground of both catchments showed that over time, the process of urban growth eliminated some of the original ground characteristics.

Governmental reports showed that the two areas under study witnessed almost equal attention in terms of public sector investments in flood protection schemes. Both upstream and downstream flood protection schemes have been implemented since 2005. Furthermore, consistent attention was paid to both areas after cyclone Gonu in 2007. Despite this, the areas have been dramatically flooded ever since with each seasonal heavy rainfall; hence, this has motivated the researcher to explore the different perspectives of resilient design rather than resistance infrastructure.

5.3.2 Urban design unit

The level of involvement in making dependable solution to mitigate surface runoff on the scale of urban design unit varied. In CS-2, participants were reluctant compared to those involved in CS-1. This was due to several reasons, noted earlier in the CS-2 section. However, the literature review paid attention to the importance of investing in the scale of an urban design unit in a pre-active mode (Leon, 2014; Salat & Bordic, 2011; White, 2008). In general, findings from both locations concerning this theme were in line with the findings from the literature review. Relatively low responses from CS-2 were actually attributed to factors like land values and the durability of urban structures, despite the fact that those factors are circumstantial. Nevertheless, useful insights were gained in both locations and can be nested in higher planning and legislative levels to gain executive power.

In CS-1, insights negotiated solutions from the smallest level of building, plot and street. This is understandable when taking into account the nature of the urban context with low storey buildings dominated mainly by residential uses and less specialised commercial uses. In a similar context, the financial aspect associated with physical interventions can be tolerable. While the case is the opposite in CS-2, the urban context is highly specialised commercial land use and relatively high economic land value. This has hindered, to some extent, large scale physical intervention scenarios. Despite the reluctant responses on the smaller plot building level witnessed in CS-2, salient solutions were introduced on urban block level and the urban spatial order. Urban design unit was powerfully addressed in participants' feedback. Although there were some variations experienced on the contribution of the three morphological components of plot, building and street between CS-1 and CS-2, the overall insights gained through discussion with participants were useful.

5.3.3 Runoff sensitive gen-morphology

The majority of the interviewees on both locations were enthusiastic about the potential role of existing ecology in each area. Taking into account the significance of each catchment, most believed that there is room for improvement that has yet to take place on the urban form performance and in association with the adjacent ecological setting. The literature highlighted the importance of coupled natural-manmade characteristics (Ahern, 2011; Zevenbergen, 2011). Likewise, the findings suggest a mutual interaction between the natural and the built in a way that is far better than the status quo. This echoed cautions rose by Ahern (2011) who brought attention to the phenomena of segregating the natural landscape by urban development.

Responses in SC-2 were more specialised and centered on the ecological setting of the area. Insights were experienced on various levels to enhance the ecological performance of the urban form during flooding. The clear contribution of the ecological aspects experienced in CS-2 was due to the clear ecological footprint of the area. This contrasted with the ecological settings in CS-1, which was isolated and shredded with urban development. Despite the strong and clearly evident ecological identity in CS-1, most of the natural features are severely disrupted with urban development and have lost their original layout and hence, their essential ecological services. Ahern (2011) represented the ecological concerns found in the literature and these findings, mentioned earlier, were clearly experienced in CS-1. This is why the majority of participants' reflections looked at ecological restoration-based solutions. Solutions targeting ecological restoration in CS-1 were influenced mainly by the relatively reliable urban setting. From an ecological perspective, CS-2 was comparatively relieved, and insights experienced a lot of ecological reform and improvement due to the area's strong identity, and less disturbed ecological context.

5.3.4 Accessible generated morphology

In both locations, insights focused on two types of connectedness across the prone and non-prone areas. These were; the conventional mode of transport routes represented by main traffic routes, and the non-conventional connectedness mode of efficiently linking adjacent spaces. The power of intervention was again higher in CS-2 due to the less disrupted ecology, and the reason way the responses were clearly categorised around the urban design unit on the three levels of plot, building, and street. Accessibility was equally importantly noted in the literature; Lynch (1981) and Tarbatt's (2012) principles of urban design, and accessibility were of particular importance. Godschalk (2003) also considered the priority of physical accessibility as an essential commodity of the urban form.

The highly disturbed ecology in CS-1 drove responses to cross-location solutions. The accessibility was targeted on a cross-watershed scale. Against all odds, the solutions of connectedness were surprisingly experienced in a mature practical way in CS-1. In a project-based scenario, a corridor of conveyance and connectedness was suggested in response to ecological disruption in the location. This significantly aligns with one government project suggested ten years ago to ease traffic stress in the area. The same was suggested but with the dual-rationality of conveying water and traffic.

Project-based insights were also apparent in participants' responses in CS-2. A specific suggestion to link two natural streams that were severely disconnected by urban development was suggested. Several participants also identified other eco-urban reformative interventions. These were detailed in CS-2, and will be developed as a project-based scenario in the subsequent chapter. Discussion on this theme was rich for both locations and yielded an unexpectedly abundant range of variables that could be translated into potential solution scenarios.

5.3.5 Redundancy

The discussion on this theme mainly centered on the factor of land use. Given the slim differences in addressing this factor across the two cases, land use was addressed sometimes indirectly by the land use specialisation, and by the direct economic value of the land itself. However, addressing occupants was a direct function of the fragility of residents of the area. Occupants and their occupation mode were evident in CS-1 and less referred to in CS-2. This was due to the robust urban structure in CS-2 compared to CS-1 where residential use consists of 60% of the total land use.

With regard to the land use redundancy, participants were critical about the lack of open spaces, whether outdoor spaces like parks, roads, right of way, and general open spaces, or within plot spaces, like car parks and schools' open yards. Open spaces, and particularly spaces with marginal functions, like parks, are considered to be the generator of reliable redundancy scenarios. Land over-densification was addressed in both areas, although the reason for this varied between the old below-standard residential area of CS-1 and high land value and commercially attractive location of CS-2.

Nevertheless, the low open space ratio is clearly evident. Interviewees from both locations believed that counterbalancing the issue of land economic value will bid fairly to occupants and their occupation mode for redundancy to be judged against. The time that this was applicable in CS-1, it wasn't in CS-2 due to the highly specialized land use dominated the area. A land use with an importance that is beyond the value of land itself or the thriving commercial activities, but with sovereignty dimensions relating to the ministries and embassies districts. Despite the low availability of land in both locations, some interviewees went deeper to categorise the least usable open spaces. In both locations two ancient graveyards and relatively small parks were addressed in terms of their potential prospective contributions.

An important process was identified at both locations that considered variations in terminology and comprehension. In CS-1 the term 'land marginalisation' was used, while in CS-2 'natural selection' was addressed and discussed. The two ideas referred to how the natural process of frequent flooding and land submergence assigns the boundaries of the ecological impact within which a logical tendency of land depreciation will occur.

5.3.4 Redundancy-runoff mitigation

For both locations, significant physical interventions on different urban levels were suggested. Ideas addressed the core concept of multi-functionality and reusability in the urban features that have lost their original function during a flood. Understanding what redundant urban features stand for echoes the findings in the literature, where Bruneau et al. (2003), stated that redundancy is the extent to which system components are substitutable. This is also reflected in the views of Vale and Campanella (2005), MCEER (2007) and Wildavsky (2007).

Responses for CS-1 were offered around the natural ground gradient and flow pathway along which the existing urban context was aligned. The redundancy tendencies were discussed in respect to their location, whether upstream, on stream or downstream. Solutions were expressed clearly, starting from the smallest level of plot and building. In the downstream areas, solutions aimed to consider the use of vast, open spaces as runoff depositors to delay the flood peak times. Meanwhile, the responses for CS-2 saw solutions categorised against time, which is potentially due to the significance of the area. This involved temporal and permanent solutions, where participants were negotiating fast ways to address the problem whilst also considering long term measurements; this attention stemmed from the significance of the area.

Other dimensions discussed in CS-2 cantered on ecological restoration. The enhancement of lost ecological services gained most attention, which considered the discrete ecological footprint of the area. Project based interventions from around the world were compared. Both locations heavily invested in deploying the redundant factor. Responses ranged from the ability of an urban form to neglect an inundated feature temporarily to practically reuse it in a manner to sustain services elsewhere. In both cases, the analysis witnessed the most physically oriented solutions and insights that were taken directly to the scenario crafting process in the interventional model.

5.3.5 Tolerated gen-morphology

Regardless of the consensus on this theme and what it refers to, a variation on the applicability dimensions was experienced across both cases. Surprising the views and conflicts based on moral and professional aspects were merely noticed, although still recorded to honestly reflect the exact tone of discussions with participants. It was important to gather all assenting and dissenting thoughts in one picture to thoroughly judge the variables that derived from this theme.

Participants in CS-2 were more likely to perceive tolerance as a mode of initial recovery rather than a resilient measure, or at least what the expected resilience response should be within the circumstances of the area. The rapidity of restoring the original state was a concern expressed. The commercial, administrative and intergovernmental importance that labelled the area focused the discussion on a faster recovery rather than accepting prolonged inundation conditions. This is why the redundancy measures were frequently highlighted directly, through the suggested projects mentioned earlier. Nevertheless, insights were gained from the perspective of tolerating a maximum level of inundation that still allows access to important sites. Nevertheless, literature cited associated resilience with tolerance when considering resilience in cities. This was the degree to which cities tolerate alteration before reorganising around a new set of structures and processes (Holling, 2011). However, in responding to this theme in CS-1 the researcher noted a slightly altered tone. The main attention was paid to residence classifications, where the extent to which an urban feature tolerates a certain level of inundation was linked to the maintenance of daily needs within the affected areas.

Between similarities and disparities across both locations, tolerance as a resilient urban character was well received and even encouraged in some situations. The absence of immediate salient solutions eventually brought more logical focus to the discussions. However, prestigious and political concerns were not neglected. The findings from both locations were summarised in Table 20.

5.3.6 Morphological index

In this section, Tables 21 and 22 display the morphological contribution involved in the physical solutions gained from participants in both cases. On a scale of 1-5 each of the six themes displayed in the analysis will be given a certain weight with respect to the influence of the urban morphology or the geo-morphology in creating resilient measures. This analysis will help to create an ecological index for each study area. This also helped to inform planners and decision makers on where to heavily invest in developing resilient generated morphology, whether in urban reliability, ecological service availability, or equally on both domains, according to contextual appropriateness.

Summary of findings	
Wadi Adi catchment CS-1	**Al-Kuwair catchment CS-2**
1 Urban design unit	
There was a good level of involvement on the three morphological levels of the urban design unit. Urban reliability encourages interviewees to invest in physical-based insights.	Interviewees were reluctant to respond on the smallest level of the urban design unit. However, interesting insights were experienced on a larger block scale.
2 Runoff sensitive Gen-morphology	
There was a low level of reflection on the adjacent ecology where attention was paid to the physical character of the urban features. However, there was the main connection with the land gradient as an ecological character.	Reflections on this theme significantly featured on the side of ecologically-based interventions. The complex urban context merely offered room for change. However, some organisational aspects were introduced on an urban block level.
3 Accessible generated morphology	
A disrupted ecological setting encourages interviewees to seek cross-location connectedness scenarios. This led to surprisingly mature project based solutions to ease the stress of inundation and vitalise the urban form with viable accessibility options.	Interviewees were mindful of the potential of ecological services in the area. Ecological restoration and recreation-based insights were highly beneficial to draw together the resilience scenarios that will take over in the next, intervention phase step.
4 Redundancy	
Interviewees were critical about two factors leading to successful redundancy measures; the marginal routes and the less occupied land uses and vacant lands. The two factors were closely linked to the type of residence in the area.	There was a little to negotiate redundancy measure upon. Interviewees were burdened with high value land use and the sovereignty identity of the area. However, residence type was not an issue.
5 Redundancy-runoff mitigation	
The clear ground gradient along the urban context was the major natural physical character that most redundancy measures were built around. Alteration to the main road profile was pointed out on many occasions and seen as a source of the problem.	Major insights were built upon significant ecological settings, benefitting from the two major natural streams and the close proximity of the sea coast as the final estuary. A detailed vision was remarkably addressed on temporal based redundancy measures to sacrifice one lane of the main transportation route in favour of another lane, for use as an emergency two way route through an effective super elevation design.
6 Tolerated generated morphology	
Residence type was given the most attention by interviewees when reflecting on this characteristic. Maintaining a minimum required level of daily needs was legitimating urban form tolerance to inundation circumstances.	Interviewees were highly alert to responding to this issue. Even with maintaining the minimum accessibility level to important locations, interviewees were not happy compromising prolonged inundation situations, even with guaranteed accessibility. But eventually with the absence of salient solutions tolerance was appreciated cautiously.

Table 20: Summary of Findings

No.	CS-1	Urban morph	Geo morph	Gen-morph	Non-physical
1	Urban design unit	3	1	4	1
2	Runoff sensitive gen-morphology	2	3	5	-
3	Accessible gen-morphology	2	2	4	1
4	Redundancy	3	1	4	1
5	Redundancy-runoff mitigation	3	2	5	-
6	Tolerated gen-morphology	2	2	4	1

Table 21: Morphological index for case study one (CS-1)

No.	CS-2	Urban morph	Geo morph	Gen-morph	Non-physical
1	Urban design unit	2	1	3	2
2	Runoff sensitive gen-morphology	2	3	5	-
3	Accessible gen-morphology	2	2	4	1
4	Redundancy	2	2	4	1
5	Redundancy-runoff mitigation	2	3	5	-
6	Tolerated gen-morphology	1	3	4	1

Table 22: Morphological index for case study two (CS-2)

5.3.7 Conclusion

The implementation of the case study design on the two locations reveals slightly altered tones; nevertheless, the main themes discussed were fairly similar. The implementation and response from CS-1 was smoother and encountered less controversy. While some surprising and relatively discouraging responses were experienced within some themes in CS-2. Similarities and disparities examined across the two cases will be summarised in the next section. The focus on the cross analysis will be on those areas that best reflect the geomorphic-based variables. Non-geomorphic variables referred to as planning or economic and as shown in the codes index Table 2 and 4, will be disregarded in the analysis. They will be considered non-physical contextual variables. The final variables, resulting from pattern matching, were assigned for recoding to appropriately device the instrumental framework. They are explained in Table 23.

5.3.7.1 Urban-ecological reliability-liability

The main issues discussed here are relevant to the trade-offs between the urban morphology and geomorphology across the two locations. Both locations had a clear urban character and significant ecological identity. However, investigating the situation individually at each site yielded different perspectives. The urban setting in CS-1 is simpler than CS-2, with its light mixed use of residential-commercial occupations. Figure 50 shows the two old and new residential neighborhoods and the mixed use corridor. These three land-use categories thrive alongside the main transportation route of the Al-Nahda road, which consists of a major stress zone during flooding times that affects the premises on both shoulders. The area has a clear and simple urban identity but has a heavily disrupted ecology. Major natural streams are almost diminished with the urban development, and have ended up completely under the construction of the Al-Nahda road. Analysing the DEM photos reveals that the original natural setting in the area had a coherent stream network. Taking into account this fact and the clarity of the urban form mentioned above, this area is addressed as ecologically liable and urban form reliable. In another words, solutions will lean towards urban morphology rather than geomorphological. Evidence from participants' feedback supports this, when the important physical intervention suggested was to revive two isolated watersheds by reconnecting them in one transportation route scheme.

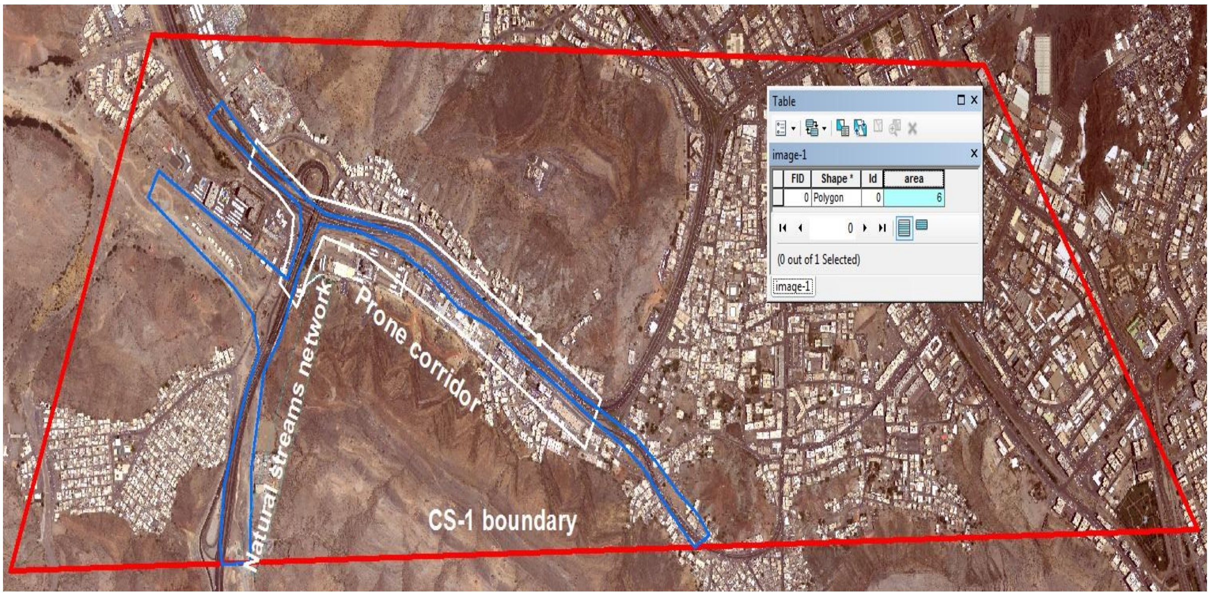


Figure 50: CS-1 catchment

In comparison, the urban setting in CS-2 is more sophisticated than CS-1, where the researcher has to consider the highly specialised mixed and administrative land use. Figure 51 shows the four land use corridors. These four land use categories thrive around a network of transportation routes, the main of which is Sultan Qaboos Street (SQS), which is also a major prone zone. The inundation occurring on this route affects the two corridors that are adjacent to both its shoulders.

The urban area has a complex range of specialised activities but a clear ecological identity. Major natural streams are finding their way to the final downstream estuary on the seashore. However, DEM photo analysis reveals an almost diminished part of the original watershed linking the two major streams that run across the area. This part of the natural steam network is completely disfigured under the construction of an elevated green zone that separates the main SQS from the ministries district. Taking into account the ecological clarity and the urban setting complexity, this area is addressed as ecologically reliable and its urban form, liable. In another words, solutions will lean towards geomorphology rather urban morphology. Evidence from participant feedback supports this description where the important physical intervention suggested was to reconnect two isolated natural streams by stimulating the original watershed character in order to ease the inundation stress on the major transportation route of SQS, and the adjacent affected corridors on both sides in one ecological restoration scheme.

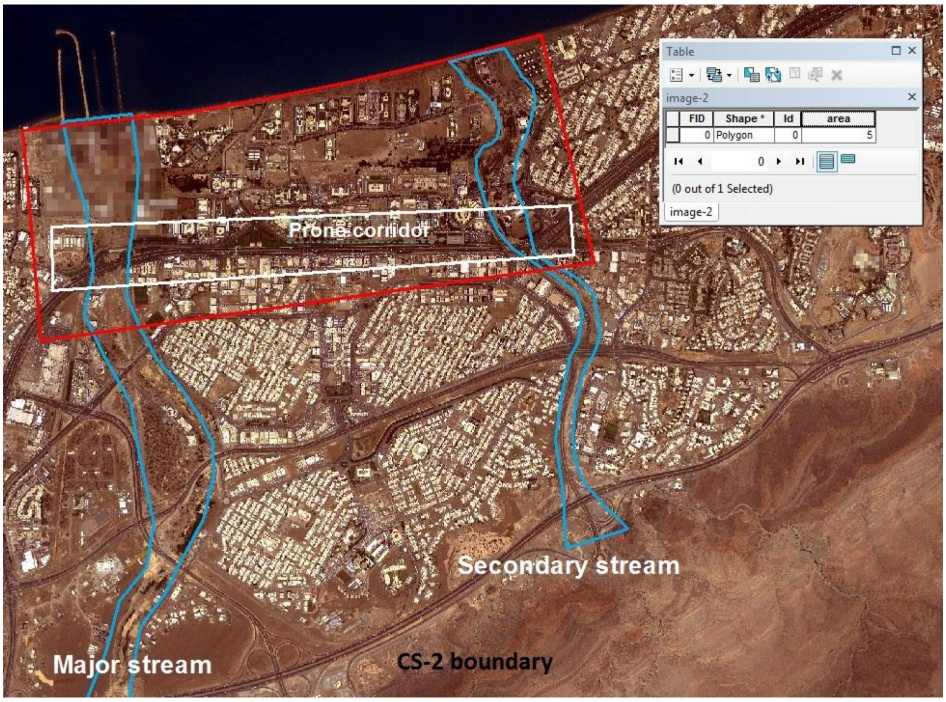


Figure 51: CS-2 boundary

5.3.7.2 Design to confront runoff excess

Most of the reflections on the themes surrendered to the reality that full protection scenarios are an impossible immediate task. Within the conception of resilience thinking, participants were negotiating their way through the reduction of escalating inundation water levels, whilst also bearing in mind that the speed at which the flood waves travel was not considerable, and that attention is paid to the depth of inundation.

Insights focused on a tolerable depth of inundation at which fragile age groups, like the elderly and children are not endangered and have access to safer places. This was on the smallest, or local within block, level. Attention was also paid to the accessibility of automobiles on a cross block level. For technical reasons associated with car engineering, these two accepted levels for pedestrians and automobiles are convergent. However, most of the insights appreciated measures that reduced excessive levels of inundation to those areas that were temporarily livable, accessible and potentially requiring shorter recovery courses.

5.3.7.3 Design to facilitate runoff conveyance

The second main important philosophy gained from the analysis was the conveyance of stressors. It involved facilitating the safe travel of surface runoff water to final natural destinations, rather than curbing the flow with insufficient infrastructure and poor urban design. This stemmed from the prototypical behavior of any natural watershed where flooding and surface runoff are essentially part of its natural existence.

A conveyance philosophy was experienced through design specific insights. Participants were enthusiastic and productive in responding to this type of thinking, which was stimulated through face-to-face discussion. This orientation was also highlighted in the literature; ideas like the sponge city, aqua-urban solutions, and living with water scenarios actually respond to the problem beyond the local considerations of single prone locations, but instead with a comprehensive awareness of the planet-scale dilemma that best defines this age.

5.3.8 Generated morphology resilient response model

The process by which the built up environment responds to stressors is not linear. It is a cyclic process of response, evaluation and progression. In best cases, if this mode of response was not attributed to the escalation of the occurrence and magnitude of natural extreme events, then it is at least associated to the unpredictable nature of natural events. In worst-case scenarios it is a combination of both. The model in Figure 52 displays the resilient response of the generated morphology across the two cases. The iterative process initiates when the generated morphology confronts a natural stressor and responds accordingly. The aim is to gain a reliable existence throughout the stress conditions in order to reach a new stability that is built on experience gained from stressors until facing a new stressor.

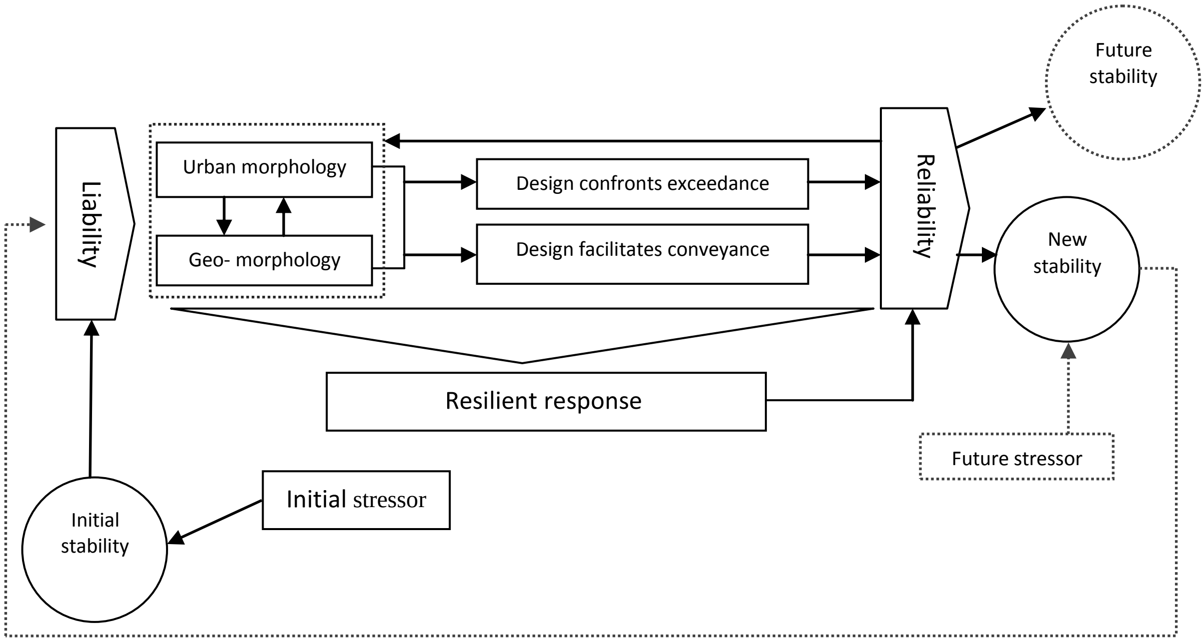


Figure 52: Summary of resilience response in both cases

CS-1 Variables	CS-2 Variables	Patterns matching and recoding for final variables	
Flow pathways	Routes connectedness	Flow pathway enablement	YES
Space interconnectedness-plot level	Conveyance space	Within-plots space alignment	YES
Horizontal space flow - block level	Block re-clustering for flow pathways	Within-block space incorporation	YES
Collective plot order-meso level	Plots geometric adjustment	Overall plot cluster geometry	YES
Fencing (Building level)	Plot levelling	Open space flatness-physical barriers clearance	YES
sealing (Building level)	Absorbent space		YES
Meso gradient design	Assisted Natural discharge	Gradient oriented design-meso level	YES
Micro gradient design	Built Artificial discharge	Gradient oriented design-micro level	YES
Prone-non prone areas linkages			NO
Safely elevated areas linkages	Rescue pathways	Non-prone pathways alternatives	YES
Linear layout – grid layout			NO
Gradient-parallel	Dynamic route design	Gradient-parallel main transportation routes	YES
Elevation responsive	Responsive road's super elevation		
Path dependency	Flow enabled route design	Gradient oriented routes design	YES
Flow facilitating spatial order	Open space connectedness	Spaces compliance with natural flow pathways	YES
Flow fragmentation	Discharge rapidity		YES
Reliable intervention	Over ground block connectedness	Building-space Infill-(small scale reliability)	YES
Costly retrofitting	Block re-clustering	Retrofitting scale-regeneration-(cost dependant)	YES
Liable evacuation			NO
Upstream-downstream location			NO
Within watershed gradient	Gradient path dependency	Identification of Within-watershed gradient directions	YES
Cross watershed gradient	Cross-watershed gradient directions	Identification of cross-watershed gradient directions	YES
Cross watershed linkages		Cross watershed gradient related routes design	YES
Watershed rehabilitation	Preserved ecological quality	Watershed restoration	YES
Natural stream rehab.	Natural stream restoration	Natural streams restoration	YES
	Multi nodal route design		NO
	Vertical retreating		NO
	Multi-node path design		NO
	Flood guided natural restoration		NO
	Automobile accessibility		NO
Food & water			NO
Health services			NO
Flow enabled design			NO
Ground level waterlogged-tolerated design	Ground mass de-intensification	Downstream de-intensification	YES
Low occupancy rate	Land use redistribution-desensitization	water-logged places desensitization	YES
Land use Redundancy	Interference zone de-intensification	Land use redundancy	YES
Land Absorbency	Over ground storage	Enhance upstream retention capacity	YES
Ground level waterlogged-tolerated design	Ground mass de-intensification	Ground floors land use redundancy	YES

Table 23: CS-1 & CS-2 Influential variables

5.4 Section 4: Developing the instrumental framework

5.4.1 Description of phenomena boundaries, impact stages and resilient response

This section displays the instrumental framework developed from both the face-to-face, semi-structured interview analysis and the literature review. The framework is built to describe a comprehensive instrument, which fundamentally consists of factors and variables resulting from participants' feedback. The research unit of analysis (generated morphology) depicts the structure around which this framework is constructed.

This framework is developed as a logical transition with antecedent research phases. The framework is built to support decision makers in the enablement of resilient responses to the urban context with flood mitigation labels. A responsive urban design deploys influential physical variables to adjust the urban form (internal context) interdependently with the surrounding ecology (external context) to reproduce an eco-compliant urban form with a resilient response (content) to pluvial floods. Figure 53 demonstrates the entire phenomena boundary within which the sequences of resilient responses will be developed. The initial impact made by flood takes place in the impact zone, directly affecting the generated morphology (unit of analysis). This in return will release interdependent physical interactions between the external-internal contexts to shape the initial resilient response (content) in the zone of influence. This will finally stimulate the physical mitigation solutions.

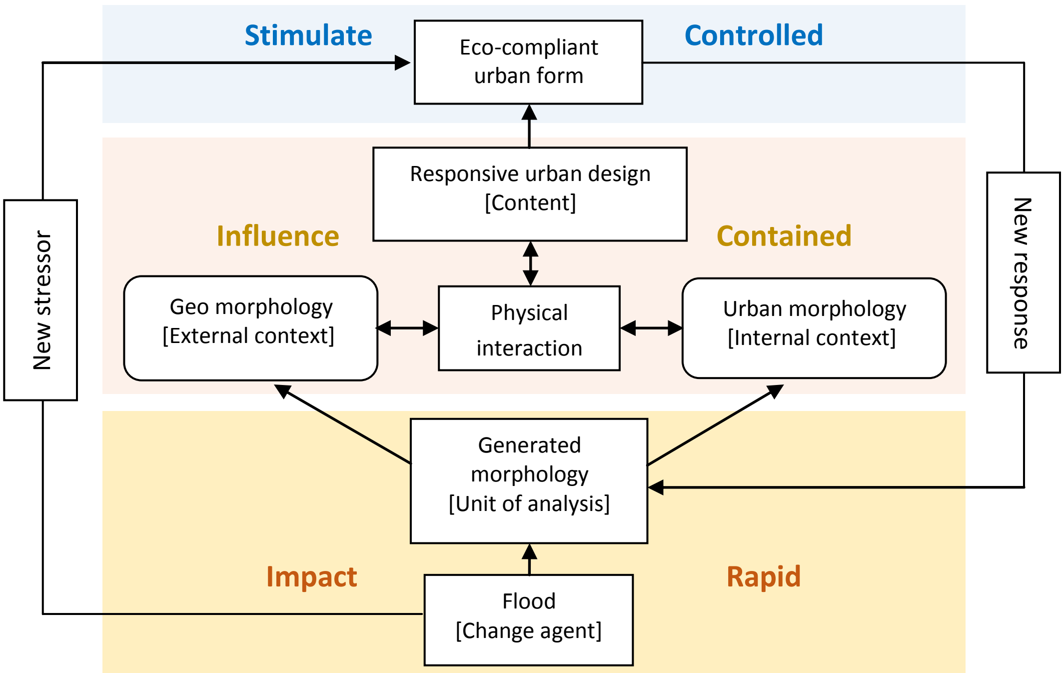


Figure 53: Phenomena boundary & impact stages and response

5.4.2 The type of response

There are two types of resilient response to stressors; a reactive (due course) response addresses the situation where resilient measures are subsequently pursued in the aftermath or after a series of infrastructural failures (shown in Figure 54). This will result in different mitigation scenarios, rather than the case pro-active response (eligibility courses) shown in Figure 55, where resilience measures are previously implemented in preparation for the problem. Although, the two prone locations of interest are first category settings, this is not surprising as it reflects the case in most places around the world, due to two key reasons; the first is resilience thinking which has recently prevailed, although is not yet seriously considered and translated into action. The second is related to the prototypical mode of infrastructural disaster resistance paradigms, where urban layouts are developed upfront and the infrastructure protection schemes come later. Structural variations between reactive and proactive types of responses are shown in Figures 54 and 55.

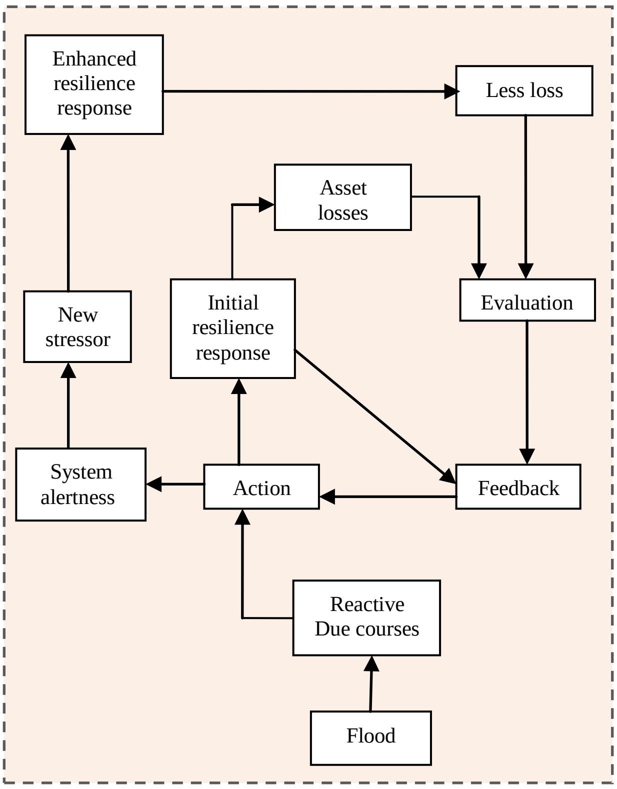


Figure 54: Due for resilience/re-action response

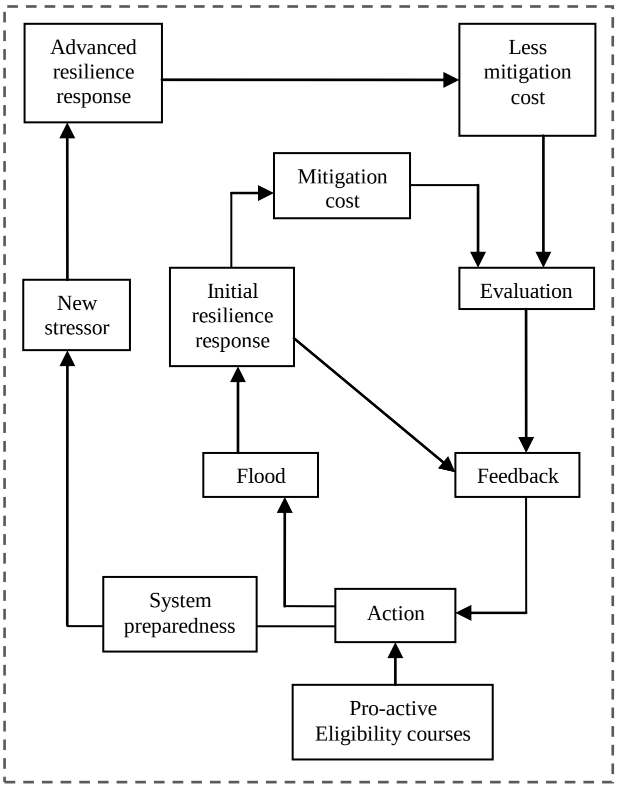


Figure 55: Eligible for resilience/pro-action response

In the two cases under investigation, mitigation scenarios depict the first resilience paradigm depicted in Figure 54, as all the infrastructure is established to meet the fail-safe logic of infrastructure resistance (explained in Chapter 2). This, in a way, signifies one of the research limitations in introducing a new way of thinking about resilience within an already existing system that has developed over many years around infrastructure robustness. However, the research task is not to force structural changes as much as to demonstrate the realisation of the benefits gained from the logic of safe-to-fail approaches concerning the resilience of urban design.

5.4.3 The instrumental framework

This section presents the instrumental framework developed from the analysis of the semi-structured interviews. The framework demonstrates the causal relationships from the initial themes to the specific factors and variables. The underlying cohesion between the two main physical dimensions of the urban context is the most important relationship demonstrated in this framework. This is represented by displaying the linkages between the physical dimensions of both ecology and urban design.

The framework is materialised and led by two major categories, the geo-morphology and the urban morphology that combine in the generated morphology to absorb the impact and demonstrate the response. Each of these two major categories is informed by the resilience principles, each of which diverges into factors and variables. The framework provides a general instrument with influential variables. These variables were taken from both case study boundaries. They were matched and re-coded to build one set of final influential variables, shown in Table 23. Eventually, selective variables will be chosen for a combination of physical intervention scenarios. Although marginal disparities between influential variables can be seen in the code index tables (Tables 17 and 19), for both cases, the final influential variables are incorporated through a cross case synthesis and presented in their final layout in the instrumental framework (Figure 56).

5.4.4 Geo morphological level

In the first of the two main categories of the framework, participants' insights, a critical theoretical review, and the review of government documents and reports helped to develop the general contribution according to which the natural settings will represent a resilient response. In this category, the focus will generally be on the sole contribution and character of the natural setting in both locations, as there will be a mutual response for both the urban and geo-morphology. Characteristics of significance within the adjacent ecology that will influence the structure of the instrumental framework are as follow:

5.4.4.1 Ecological restoration

This section is about the measures and prerequisites taken to enhance the damaged ecological performance by the overexploited urban process. Interviews witnessed a wide range of suggestions to boost the ecological service that has suffered from negligence. Among all the experienced insights, the following were proved influential variables:

a) Natural stream restoration.
b) Flow pathway enablement.
c) Watershed restoration.

5.4.4.2 Ecological services

The ecological adjustment is about maximising the benefits of the existing ecological services to improve the mitigation scenarios. Experienced insights focused on maximising the functionality of well-established ecological services and re-operationalising those that were disrupted by urban development. Effective influential variables are:

a) Identification of within-watershed gradient directions.
b) Identification of cross-watershed gradient directions.

5.4.4.3 Urban morphology

This is the second category of the generated morphology duality. This part generated important insights from participants. Feedback on this category concerned how flood mitigation can produce responses that are both sophisticated and specialised. Substantial contributions made on this section resonated with the prototypical urban practices and common faults that were deeply nested in the urban systems. The interactions on this topic were experienced by the researcher as wake-up calls that echo far beyond routine practices. Insights were gathered on project-based interventions with a clear vision on implementation, and internationally relevant examples were offered by participants as successful mitigation practices. Characteristics of significance in the urban morphology for the instrumental framework are as follows

5.4.4.4 Urban space management

The character of flood phenomena, as a volumetric manifestation, and the propagation and depth of the flood wave gives priority to urban space as an important arena for expected change. Urban space has long suffered from over exploitation and violation by favoring built up areas over open space. The reasons for this are unclear, whether this is due to a lack of policy enforcement or to the importance of land use zones or the absence of awareness of the importance of open spaces within the urban context. Whether part or all of these reasons are behind the depletion of the urban space, this unfortunately reflects negatively on the capacity of urban forms to deal with extreme events. Among all the points raised, the following proved influential variables:

a) Control building-space ratio over-exploitation
b) Enhance open space standards
c) Municipal-led desensitised land use management
d) Identify zones of interference

5.4.4.5 Urban space restoration

Some important feedback was gathered in response to questions within this category. Technical suggestions with direct physical parameters were suggested by participants. These insights were influenced by geometric assence and associated with the urban design discipline. The relevant influential variables that fed the framework are:

a) Within-block space incorporation
b) Overall plot cluster geometry
c) Within-plot space alignment
d) Open space flatness-physical barrier clearance

5.4.4.6 Urban morphological adjustment

This category is specified to the physical interventions of urban design that restore the performance of the urban form in extreme events. In the study areas, the urban capacity to occupy and transfer surface water has been in consistent deterioration throught the last fifteen years, as the historical rain gage stations have shown. This was a reflection of inappropreate urban practices. Thus, insight gathered from discussions around this topic directly addressed reformative urban design techniques, which were the influential variables of:

a) Building-space infill-(small scale reliability)
b) Retrofitting scale-regeneration-(cost effectivness dependancy)
c) Water-logged places desensitisation-(land use management)
d) Land use redundancy
e) Ground floor land use redundancy

5.4.4.7 Generated morphology level

After addressing the sole contribution of urban morphology and geo-morphology in the structure of this framework, the third section describes the geometrical nexus between these two morphological levels that form the generated morphology. Three out of six questions addressed the generated morphology driven by the theoretical resilience framework developed. Influential variables from this level are represented across three categories, as shown:

5.4.4.8 Natural-built space adjustment

a) Enhance upstream retention capacity (surface sealing ratio & retention pounds)
b) Downstrem de-intensification (land use hollowness)

5.4.4.8.1 Natural-built path dependency

a) Space design in compliance with natural flow pathways.
b) Gradient-oriented route designs
c) Gradient-parallel main transportation routes
d) Cross watershed gradient related route designs
e) Non-prone pathway alternatives

5.4.4.8.2 Cross natural-built surface gradient

a) Gradient-oriented design-meso level
b) Gradient-oriented design-micro level

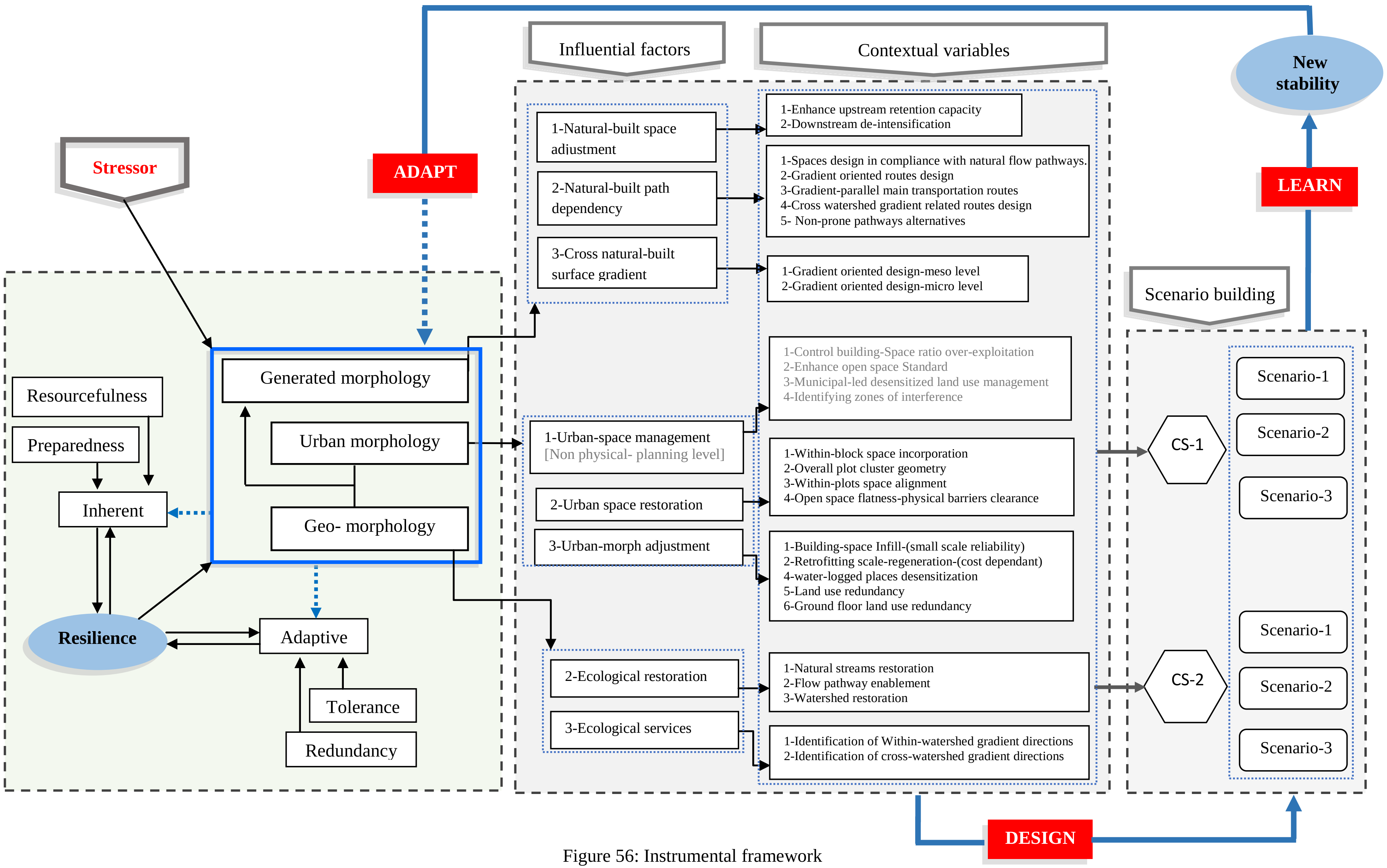


Figure 56: Instrumental framework

5.5 Summary

This chapter outlined the content analysis and findings from the two case studies, CS-1 and CS-2. A description of the findings was demonstrated through general themes and factors that arrived at the influential physical variables. The two case analyses were followed by a cross case synthesis, identifying similarities and disparities in the two areas responses. Also, the ecological and urban significance for each case was explained. The previous stages prepared for the next stage of developing the instrumental framework.

The instrumental framework will aid the process of the next chapter, which is the scenario building, where a selection of physical variables will be placed in different intervention scenarios. A simulation platform will run the flood circumstances for each developed scenario. The result reflects the extent of mitigation and will help to judge the viablity of the selected scenarios.

Before moving towards implementation a decision making process is required, however this is outside the scope of this research. Nevertheless, the reserch has developed a diagram that will be available and potentially useful to decision makers. The diagram encompasses scenario mitigation extents that can be compared with the current prone situation. It also identifies the cost of scenarios and the implementation practicalities that need to be understood by the decision maker in order to have a clear picture of whether to continue with implementation, to postpone, or take a decision on the next scenario. The next chapter will continue the scenario building process for the two case studies.

Chapter 6: Physical intervention scenarios

6.1 Introduction

This chapter describes the physical interventions scenarios developed to mitigate flood consequences, and represents the quantitative part of this research. Variables driven from the analysis of each case study will selectively stand for numerical quantification within the software in order to calculate their influence on the current prone situation. Scenarios were built from factors and variables extracted from the analysis of the two case studies. The developed mitigation scenarios were driven from both urban design and ecological natured parameters. A set of variables were selectively grouped to build one mitigation scenario generally based on direct recommendations from participants during the interview process. The researcher's experience, observations and acquaintance of the case study areas helped with shaping these scenarios into appropriate and cost effective implementations. Creswell, (2009, p.212) stated that, 'in mixed method, researchers have to make some decisions about which findings from the initial qualitative phase will be focused on in the subsequent quantitative phase.' At least one scenario was developed for each study area, based on the following guidelines:

1. Scenarios stemmed from the convenience of the chosen physical variables.
2. Underpinned with cost and implementation reliability.
3. Project based interventions comprise two or more variables.
4. Generally driven from the analysis and specifically from participants' insights.
5. Guided by the researcher's experience, knowledge in the area and direct observations.

6.2 Data processing phase

The geo data set (DEM, satellite images, and urban and natural features shape files) was initially processed in Arc GIS (ver. 10.1). The processing includes various operations on the DEM (digital elevation model) layer. This includes, but si not limited to, the satellite image and the shape files of the existing land uses, road networks, natural settings and other features on the ground that were digitized for the convenience of the analysis. The geo data set was processed into two consequent phases: firstly, the data-processing for the current situation, and secondly, data-processing for scenarios.

6.2.1 Phase one: Data processing for the current situation

This phase included the handling of the geo data set to prepare it for the current situation simulation and analysis in order to build the status-quo conditions for the case study area. This allowed a comparison background to contrast against the later scenarios. The current situation data processing covered the following:

6.2.1.1 DEM processing

The processing in this phase allocated the area of interest for the analysis according to the boundary of the prone areas. This was achieved by clipping the Digital Elevation Model (DEM) for the study area boundary out of the DEM layer of the Muscat metropolitan area, shown in Figure 57. The process was carried out by establishing a polygon in Arc GIS depicting the preferred boundaries of the case study area. The established polygon masked the desired area out of the whole DEM layer of Muscat area. This will efficiently facilitate analysis in terms of precision and processing time.

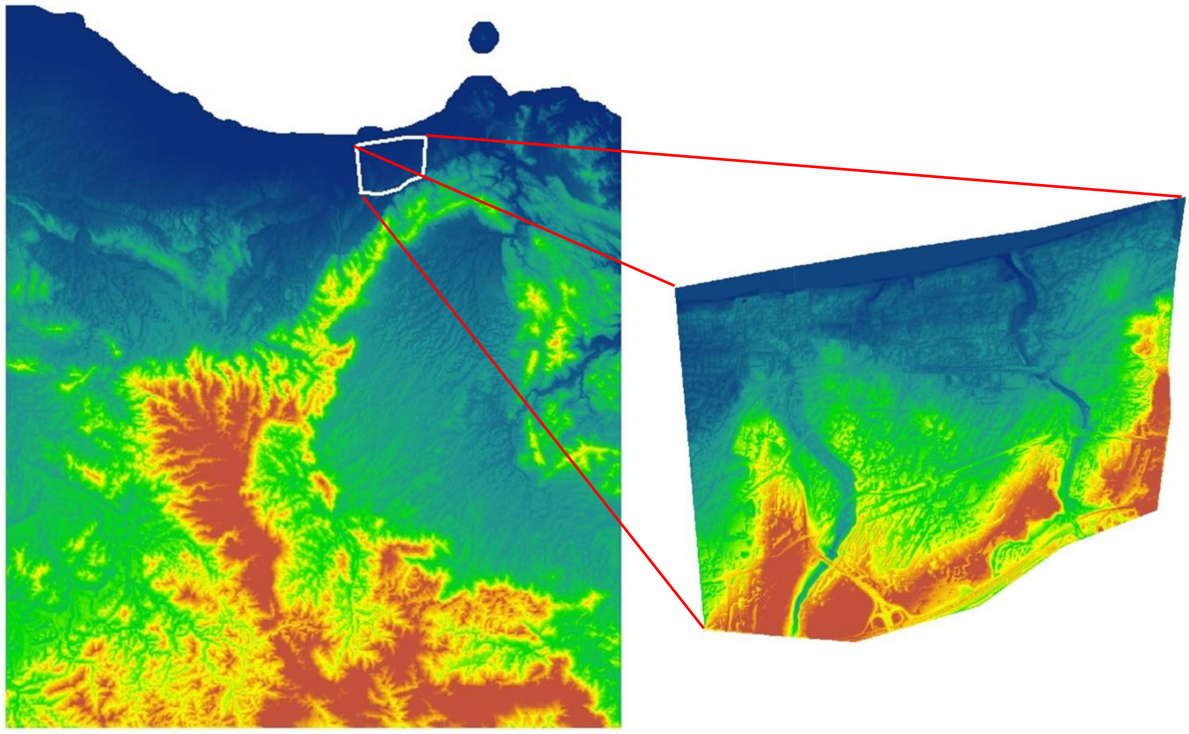


Figure 57: Muscat DEM layer with a close down to the DEM layer of the study area CS-2

6.2.1.2 Satellite imagery processing

A resolution of (5m) satellite imagery was acquired from the data provider, the SCP in Oman. These images came in the form of mosaic batches specified with unique ID and located as shown in the mosaic diagram in Figure 58. The area of interest was outlined and elaborated to form separate layers of batches that exhibited the case study boundaries. The selected batches were processed in Arc GIS to form one mosaic for the purpose of analysis appropriateness, (shown in Figure 59).

CS-1 covered the (FM5208/FM5210/FM5212/FM5214/FM5608/FM5610/FM5612/FM5614) mosaic batches with a total of eight batches; meanwhile, CS-2 is comparatively smaller covering a total of six mosaic batches, and they are; (FM4008/FM4010/FM4408/FM4410/FM4808/FM4810).

Figure 58: Muscat area satellite imagery batches

Figure 59: CS-2 mosiac

6.2.1.3 Digitizing

Digitizing is the process of transferring selected features on the ground from its raster format into a vector format to facilitate further analysis. In Arc GIS, there are three ways of doing that throughout three geometric elements; point, line, and polygon. The point is normally used to identify the location of a small urban feature, like tree or a lighting pole; a line is mostly used to digitize roads or pipe lines and other linier features, whilst a polygon corresponds with features with a certain surface or an area, like a building, road profile, or/and natural features, like parks or lakes.

The digitizing process was carried out mostly for buildings, building blocks, streets, natural streams and open and vacant lands, and this was mostly done by using the polygon feature in Arc GIS. Separate layers of digitized information were built to facilitate the flood simulation. Among all, there were the land use layer, road layer, and some site-specific features like open areas and natural streams. Figure 60 shows the digitized layers used in this analysis for the case of CS-2.

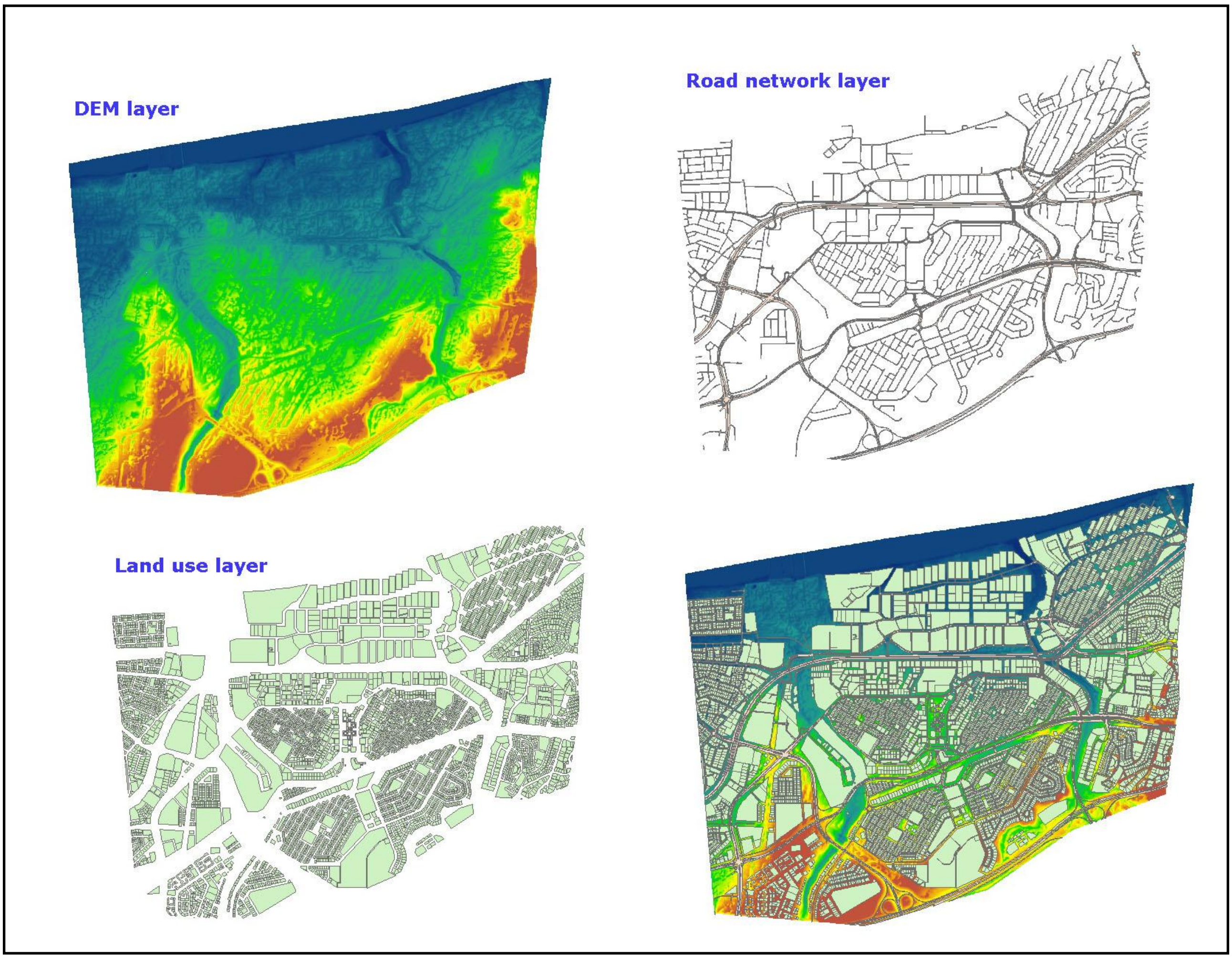


Figure 60: CS-2 Digitized layers

6.2.2 Phase two: Data processing for scenarios

This phase demonstrates adjustments conducted on the geo data set to facilitate the building of the desired scenarios. A group of urban design and natural-based parameters were adjusted according to the developed scenarios to allow a simulation of the flood wave in the study area with the newly introduced physical interventions. Adjustments will make changes to the current elevations, dimensions, directions, size and/or allocation of built and natural elements in the generated morphology of the urban context.

The technical aspect of how these changes were introduced is explained in each scenario as they were site specific changes. Figures 61and 62 exhibit an example for the processing stage; they are the DEM's of the existing situation along with scenario situation. The DEM was manipulated to simulate the restoration of a demolished stream that should connect to parts of the watershed and maintain important parts of the lost natural flow process.

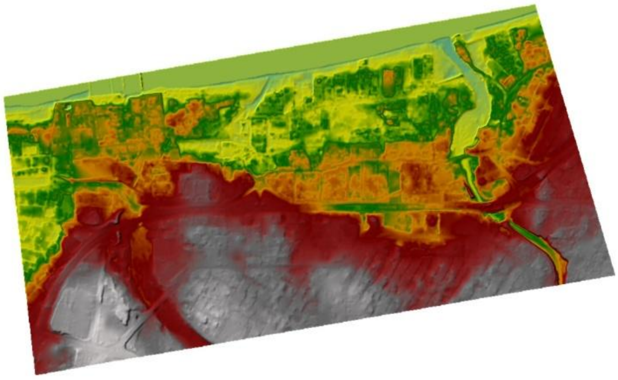


Figure 61: Existing situation DEM

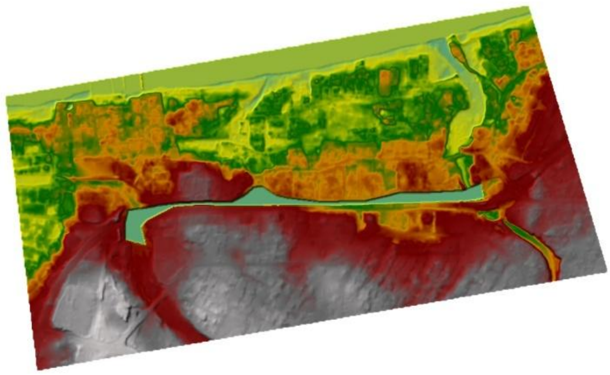


Figure 62: Scenario-1 situation DEM

6.3 Analysis phase-scenarios crafting

Intervention scenarios were modeled through the software in two stages; the first resembled the existing situation and how the surface runoff reacted with the existing urban setting based on historical rainfall data. This allowed the analysis to simulate the surface flow situation to be compared with the subsequent phases of intervention scenarios. A description of the second phase will follow after introducing the physical variables driven from the analysis in one predefined scenario. Scenarios will be established based on the chosen variables; the urban setting was altered into new physical setting where both morphological and geomorphological related measures were in place. The new generated morphology allowed the propagation of a new flood wave onto the new setting to explore the extent of mitigation. The two faces were handled in Arc GIS software in the pre processing phase, and afterwards were simulated in the flood simulation platform (HEC RAS 5.0.3). All scenarios were processed according to this method. The influence by which the flood propagation decreases in depth and coverage area determined the salience of the physical solutions.

Scenarios varied in orientation following the potentials in each area. As mentioned in the cross case synthesis, the two areas had different urban and ecological footprints. The cross case analysis revealed that the main identification of the two case study areas were in the sense of urban and ecological reliability-liability. It was concluded that case study one (CS-1) was found to be ecologically liable and reliable in terms of urban context. In contrast, case study two (CS-2) was ecologically reliable, reflecting an urban context liability. This was echoed directly on the pathways of mitigation solutions and led the scenario crafting.

6.3.1 CS-2 Scenario crafting

Initially, flood simulation was made available for the existing situation for comparison purposes. Consequently, three scenarios were developed for case study two (CS-2). The three scenarios were developed with respect to the selected variables. They were as follows:

- Scenario one: upstream-downstream flow conditions rehabilitate.
- Scenario two: mitigating road corridor surface runoff by a natural stream restoration.
- Scenario three: a combined scenario.

6.3.1.1 CS-2Existing situation

In this simulation, the current situation with the existing urban and natural settings will be simulated against an extreme flood event that was ranked as a one hundred year return period, storm that took place in June 2007. A tropical cyclone, called Gonu, (shown in Figure 63), hit Oman generally and the Muscat and southern coast regions severely; however, the impact was the worst in the Muscat region in terms of assets loses. Further statistics about the event are attached in appendix-1.

Figure 63: Cyclone Gonu 2007, and CS-2 area one day after the cyclone ends (SCP)

The module was prepared in Arc GIS by elaborating the DEM and the aerial photo to the extent of the case study area boundaries. The digitizing stage followed to demonstrate the important land use and road layouts among other natural and manmade features. The processed geo data set was introduced to the HEC RAS platform, (shown in Figure 64), to simulate the existing flood situation of that extreme event (shown in Figures 65 and (66).

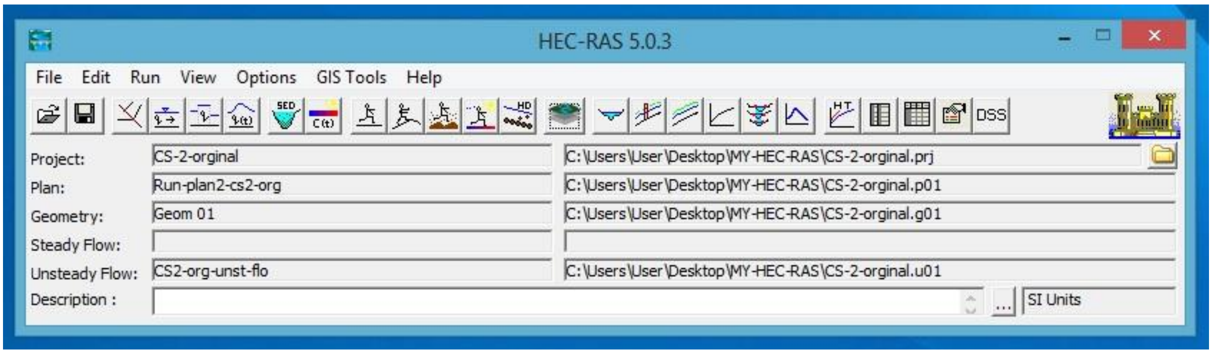


Figure 64: HEC RAS platform for CS-2 existing situation

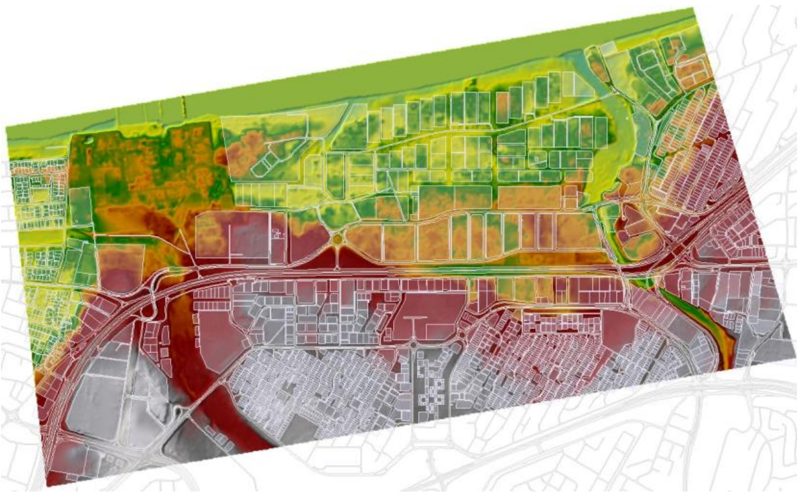


Figure 65: CS-2 before-event condition

Figure 66 displays the full flood magnitude of the situation; this was before any intervention scenarios. The result of this simulation will build the comparison background for all scenarios in terms of flood wave depth, direction and coverage area. Although depth and coverage area were the most important readings in the case of this study, due to the reasons explained in the literature review and the content analysis, one of HEC RAS platform capabilities is to measure the travel velocity of the flood wave. The flood wave velocity was monitored all the way through from the initial conditions to the final event outcomes. No significant runoff velocity was found to be merit recording.

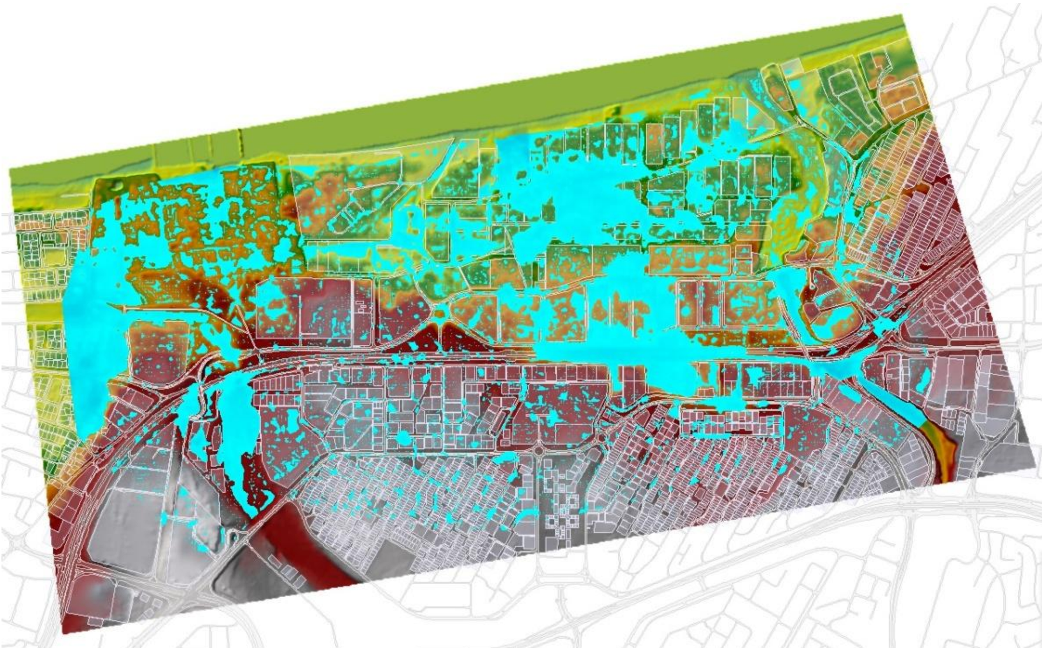


Figure 66: CS-2 full flood magnitude end-of-event

6.3.1.2 Results

A profile line was asigned along the affected corridor, shown in Figure 67. This profile line depicted the peak of the event. A combined model of rainfall data and natural stream flow was built in HEC RAS platform, shown in Figure 68. The module simulated an unsteady flow resulting from 16.5 hours of convective rainfall in the study area, referred to as CS2-org-unst-flo in Figure 64. The extent of the flood wave depth and coverage across the event period was indicated. The profile line shows the levels to which runoff depth and coverage were arriving. The area between 1.4 km and 2.3 km, (in Figure 67), was heavily susceptible to inundation. A maximum depth of around 1.6 metres was recorded as a peak flood depth at some point on this part of the main street corridor. Meanwhile, the real reading taken from the ground at that time was 1.65 at aproximately the same location. The result from the simulation is 0.05 meters less than real measures recorded in 2007. Arguably, this can be considered a good indicator for the simulation precition, as, according to the general logic governing the tolerance of error margins, a 3% metre is a tolerable marginal error. This initial judgment in the circumstances of the overall resolution of the digital elevation model images (DEM) is made with a horizontal resolution of 5 metre s and vertical resolution of 0.2 metres.

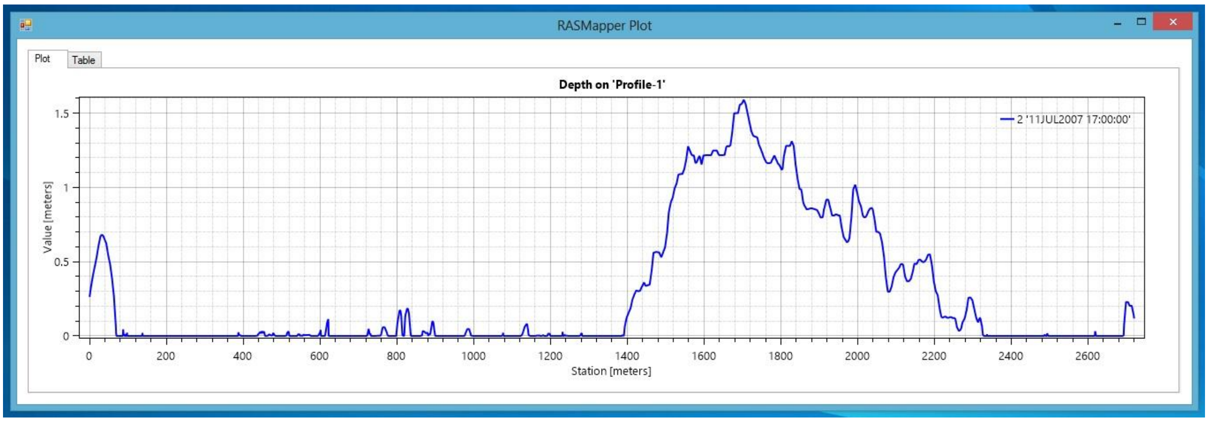


Figure 67: CS-2 Existing situation profile line along the prone corridor

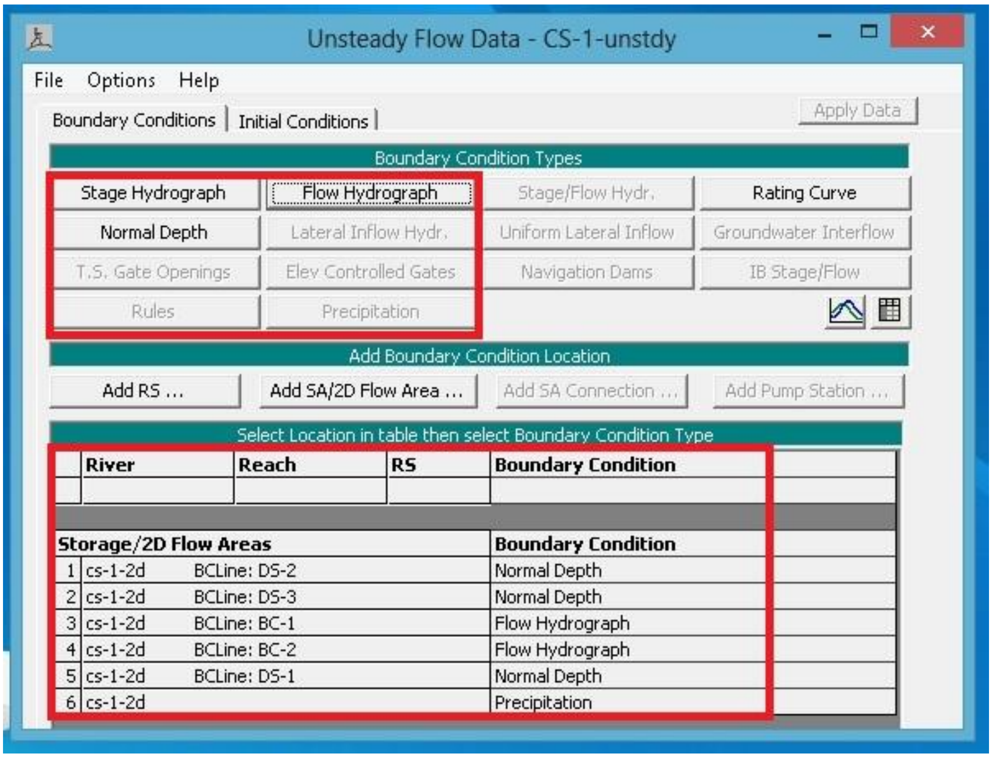


Figure 68: Combined rain-unsteady flow parameters interface in HEC RAS

6.3.1.3 CS-2 scenario one: major stream restoration

Mitigation scenarios were developed, as previously stated, according to several factors among which featured participants' insights, the researcher's experience and the evident potential of the adjacent ecology. The first scenario for CS-2 stemmed from four influential variables from three different morphological levels; urban morphology, geo-morphology and generated morphology. Those variables, along with their reflection in the area of study, are displayed in Table 24.

CS-2 scenario one variables and reflections		
Variables	**Variable orientation**	**Variable manifestation**
▪ Natural stream restoration ▪ Watershed connectedness	Geo-morphology	▪ Natural stream course was restored. This was done in the virtual environment of Arc GIS giving interpolated geometric characteristics for this feature according to its starting and ending point. ▪ The restored natural stream was originally connecting the two major streams running across the study area. Having them connected as they were in their original context will meet the variable set to this scenario.
Land use redundancy	Urban morphology	Green area that covered the vanished natural stream was set to be part of natural stream network and flood process. In drying times it can be used as a luxury walking path by providing proper pedestrian pathways.
Gradient oriented route design	Gen-morphology	The dual carriage way adjacent to the restored stream is already designed with cross sectional gradient towards the green area. This slope was causing a problem to the clockwise direction as the surface runoff accumulated in it. With the restoration of the stream, surface runoff will steadily the flow into the stream reducing the previous inundation depth to maintain new acceptable limits as it is shown in the profile lines

Table 24: Influential variables for CS-2 / scenario one

Building up this scenario was based on the recommendations of participants during the interview. It was clear in the mind of participants, and from the geographical reality, that the demolition of a previously existing natural stream under increasing urbanism that started 25 years ago has culminated with a total disappearance of this natural feature. This left a significant impact on the hydraulic performance of the area with respect to surface runoff. The restoration scenario was to bring this feature close to its previous setting. The cross section of the existing main street was already designed to have a gentle slope towards the natural stream where it had existed previously, as it was naturally running in parallel to the main street linking two bigger streams that ended at the sea coast. Figure 69 outlines the area boundary's initial conditions with the restoration of the natural stream before the event. Figure 70 exhibits the peak event of the flood wave demonstrated in the HEC RAS flood simulation platform, while Figure 71 examines the end of the event.

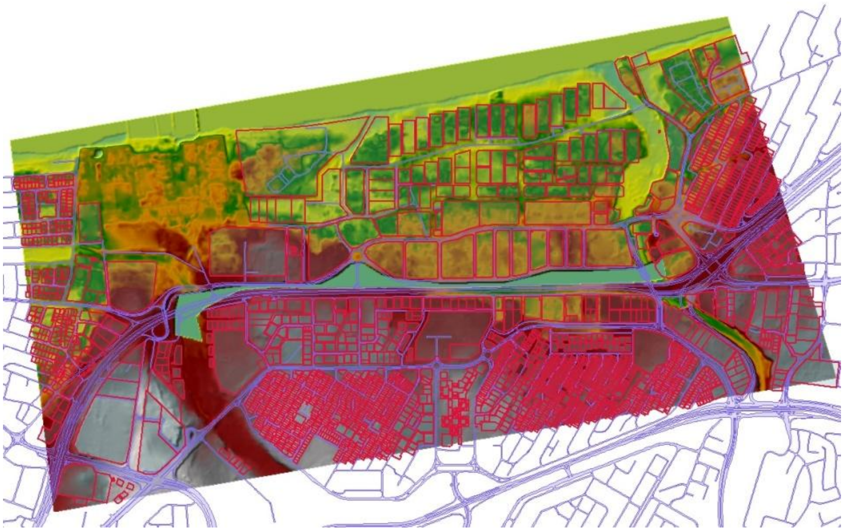


Figure 69: CS-2 Scenario-1 showcasing the restored natural stream

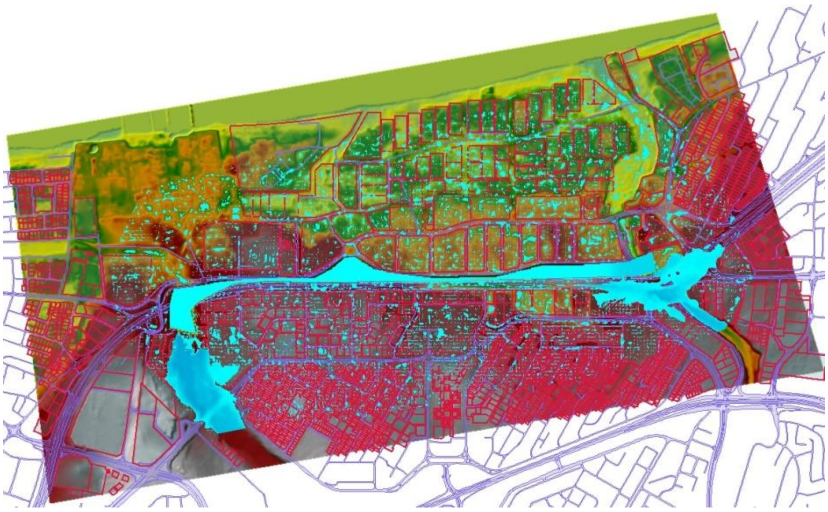


Figure 70: CS-2 Scenario-1 flood wave peak in HEC RAS

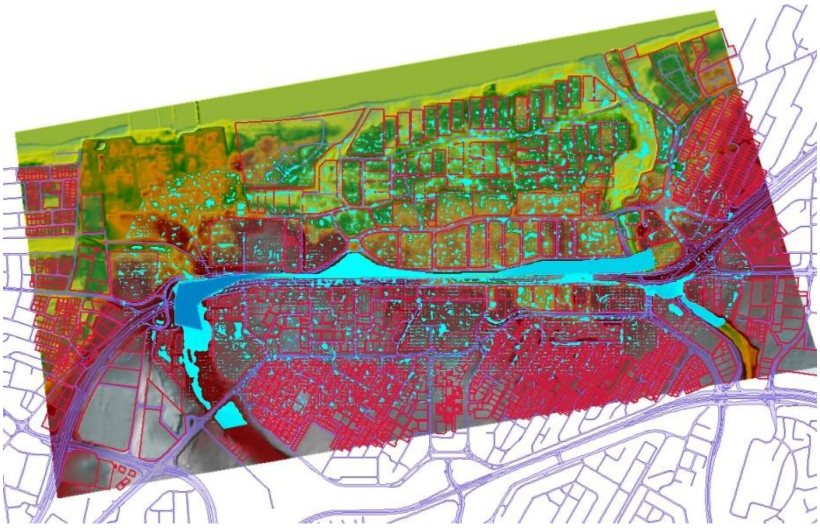


Figure 71: CS-2 Scenario-1 end-of-event wave in HEC RAS

The crafting of the scenario was initiated by feeding the manipulated geo-data set into the simulation platform. This geo-data set was treated and prepared in arch GIS in order to build the physical desired intervention after which a flood simulation phase was facilitated by the HEC-RAS platform. This has clarified the extent to which the changes have influenced a resilient response.

6.3.1.4 Results

Using the capabilities of the HEC RAS platform, shown in Figure 72, a profile line was created along the prone area. The profile line allowed the planner and decision maker to trace the impact extent along its alignment and in different simulation times. Figure 73 shows the profile line and how it was designed to run along the affected area which was inundated with a 1.6 meter surface runoff in the existing situation. The mitigation scenario shows how the depth and coverage of the surface runoff has significantly ameliorated across the whole prone area alignment.

By visually comparing the flood wave propagation through the animated virtual software within the intervention situation, and also by following the event escalation from the start to the peak all the way to the end of event, a noticeable reduction of flood consequences took place along the profile line. Figure 73 shows the maximum levels at which the surface runoff arrived through the event all along the prone area, from stations 0 to 2,3 km. The levels of surface runoff depths fluctuated between 0.01 meter to 0.1 meter at almost the whole alignment, except for the area on the road corridor between stations 1.8 km and 2.05 km, where a significant inundation of almost 0.68 meters was left after the end of event. This is a considerable reduction in flood consequence. These levels were compared to the already recorded levels of surface water depths before introducing the selected physical interventions. The status quo situation witnessed in the simulated event a consistent inundation on the whole road corridor, ranging from station 0 (1 meter) all the way to station 1,1 km and 0.6 - 0.3 meters along the rest of the prone corridor.

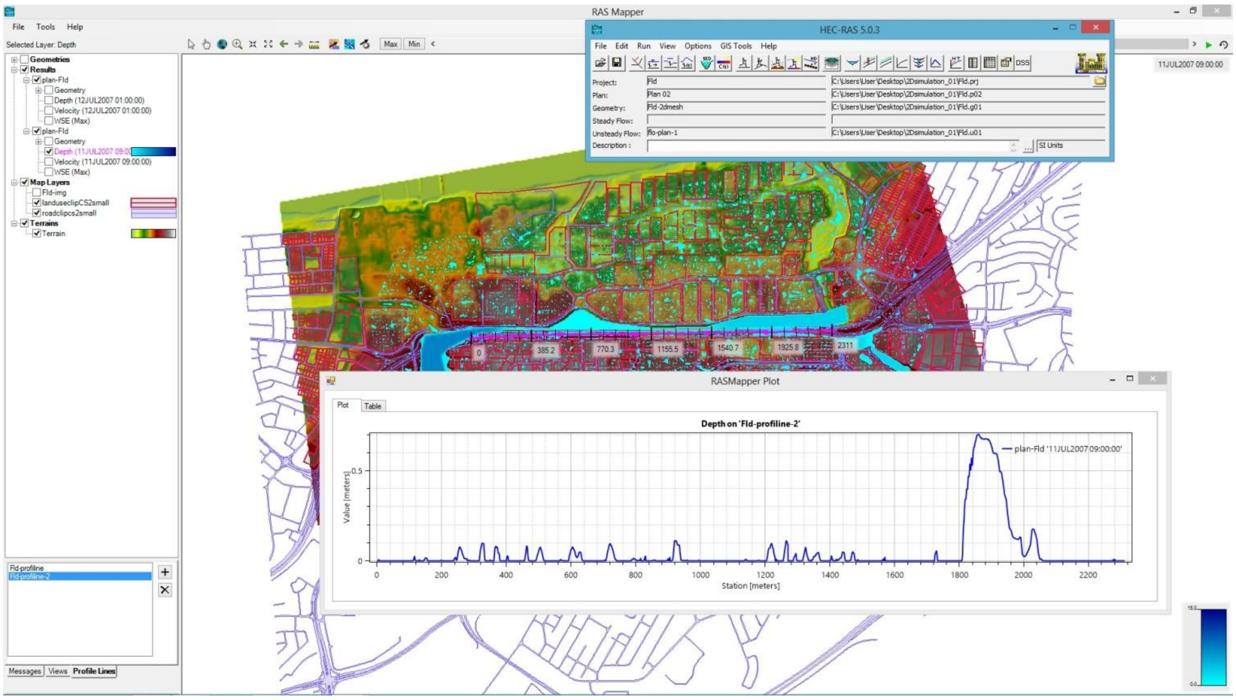


Figure 72: HEC RAS 5.0.3 platform interfaces

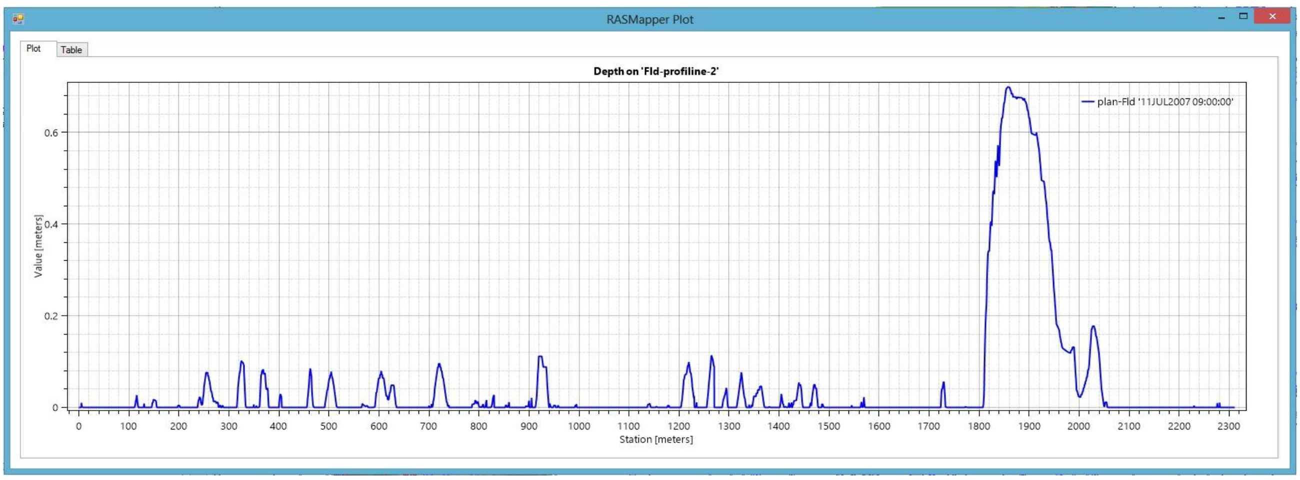


Figure 73: Profile line along the prone corridor

6.3.1.5 CS-2 scenario two: secondary stream rehabilitation

In this scenario, and following the site observation, the physical intervention targeted an important intersection. It is the location of transportation node where the main corridor of the prone area diverges into three different directions, shown in Figure 74. The node was a major prone spot for flood inundation during previous events. Even with box culvert that was placed in 2001 (circled in red), the problem of inundation worsened at that point in concurrent events. Reasons behind the hydraulic performance deterioration resulted from the encroachment of the urban development of buildings, roads, and sealed surfaces into the body of the natural stream. This had changed the watershed characteristics by increasing surface runoff velocity and eroding the ground capacity to absorb runoff water. Also, the retention factor was reduced due to the natural earth surface sealing.

Figure 74: Al-kwuair intersection

The development of second scenario for CS-2 stemmed from three influential variables and from two morphological levels; urban morphology and geo-morphology. It was generally built around the rehabilitation of the natural stream that is running across the area towards downstream. A group of dependant urban design measures was associated with the physical intervention assigned for the natural feature. The rehabilitation process involved the restoration of both the right-of-bank and left-of-bank conditions for the natural stream. These bank conditions were encroached on by urban development, as mentioned earlier. Three influential variables from the two morphological levels were applied in this scenario, and they are as displayed in Table 25;

CS-2 scenario two variables and reflections		
Variables	**Variable orientation**	**Variable manifestation**
▪ Natural stream restoration ▪ Flow pathways	Geo-morphology	▪ Natural stream body course was restored by assigning new right-of–bank and left-of-bank conditions. ▪ Natural stream alignment was corrected.
Land use redundancy	Urban morphology	▪ Parking area will be redundant in favor of stream flow during event times. ▪ Secondary connecting road will be closed and submerged in favor of stream flow during event times.

Table 25: Influential variables for CS-2 / scenario two

A flood simulation depicting the extreme event of 2007 was carried out for the area using HEC RAS platform (shown in Figure 75). Historical rainfall data, along with stream flow conditions, were fed to the software engine to build scenario-two. This aimed to measure the extent of flood depth and coverage to enable a comparison with the existing situation readings. Initial results showed a significant mitigation in terms of inundation depth and coverage area.

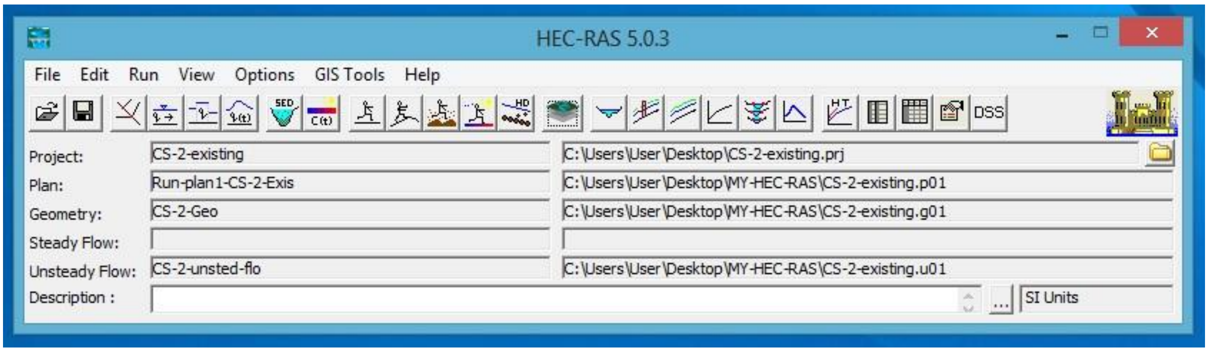


Figure 75: HEC RAS interface for scenario-two

The rehabilitation of an already existing natural stream includes the correction of the original natural path following the general geomorphological guidelines stemming from the DEM imagery analysis. The marked area in Figure 77 delineates the area where the physical intervention was placed. The extent of the physical change will be much clearer by comparing it with the original area DEM shown earlier in this chapter.

6.3.1.6 Results

After feeding the combined rainfall and stream flow data into HEC RAS engine, the simulation results revealed the extent of the flood wave depth and the coverage for the area, shown in Figure 78. The initial reflection taken from the profile line Figure 76, that was assigned across the prone area showed a significant reduction in flood depth and coverage. Generally, we can notice that the entire corridor has no more than 0.2 meters of inundation depth, which is 5cm less than the accessible level of inundation of 25 cm (gained from interview). The flood coverage area was also significantly reduced as indicated in Figure 78. Figures 77 and 78 showcase the scenario-two 'before-event' conditions, and with full flood magnitude at the peak situation.

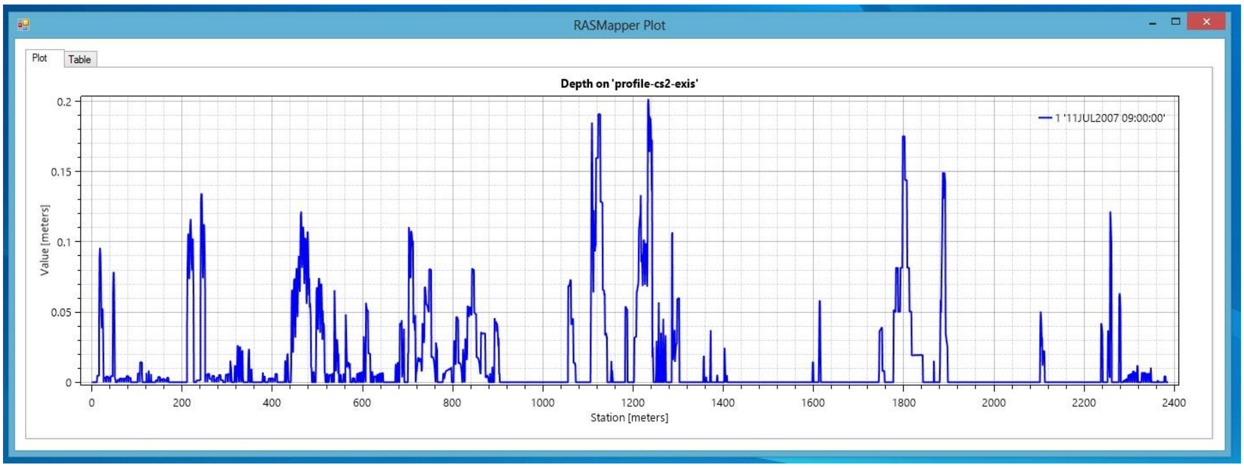


Figure 76: Profile line for CS-2 scenario two

Figure 77: CS-2 before-event scenario-two

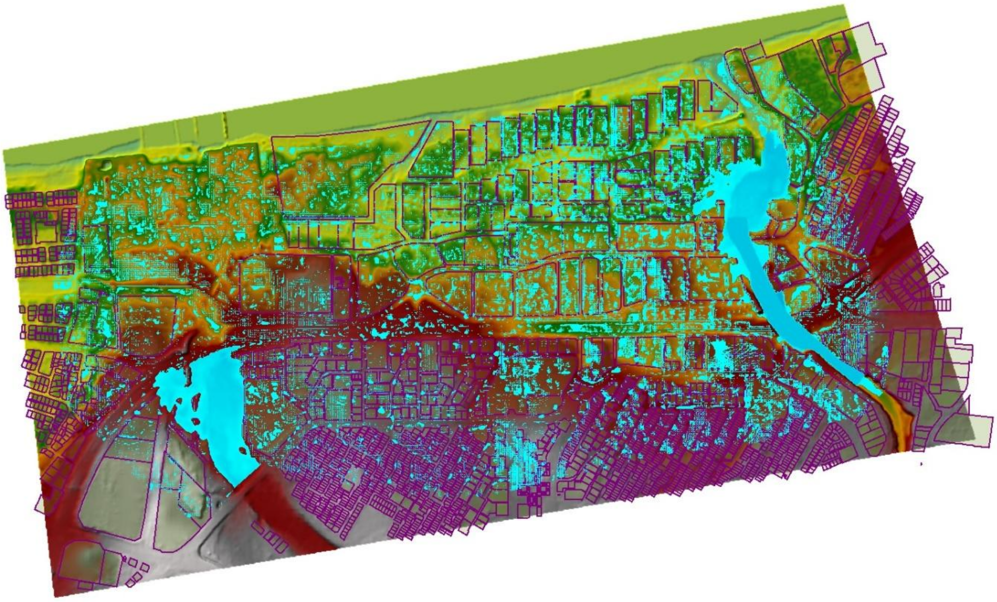


Figure 78: CS-2 end-of-event scenario-two

6.3.1.7 CS-2 scenario three: combined scenario

For this case, the two previously exhibited scenarios (one and two) were merged to form the third scenario. This scenario exhibited a full restoration of the watershed. Philosophically speaking, it stood for urban-ecological compliance. Joining the advantages of the two scenarios against the estimated aggregate cost of implementation would help decision makers to draw actionable pathways to move forward with whichever scenario is more convenient for implementation. The two adjusted natural features were dependent on other urban related measures, such land use redundancy.

There are a variety of related urban and natural-oriented complementary adjustments that can be carried out by the decision maker according to implementation and cost appropriateness. Within the limitations of the area and resources allowed in this research, not all possible scenarios were simulated, although the researcher developed solid scenarios according to the guidelines stated in the introduction of this chapter. Further research and client actions could be taken forward to reveal all the possible ways in which urban design and ecology ultimately achieve a resilient response to flood. The role of this research is to open the door and draw attention for new theoretical thinking, underpinned with applicable empirical examples. All factors and variables involved in shaping this scenario are explained in Table 26. They are the combined variables from scenarios one and two:

CS-2 scenarios		
Variables	**Orientation**	**Manifestation**
▪ Natural stream restoration ▪ Watershed connectedness ▪ Flow pathways	Geo-morphological	▪ Restoration of major natural stream. ▪ Rehabilitation of secondary natural stream ▪ The two restored natural stream reinforces watershed connectivity. ▪ The flow pathways were re-established closer to original setting enhancing the overall watershed discharge rate. Having them connected as they were in their original context will meet the variable set in this scenario.
Land use redundancy	Morphological	▪ Green area covered the vanished natural stream was redundant in favor of natural stream network and flood process. ▪ Parking area will be redundant in favor of stream flow during event times. ▪ Secondary connecting road will be closed and submerged in favor of stream flow during event times.
Gradient oriented routes design	Gen-morphological	▪ The dual carriage way adjacent to the restored stream is already designed with cross sectional gradient towards restored natural stream. ▪ Further slope-oriented design can be achieved for the route super elevation to facilitate a discharge inundation spot identified in the profile line.

Table 26: Influential variables for CS-2 / combined scenario

6.3.1.8 Results

By examining the readings revealed from the profile line of the prone area, generally the whole corridor was covered with 0.15 meters, as shown in Figure 79. Only in one location does inundation exceed this limit, reaching 0.2 meters, which is still within the acceptable limits for both automobile and pedestrian accessibility.

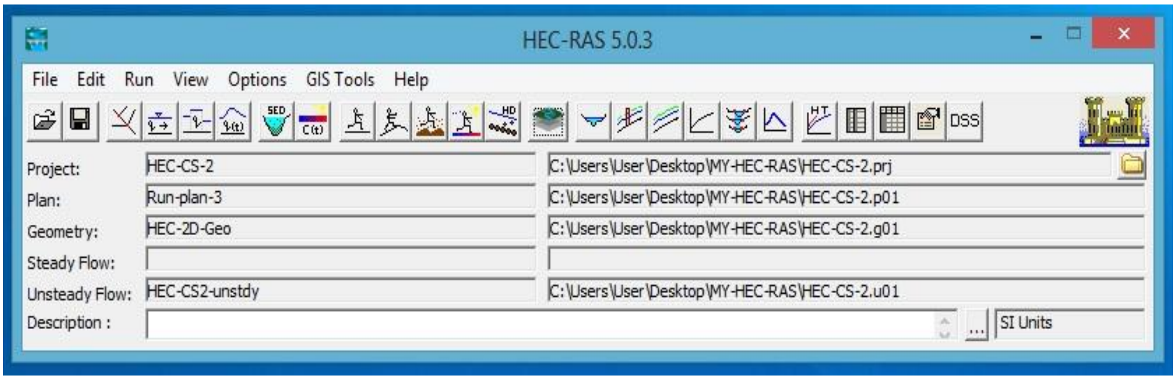


Figure 79: HEC RAS interface for CS-2 combined scenario

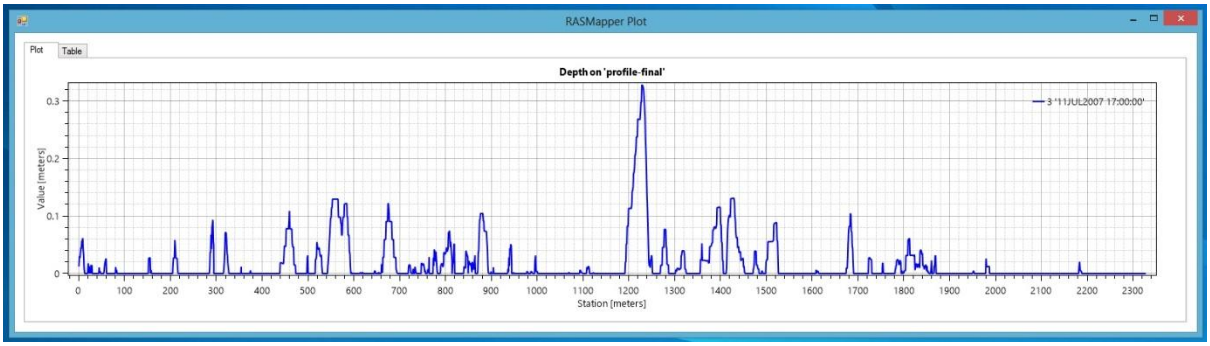
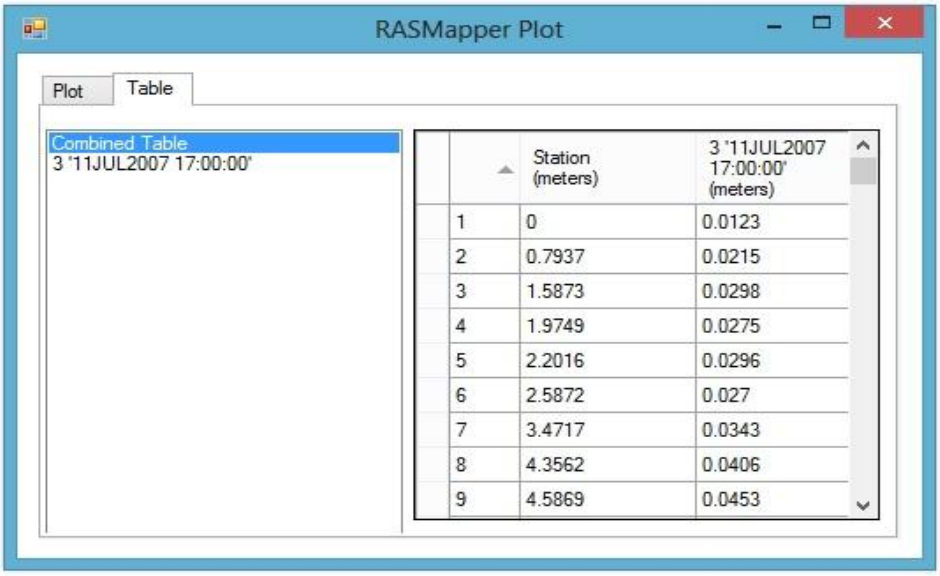


Figure 80: Profile line for CS-2 combined scenario



	Station (meters)	3 '11JUL2007 17:00:00' (meters)
1	0	0.0123
2	0.7937	0.0215
3	1.5873	0.0298
4	1.9749	0.0275
5	2.2016	0.0296
6	2.5872	0.027
7	3.4717	0.0343
8	4.3562	0.0406
9	4.5869	0.0453

Figure 81: Detailed station readings displayed from the profile properties

Figure 80 shows the extent of the flood circumstances of the coverage area for this scenario, detailed in the profile line. Meanwhile, Figure 81 shows the further capabilities of the HEC RAS platform to extract the depth of plenitude of stations along the profile line on a smaller scale. Furthermore, medium depths, along with other statistical operations, can be determined in further geo-technical design for surface sealing, slop oriented design and/or the allocation of services and road furniture. The level of these detailed design techniques is associated with level of urban innovation, mentioned in the introduction chapter; however addressing this is beyond the scope of this study. Nevertheless, they are mentioned here to refer to the collaborative efforts that can cohesively initiate all acting systems in the city's urban-ecological context. Figures 82 and 83, display flood conditions before and after the event.

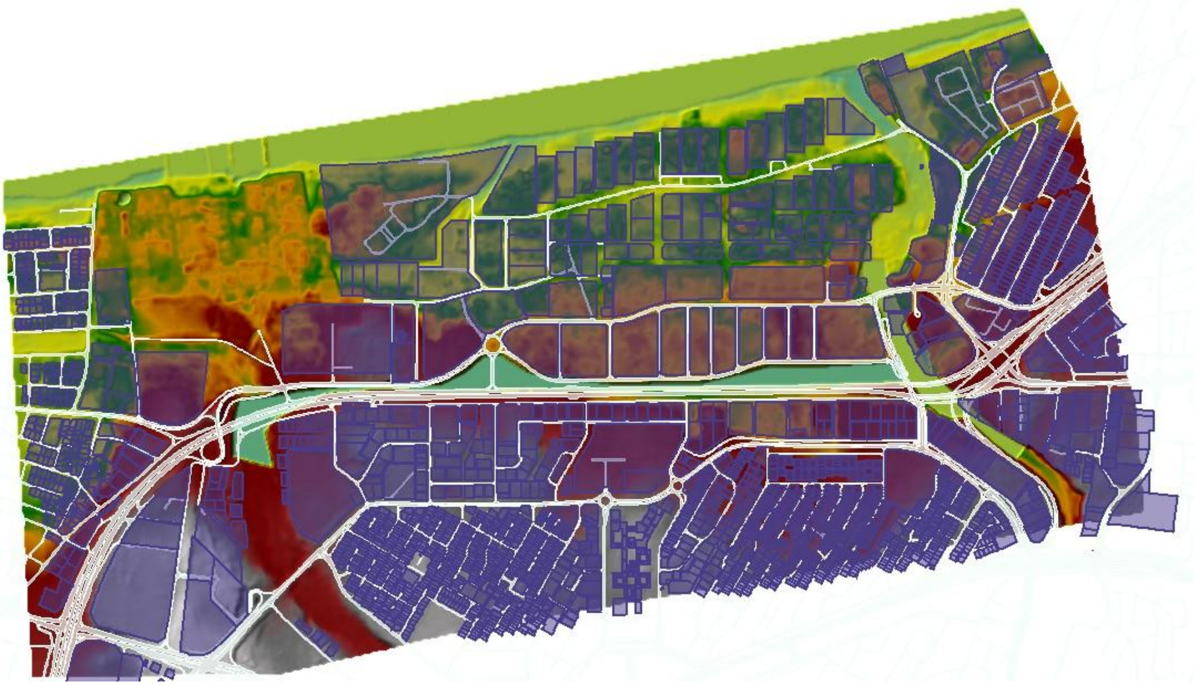


Figure 82: CS-2 / combined scenario before event situation

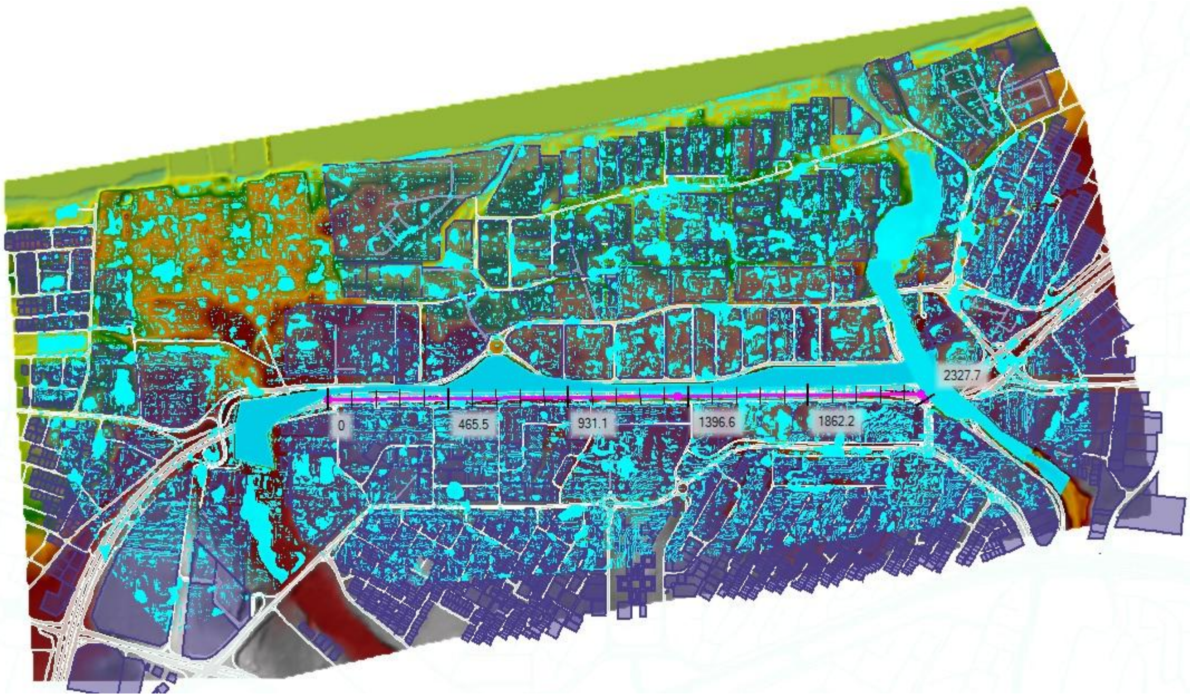


Figure 83: CS-2 / combined scenario full event situation

6.3.2 CS-1 Scenario crafting

Initially, flood simulation was made available for existing situations to enable comparisons. Consequently, one scenario was found to be convenient for the simulation analysis developed for case study one (CS-1). The intervention scenario was developed with respect to selected variables. They are associated with the upstream-downstream flow of conditions concerning the rehabilitation and urban retrofitting by building evacuations.

6.3.2.1 Existing situation

In this section, the current urban and natural settings of the Wadi-Adi catchment will be simulated against the flood event of June 2007. The tropical cyclone, Gonu, severely affected the CS-1 area, as its impact was one of the worst across the Muscat areas in terms of flood depth, Figure 84.

Figure 84: Tropical cyclone Gonu-Wadi Adi catchment

For the purpose of the flood analysis, the DEM layer of the study area was elaborated to match the existing setting. The DEM layer is the best available source that incorporates digital elevation readings for the urban and natural surfaces. Without a digital terrain model (DTM) available -even with the SCP- the researcher had to 'set-to-real' a lot of surface features through elevation rectifications and interpolations. Although this was a lengthy process using the Arc GIS raster analysis tool, the method of rectification ensures precision results with reliable outcomes compared with real flood readings taken from the ground during the event. However, it represents a considerable challenge for the researcher in terms of the time and effort invested in the process. Areas circled in Figure 85 refer to the locations where a nesessary rectification for the land surface was made. The process was carried out in Arc GIS software in the data pre-processing phase.

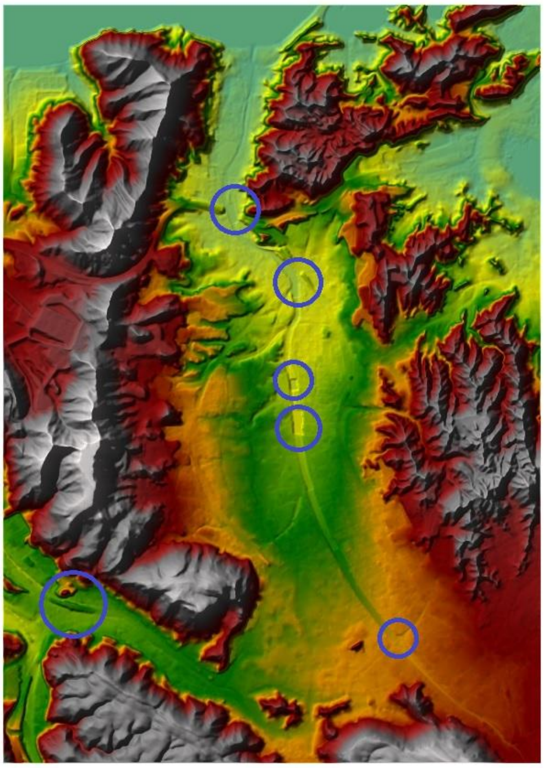


Figure 85: DEM for the study area CS-1 with geographic enhancement

The existing situation of the urban setting, along with natural topographic features, were introduced to the HEC RAS platform, Figure 86, to simulate the current flood situation. Data for the rainfall readings and natural stream flow was deviced in the software simulation engine. A combined module of rain and river flow was created to build the status-quo conditions for the purpose of later comparisions.

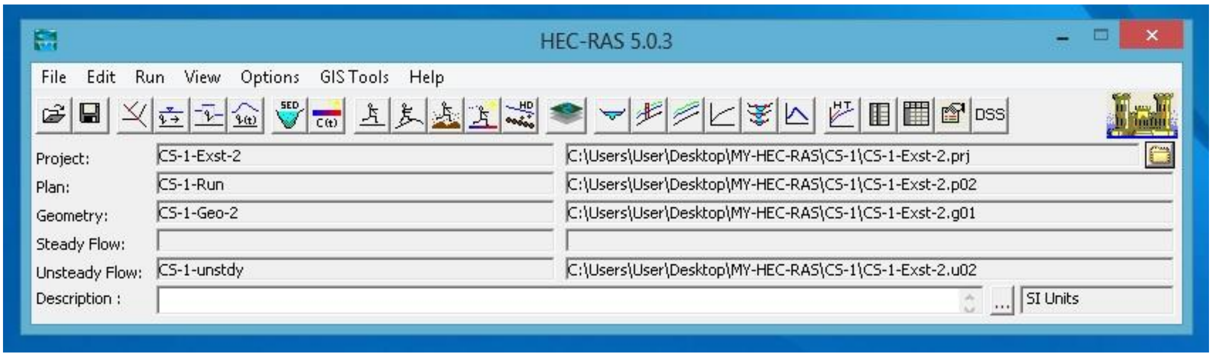


Figure 86: HEC RAS platform for CS-1 existing situation

6.3.2.2 Results

A profile line was asigned along the affected corridor, shown in Figure 87, and this profile line depicted the peak of the event. A combined model of rainfall data and natural stream flow was built in the HEC RAS platform. The module simulated an unsteady flow resulting from 24.5 hours of convective rainfall in the study area, referred to as CS1- unstdy in Figure 86. The extent of the flood wave depth and coverage across the event period, mentioned above, was revealed. The profile line shows the levels to which runoff depth and coverage arrived. The area between 0.24 km and 0.6 km, shown in Figure 87, was heavily susceptible to inundation. A maximum depth of around 2.85 metres was recorded as a peak flood depth at some point on this part of the main street corridor. Meanwhile, the real reading taken from the ground at that time was 2.7 at aproximately the same location. The result from the simulation is 0.15 meters less than real measures recorded in 2007. Although this is a considerable variation margin, it is the best result produced after calibrating the simulation in the three different mesh resolutions, which will be explained in the simulation calibration. This 5% marginal variation means the overall resolution of the digital elevation model images (DEM) coming with a horizontal resolution of 5 meters and a vertical resolution of 0.2 meters. However, it is higher than the readings extracted from the real situation. Although this can affect the precition of the simulation, it can arguably reflect an implicit 0.15 metres less than the reduction in water depth when applying the mitigation scenario. Figures 88 and 89 outline the existing situation compared to the full flood peak at the end of event.

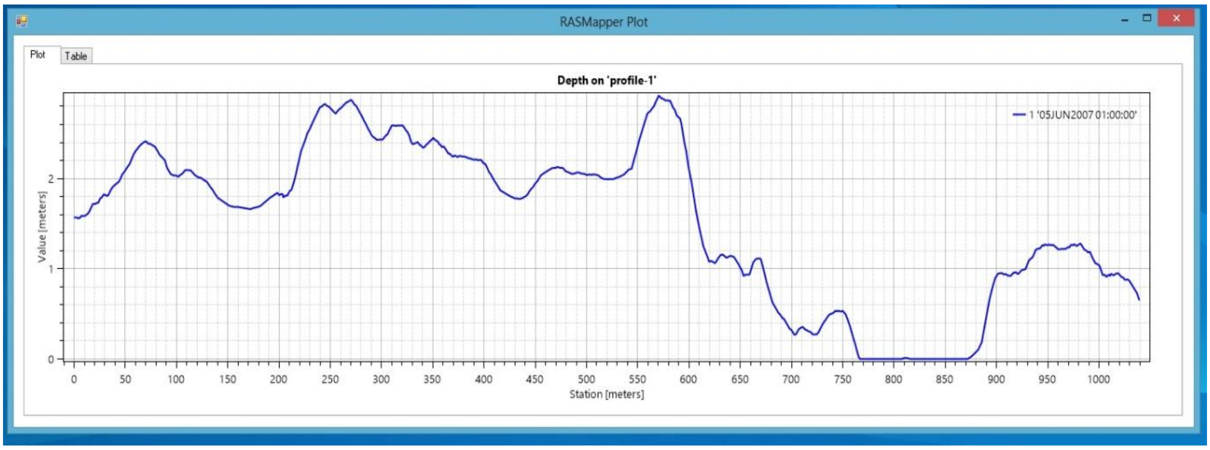


Figure 87: CS-1 existing situation-profile line on the prone corridor

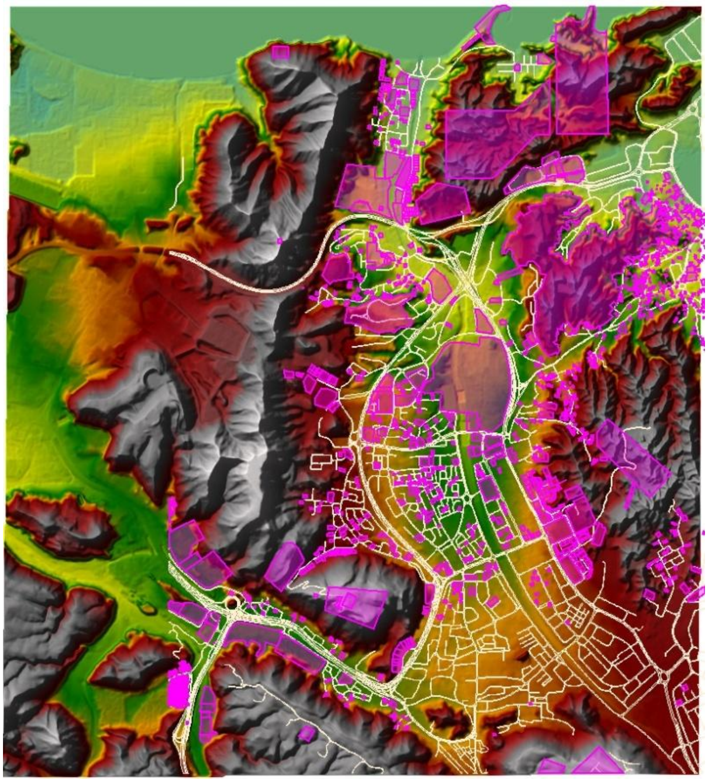


Figure 88: CS-1 before event conditions

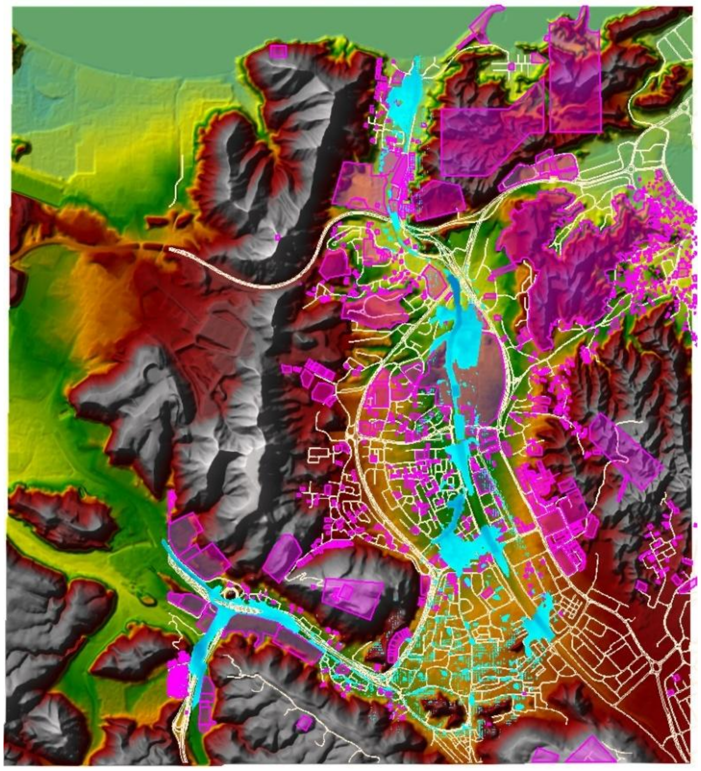


Figure 89: CS-1 at the end of event conditions

6.3.2.3 CS-1 scenario one

A sole intervention scenario was developed for CS-1 area. The physical intervention targeted an important intersection in the prone area, (shown in Figure 90), at which the runoff readings were the highest recorded in the area. The problem of flood inundation initiated almost one kilometer before that intersection, on the main road approaching the intersection from Al-Amerat district. The location significantly involves traffic diverging into two main directions and one local route. Areas (a) and (b) on Figure 90 respectively delineate a boundary of maximum inundation depth, and an ecologically critical area with a natural stream pathway that has been disturbed.

A major project that was implemented on 2012; the project was a combined solution of one flyover, converting the existing roundabout into signalised intersection and box culverts improvement. The project budget was nearly 24 million Omani Rials. However, as a result of full implementation, the problem of congestion eliminated significantly, opening free connection routes to the rapidly expanding Al-Amerat residential area (Appendix-1). Yet, the project lacks the proper understanding of the ecological setting in the area. One interviewee referred to the inappropriate handling of the new road design near Al-Nahdah hospital by elevating the street corridor and lowering the prone right of way land use. A spot on the prone corridor witnessed frequent flood inundation incidents, which has led to the entire ground floor of the hospital being closed down after one heavy rainfall event.

The problem of the inundation was witnessed frequently at that area, even with the recent major works mentioned above. Reasons behind this relate heavily to relying on protection infrastructure, and less importance was given to the handling of the delicate ecological settings. Expanding the urban development of buildings, roads, and sealed surfaces blocked the connection continuity of a major stream running across the area. This changed the watershed characteristics and led to an exacerbation of the problem.

Hence, the development of the scenario for CS-1 stemmed from three influential variables, and from two morphological levels; generated-morphology and geo-morphology. It generally followed natural rehabilitation and urban evacuation. The rehabilitation process involved maintaining a vital link for the natural stream's disrupted sides. This was achieved by removing the encroachment of road and building developments. The three influential variables from two morphological levels applied in this scenario are displayed in Table 27;

CS-1 scenario one variables and reflections		
Variables	**Variable orientation**	**Variable manifestation**
▪ Natural stream restoration ▪ Flow pathways	Geo-morphology	Natural stream rehabilitation by maintaining a vital link connection.
Compliance of space design with natural flow pathways	Generated morphology	▪ Building evacuation. ▪ Secondary road removal (Alternatively elevated by culverts)

Table 27: Influential variables for CS-1 / scenario one

Figure 90: CS-1 catchment

The physical intervention for scenario one was introduced to the HEC RAS platform, Figure 91, to simulate the current flood situation. Data for rainfall readings and the natural stream flow were added to the software simulation engine. A combination of the rain and stream flow module was created to build the status-quo conditions for the purposes of later comparisions.

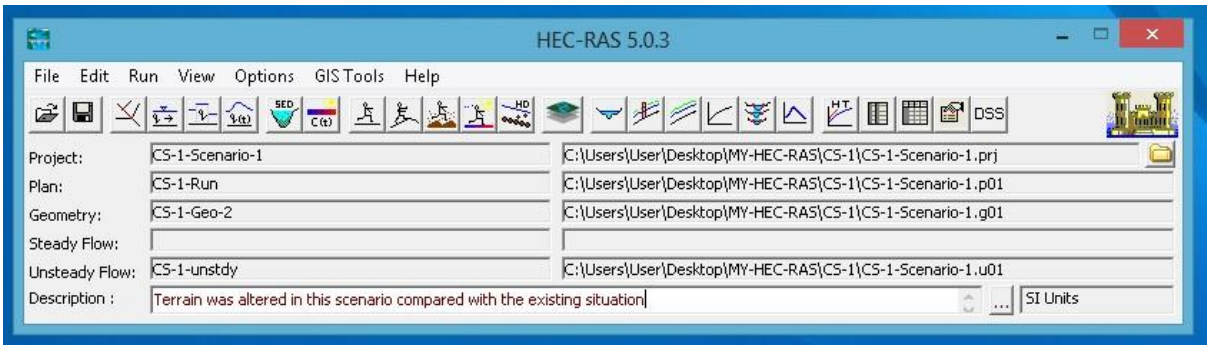


Figure 91: HEC RAS platform for-CS-1 scenario one

6.3.2.4 Results

A profile line was asigned along the affected corridor, Figure 92; this profile line depicted the peak of the event. A combined model of rainfall data and natural stream flow was built in the HEC RAS platform, Figure 93. The profile line shows the levels to which runoff depth and coverage arrived. The extent of the flood depth and inundation coverage area was significantly reduced on the main corridor.

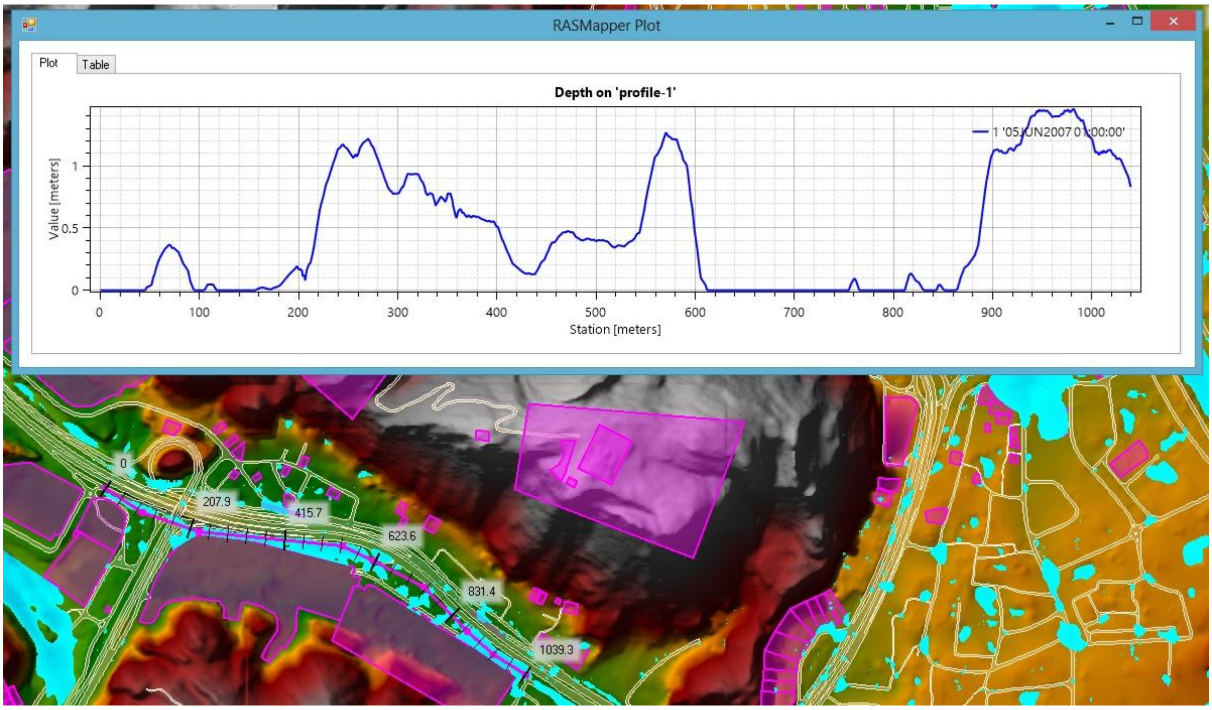


Figure 92: HEC RAS platform for CS-1 scenario one

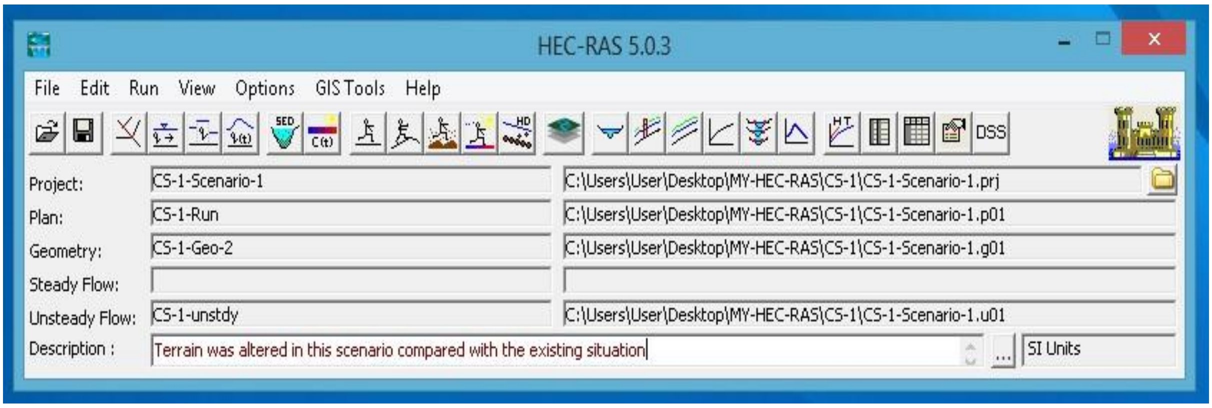


Figure 93: CS-1 scenario one profile line

A maximum depth of around 1.4 metres was recorded as a peak runoff depth, but at the bottom of the surface runoff chanalisation, Figure 96. However, this scenario involved a few building evacuations and one mosque building. It was essential to completely clear the natural stream path and eliminate any chance of flood exposure for buildings or vulnerable individuals. Aside from the compensation cost, there were some socio-cultural challenges associated with religious buildings, specially in vernacular areas, like Wadi Adi. However, this is a challenge for decision-making, and there is a slim chance that such a move would be challenged ,considering the government's capabilities, particularly with extensive experience and successful practice in compensating both individuals and other commercial parties. Figures 94 and 95 show the existing situation compared to the full flood peak at the end of event. The velocity check for all scenarios showed no significant runoff velocity that could be taken as a risk factor for consideration in the planning for suitable measurements.

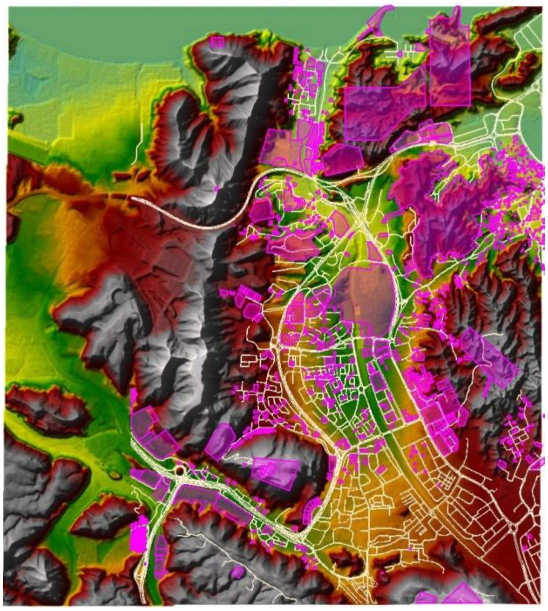


Figure 94: CS-1 existing condition

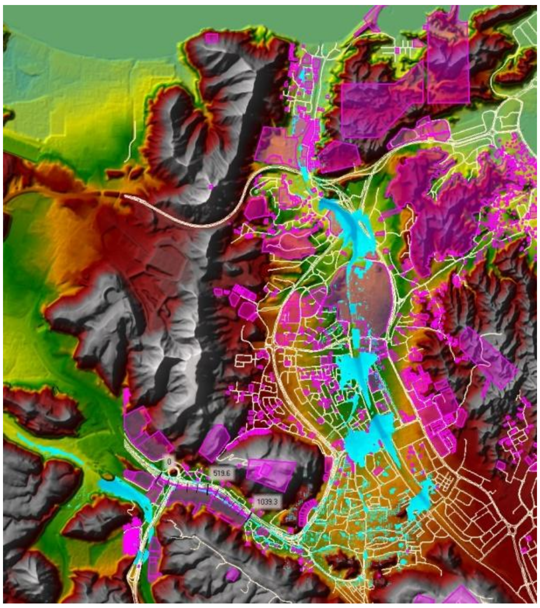


Figure 95: CS-1 full flood event condition

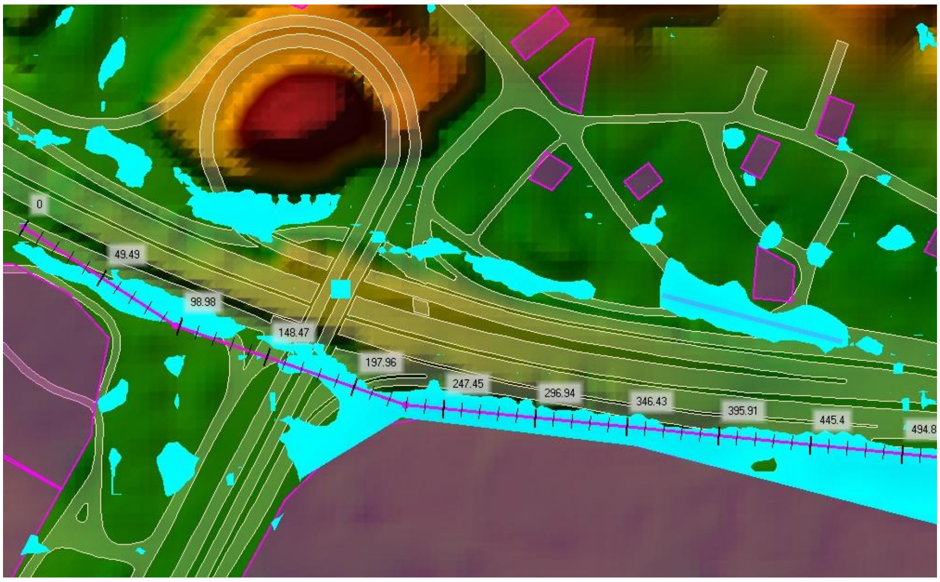


Figure 96: Surface runoff mainly running at the channels between the buildings and street corridor

6.4 Model calibration and challenges

The process of model calibration was performed to check the reliability of the results taken from the simulation. The process was conducted across two complementary phases. The first was the geo data set validation; this incorporates a real time survey manually done at the study area by surveying the prone area urban context for any significant changes that took place after the satellite images and digital elevation model were aquired. The process is explained in detail in Appendix-2.

The second phase was carried out through the simulation process, by running different simulation sessions, each of which had different resolution settings for the 2D computational mesh in HEC RAS. The simulation ran the combined unsteady flow analysis for each selected resolution setting in separate simulation sessions. Findings from each simulation were comapared to the existing readings of the maximum depth taken from the ground during the event. The close the results appear to the real readings, the more accurate they will be. Accordingly, the chosen resolution for the computational mesh was considered dependaple.

In CS-1, the computational mesh, in Figure 97, was first set at 5X5 meters, as this was the resolution of the underpined terrain (DEM). This approach is usually undertaken when the resolution of the computational mesh in the HEC RAS is similar to that in the DEM; this tend to yield more dependable results,. Nevertheless, it does not produce the required level of precision. Hence, the simulation run the second experimental resolution of 10X10 meters, where, athough the results was closer, they were a little far from the real reading. The process continued with 15X15meters, and the results improved until finally the 20X20 meters returned the most accurate results. The logic behind the laying between the computationl power of the software and to the interpolation of flow at each single cell in the computational mesh is that the calibration for each case study should be carried out with seperately as the terrain is different.

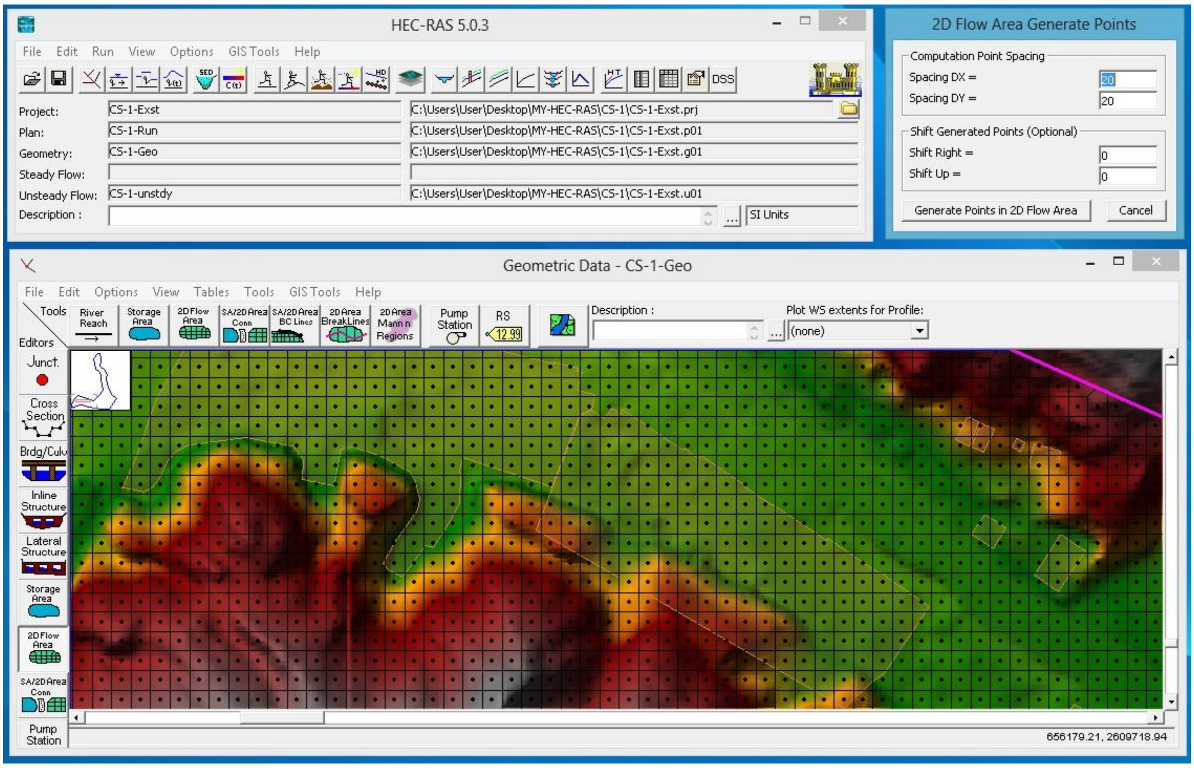


Figure 97: CS-1 resolution of the calibrated mesh of (20X20) meters

Fortunately, CS-2 returned dependable results from the first simulation session with a computational mesh of 5X5 metres, shown in Figure 98. Meanwhile, the simulation trials in CS-1 took a long time to process as each single session could consume 5-10 hours depending on the assigned resolution. One of the seesions consumed 15 hours, as shown in Figure 99. This was one of the challenges that the researcher had to deal with in the process of scenario building. This issue was experienced due to the limited processing power of the personal PC used in the process. Usually, flood simulation software is built within special super processor mainframes for time effectiveness. Moreover, the higher the resolution, the larger the area and the more time consumed in the simulation.

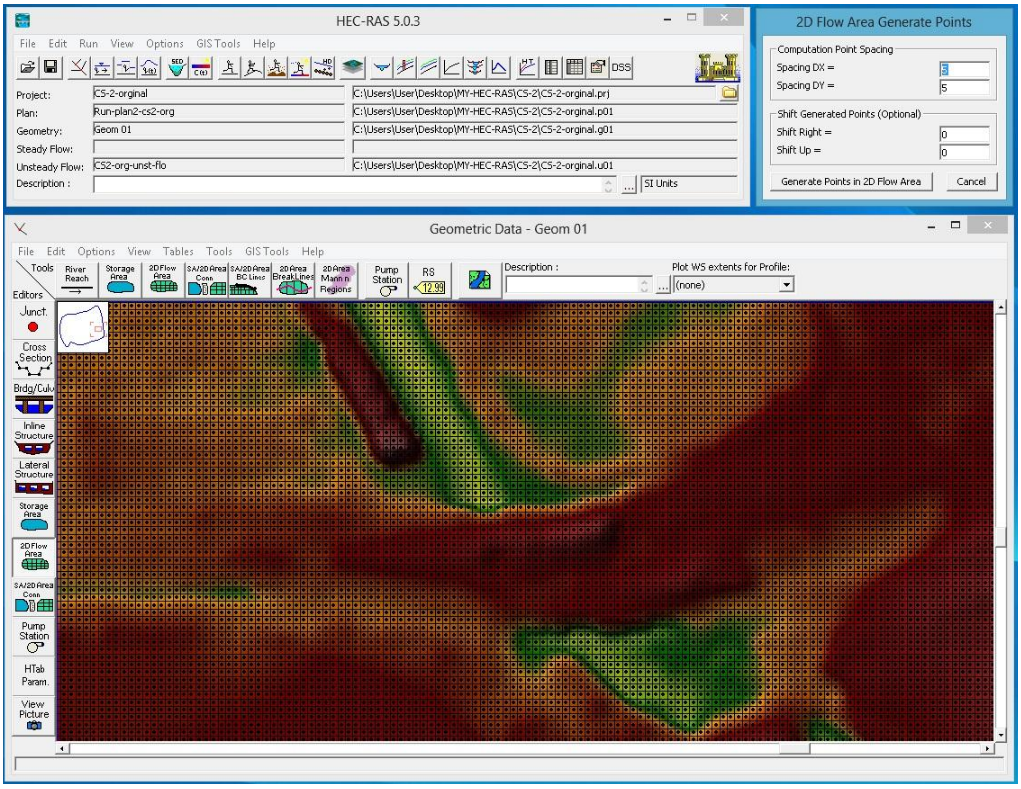


Figure 98: CS-2 resolution of the calibrated mesh of (5X5) meters

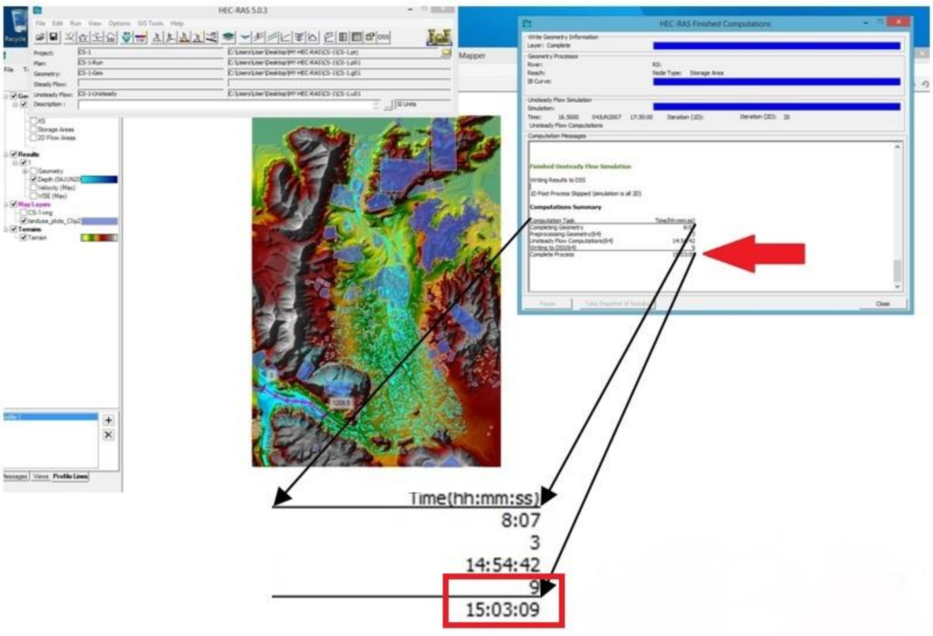


Figure 99: lengthy processing time for CS-1

6.4.1 Scenario evaluation for decision making

This section will demonstrate the solution identified by implementing the three scenarios. They were all evaluated in terms of the preliminary cost and the level of resilient response represented in the surface runoff reduction in depth and coverage area. The results from a single scenario will guide decision makers to map an area of interest around the convenient implementation scenario. The process of decision-making that can be taken forward afterwards is not within the scope of this research; instead, this research demonstrates eco-built solution possibilities. Figure (100) showcases the three scenarios to facilitate this comparison.

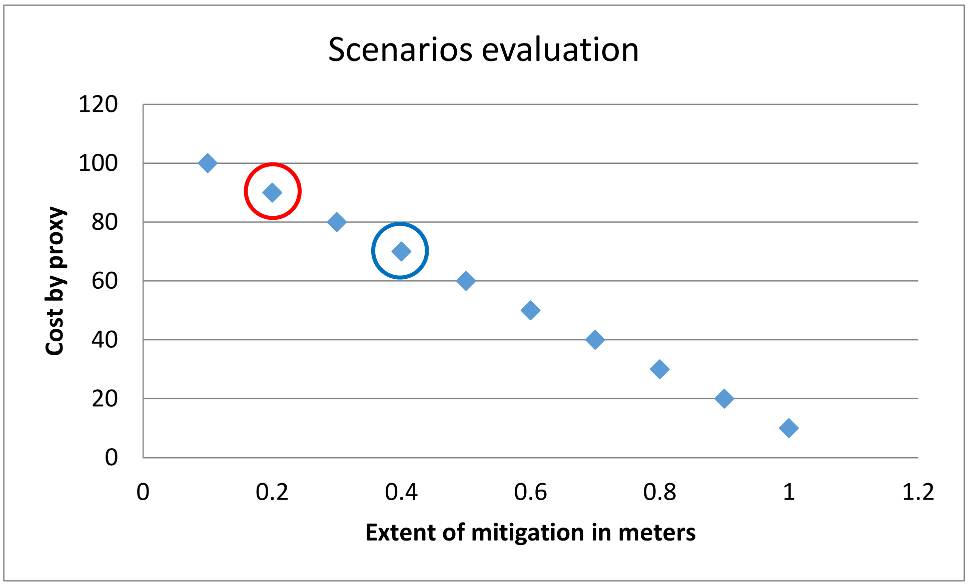


Figure 100: Convenient of mitigation scenarios

In Figure 10, all scenario results are displayed in terms of the mitigation extent in inundation depth and the associated cost of solution; thus, the greater the reduction of a solution in terms of the inundation depth, the greater the cost. An appropriate resilient response will be chosen by the decision maker through the settlements between the X and Y parameters. The blue circled solution might, for instance, be the mitigation option preferred by the decision maker due to the underpinning rationales associated with cost, implementation, or the desired response. However, the red-circled solution might be a departure point where the mitigation solution cannot be met for the same underpinning reasons.

Building an eco-compliant resilient response in the urban context is an ongoing process of design, learn and adapt. This can be explained in terms of the phases of the taken action from the pre project to the within project stages and finally towards post project factors. Desouza and Flanery (2013, p.98) confirmed that, 'with interactions, variations, and selections as the chief planning, design, and management lens to enhance self-organization, distributed learning, and overall adaptive capacity, cities can focus more effectively on evaluating network vulnerabilities and potential physical and social adjustments to threats and opportunities'.

The process of design-learn-adapt, mentioned above by Desouza and Flanery, will substantiate the current response into future required actions in a sense that promises less future mitigation cost. Building resilience is a cumulative process shaped and developed by time. It associates with the two types of resilience; inherent and adaptive, where each strengthens the other. Figure 101 showcases the ongoing process of resilient response initiation and development over multiple events.

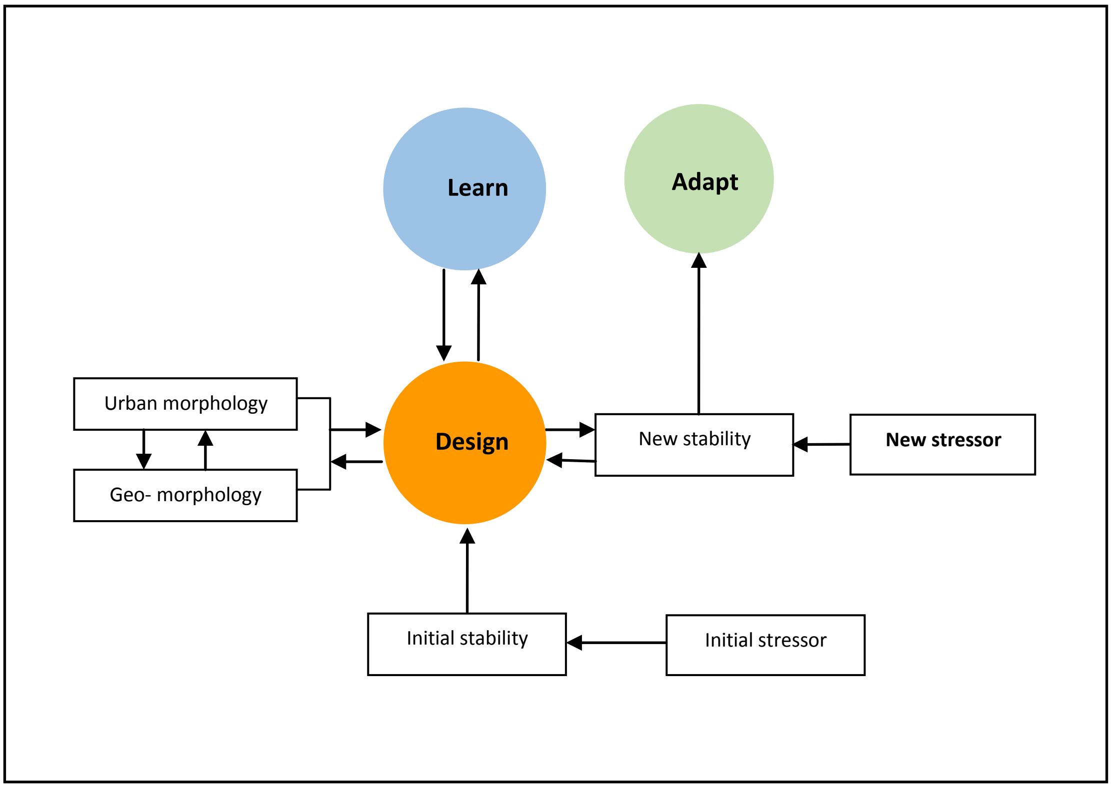


Figure 101: The design-Learn-Adapt strategy in developing resilient response

6.5 Summary

The two case study locations allow for a different number of scenarios. This was developed for the different urban-ecological settings at each location. The cross case synthesis concluded the scene for CS-1 and CS-2 with one key morphological finding; in terms of susceptibility for change and intervention, CS-1 was found to be ecologically liable with a relatively reliable urban context,. Meanwhile, CS-2 was ecologically reliable with a lot of ecological potential, yet with a limited reliability in terms of the urban context.

This reflected directly on the scenario building, as witnessed in CS-2 which it was convenient for ecological alternatives that aided mitigation solutions. However, CS-1 was not that ecologically relieved. Nevertheless, the local ecology was a great liability as urban development was expanding within the foothills of steep mountains that negatively impacted the area in times of rainfall by pouring the accumulated upstream surface water right into the city.

Despite the limitations partially associated with the limited scenarios for CS-1, levels of surface runoff were significantly reduced in terms of the depth and coverage area. In most of the scenarios, accessible urban form status was reached. Partners in the SCP welcomed the ecological approach and its product. This was experienced throughout the discussion sessions during the focus group activity, which were conducted to validate the framework. The estimated costs of the physical intervention scenarios were detailed next to the expensive infrastructure financial allocations for the current year's plans and the next five years' plans. Initial comparisons with decision makers promised good foreseeable resilience influence for the physical intervention scenarios on the level of flood management practice.

Chapter 7: Research validation and discussion

7.1 Introduction

This section examines the validity, plausibility, and criticality of the research. An evaluation of the research methodology and the underpinning procedures was carried out to check if they are fit and up to the required standard. Aside from the general research validity check, the instrumental framework validation and plausible rival explanations will be explained.

7.2 Research validity

There are many sets of criteria developed to examine research validity. Golden-Biddle and Locke (1993) devised three main criteria to assess the quality of ethnographic text, and they were; authenticity, plausibility and criticality. Yin (1994) adopted four criteria to assess the quality of research, and these were mainly concerned with positivist case studies: construct validity, internal validity, external validity and reliability. Meanwhile, Miles and Huberman (1994) formulated five criteria to assess the quality of the research of a realist case study: objectivity, reliability, internal validity, external validity, and utilization.

In qualitative research, the researcher is bound, not by tight cause-and-effect relationships among factors, but rather by identifying the complex interactions of factors in any situation. Researchers engage in validation, often using multiple strategies, which include confirming or triangulating data from several sources, having their studies reviewed and corrected by participants, and having other researchers review their procedures (Creswell, 2007). Qualitative validity means that the researcher checks for the accuracy of the findings by employing certain procedures, whilst qualitative reliability indicates that the researcher's approach is consistent across different researchers and different projects (Gibbs, 2007).

Angen (2000, p.387) suggested that, within interpretive research, validation is, 'a judgment of the trustworthiness or goodness of a piece of research'. The research design may even specify that two researchers will come from different disciplines to give (reliably) different views (Richards, 2010, p.108). The purpose of all these criteria is to ensure rigor is achieved, and the entire research approach, methodology, and findings are robust. Accordingly, and since this study was based on qualitative research, the chosen criteria adopted to assess its quality was based on the internal validity, external validity, reliability and generalisability. Hartley, (2004) argued that the case study, as a research strategy, mostly yields too many 'variables' for the number of observations made, and so the application of standard experimental or survey designs and criteria is not appropriate. Otherwise, issues of reliability, validity and generalisability are addressed, but with different logic and evidence. Therefore, the quality criteria of the internal validity, external validity, reliability and generalisability were applied to this research across the two case studies, CS-1 and CS-2.

7.3 Internal validity

Guba and Lincolin (1981) referred to the credibility of qualitative research, rather than the internal validity in quantitative research; a qualitative study is credible when it presents such faithful descriptions of a human experience or interpretations of a human experience, that subjects would immediately recognise it from the descriptions or interpretations as their own. A study is also credible when other researchers or readers can recognise the experience when confronted with it after having only read about it in a study.

A research design is internally valid when there is a confidence that the findings are characteristic of the variables being studied and not the investigative procedure itself (Sandelowski, 1986, p.29). Meanwhile, Silverman (2006) stated that research validity is achieved when the account accurately addresses the phenomena under consideration. Therefore, multiple data sources were used to achieve internal validity. Internal validity is also assured by the triangulation of the data; this is the approach by which evidence is deliberately sought from a wide range of different, independent sources and often by different means (Mays & Pope, 1995). Thus, data from the interviews, official documents, and consultancy studies were all considered in the research analysis.

Yin (2003) stated that using multiple sources of data would improve the internal validity of the research; hence, triangulation is another agent for internal validity. Triangulation refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of phenomena (Patton, 1999). Stake (1995) devised four components against which triangulation can be accomplished, and they are:

- Data source triangulation.
- Investigator triangulation.
- Theory triangulation.
- Methodological triangulation.

7.3.1 Data source triangulation:

Three of the triangulation strategies suggested by Stake (1995) will be met. Primary data source triangulation was achieved when data was collated from interviews and observations, along with secondary data obtained from official reports, project cases and consultancy studies. Different sources of the data were analysed to realise a rich, reliable description of each case.

Aside from the diversification of the data sourcing, the types of data collected and analysed in this research were both qualitative and quantitative. In this sense, Creswell (2007) confirmed that collecting both qualitative and quantitative data is one ways to triangulate the source of data. He also mentioned that quantitative data is not exclusive to quantitative research; qualitative researchers might use quantitative data, and the reverse can be true for quantitative research. Likewise, Patton (2002) mentioned that qualitative data could be collected in experimental design; whilst, some quantitative data may be collected in naturalistic inquiry approaches. Willis (2007) asserted that quantitative research uses numbers as data, whereas qualitative research does not. In fact, this is not true; qualitative researchers often use number based research methods, and a growing number of quantitative researchers use qualitative data.

7.3.2 Methodological triangulation

Methodological triangulation is achieved when the researcher works back and forth between the themes and the database until they establish a comprehensive set of themes (Creswell, 2007). This was met in the data analysis and the interpretations at different stages of the data collection phase. First the interviews data were reduced and categorised by using Nvivo software. The next step involved both deductive and inductive coding for the elaborated data in order to determine the influential factors and variables.

Also, the interviews were managed on four sequential steps: firstly, by giving the interviewees information sheets prior to the interview, secondly, by conducting an audio recorded semi-structured interview, thirdly by transcribing the audio files into text, and then finally, sending the transcripts back to the participants to revisit their responses, and to amend and substantiate them if required.

7.3.3 Theory triangulation

According to Stake (1995), theory triangulation is attained when the whole account of the case procedure is accessed for evaluation by other researchers conveying different theoretical backgrounds. Creswell (2007) also mentioned this form of triangulation when other researchers view and evaluate the whole case study procedure. Views from different researchers will not subside the account of the procedure; however, it will reveal richness and accountability (Stake, 1995).

Although theory triangulation was not conducted for the whole research study; nevertheless, and according to Stake's definition above, the instrumental framework was validated when five external experts accessed and evaluated the results (section 7.11). Also, a Delphi study was conducted to elicit the experts' choice of the selected resilience principles (Appendix-3). Table 28 summarises the types of triangulation used in research.

No.	Type of triangulation	Reflection in research
1	Data source triangulation	▪ Participants from different professional levels ▪ Document review ▪ Multiple contexts-Multi case study
2	Methodological triangulation	▪ Content analysis ▪ Open ended interview ▪ Cognitive mapping ▪ Collecting qualitative & quantitative data
3	Theory triangulation	▪ Focus group activity: checking the account of the instrumental framework with participants from different theoretical backgrounds. ▪ Delphi study: identifying the set of relevant resilience principles.

Table 28: Types of triangulation in use

7.4 External validity

Sandelowski, (1986) stipulated that, in a qualitative enquiry there are fewer threats to the external validity in comparison with those associated with external validity in a qualitative enquiry. This is due to the fact that qualitative enquiry emphasises the study of phenomena in their natural settings and with few controlling conditions. Meanwhile, Creswell (2007) asserted that rigor is achieved when extensive data collection in the field occurs, or when the researcher conducts multiple levels of data analysis (*within-case-analysis*, where a detailed description of each case will be presented, followed by *cross-case-analysis*). Rigor means that the researcher validates the accuracy of the account using one or more of the validation procedures, such as member checking, triangulating sources of data, or using peer or external account auditors.

The external validity of this study was strengthened by undertaking two case studies. It was also assured by the fact that the findings from the two case studies, CS-1 & CS-2, were generally aligned. It is safe to assume that the results could be generalised to other contexts across Oman. However, it cannot be claimed that the findings from these two case studies can be generalised in a broader sense internationally. It was suggested in the cross case synthesis that, if the areas, factors and/or variables were well managed, this might influence an ecologically resilient response. Nevertheless, definitive claims were made in these case studies that a particular factor/variable was generally the reason behind the positive response, as seen in Chapter 6, on scenario building. Finally, the method followed to apply ecological resilience to urban design can be replicated internationally; however, the researcher expects that new contextual variables might emerge.

7.5 Reliability

According to Yin (2003), reliability is closely linked to the possibility of yielding fairly similar findings if the whole of case study data collection investigation and results were repeated; thus, the goal of reliability is to minimise errors and illuminate biases, although the essence of reliability for qualitative research is situated within consistency (Carcary, 2009).

In this study, reliability was tested by ensuring that key findings were supported by evidence from the analysed data. The researcher was keen to question interviewees on all the tested themes; furthermore, evidence from all available data sources was used. Sandelowski (1986) referred to the major threat of the truth-value of a qualitative study; this lies in the closeness of the investigator-subject relationship. Likewise, Fraenkel and Wallen (2003, p.453) confirmed that it is imperative that observers try hard to remain non-judgmental and 'control their biases'. Yet, from the inception of the research, the researcher was aware of the challenges of potential biases. Hence, they were minimised and carefully handled as the researcher was alert from the initial stages of data collection to the potential biases that stemmed from his involvement in the main authority of planning and infrastructure in Oman. Being an urban and infrastructure planner in the Supreme Council of Planning for more than ten years could increase biases. Mays and Pope (1995) confirmed that feeding the findings back to the participants to see if they regard them as a reasonable account of their experience are one of the validation strategies used in qualitative research. Therefore, the researcher carefully managed such issue; for example, during the interviews he introduced himself as a researcher rather than a former SCP employee. Furthermore, the researcher returned the transcribed interviews to participants so they had the opportunity to check the authenticity of the transcriptions and comments.

Lincoln and Guba (1985) suggested that the dependability of the results could be ensured through the use of three techniques: the investigator's position, triangulation, and audit trial. Triangulation was detailed in section (7.2), whilst Lincolin and Guba defined the investigator's position and audit trail as follows:

1- The investigator's position: In order to increase the reliability of the research, the investigator needs to clearly explain the different processes and phases of the inquiry. Therefore, the researcher should elaborate on every aspect of the study. The researcher should describe in detail the rationale of the study, the design of the study and the subjects. As a reflection of this, the researcher presented clear research rationales for the study in Chapter 1, which included, but was not limited to; the research objectives, contribution, motivations, and limitations. The research design was explained briefly in Chapter 1, as were the entire research journey, including the research philosophy, methods and methodology in one visual design (Figure-1, Chapter-1). The research design was also clarified in more detail in Chapter 4.

2- Audit trail. In order to fulfill this procedure, the researcher should describe in detail how the data were collected, how they were analyzed, how different themes were derived and how the results were obtained. This detailed information can help replicate the research and thus, contribute to its reliability. As a reflection of this criterion, the researcher described the sequence of data collection throughout multiple field visits. Each of these visits was detailed in terms of the accomplishments and challenges, (shown in Appendix-2). The data analysis was expanded within Chapter 5, and a content analysis was undertaken across two case studies resulting in a set of factors and variables that ultimately constituted the study's instrumental framework.

7.6 Generalisability

Yin (1994) argued that multiple case studies should follow a replication, not a sampling, logic. He further argued that the development of consistent findings over multiple case studies could lead to robustness in the analysis. Creswell (2009) stated that the focus of a qualitative generalisation is on the particularity, not the generalisability.

However, Leung (2015) mentioned that the approach to generalisation in qualitative enquiry is based on judging the extent to which the findings in one study can be generalised to another, based on a similar theoretical foundation, and the proximal similarity model, where generalisability of one study to another is judged by the similarities between the time, place, and people.

Meanwhile, Lincoln and Guba, (1985) stated that interpretation involves stating the larger meaning of the findings and personal reflections about the lessons learned. Thus, building on the discussion above, it is clear that generalisation in a qualitative study has a different tone compared with a quantitative study; where absolute the repeatability of the sampling logic is what governs its generalisability. Meanwhile, similarities between times, place, and people and the overall replication of the whole case study account is what defines generalisability in qualitative enquiry. "The goal of interpretive research is an understanding of particular situation or context much more than the discovery of universal laws or rules" (Willis 2007, p.99).

Adler and Adler, (2012) stated that quantitative researchers capture a shallow band of information from a wide swath of people and seek to objectively use their correlations to understand, predict, or influence what people do, while qualitative researchers generally study many fewer people, but delve more deeply into those individuals, settings, subcultures, and scenes. Both research strategies offer possibilities for generalization, but about different things, and both approaches are theoretically valuable.

According to Migiro and Magangi, (2011) mixed method research can be used to increase the generalisability of the results. Therefore the research devised multiple case study analyses in order to establish a replication order. This can be seen in the 'within case' analyses for CS-1 and CS-2 and also through the 'cross case syntheses' afterwards. Consequently, generalisation in the research is sought after similarities and cohesions are found in the explanations, represented in themes and influential factors in the pre-project factor stages, and the project factor phases shown in the instrumental framework. Meanwhile, influential variables produced site-specific findings at each case study location. They can also be seen in the post-project factors phase in the instrumental framework. Table 29 exhibits a summary of the validity components and how they were met in the research.

Testing components	Procedure	Action in this research
Internal validity	Data source triangulation Explanation building	Primary and secondary data were collected Themes, factors and variables were developed from the content analysis
External validity	Reflecting investigation logic in multiple contexts	Structurally, two dissimilar contexts were investigated and analysed, governed by a similar inquiry logic
Reliability	Drawing a cohesive road map to meet the research objective embodied in the research process and procedure diagram	The whole research journey was explained in sequential order; all field visits were documented demonstrating the achievements and challenges faced. An alternative line of thinking was also considered.
Generalizability	Results consistency	Findings from both cases were fairly alike on the level of themes and factors. Slim variation appears deeper in the influential variable level

Table 29: Summary of validity components and their reflections in the research

7.7 Assessment of the reviewed official document

Documents represent a reflection of reality when they become a medium through which a researcher searches for correspondence between its description and the events to which it refers. It allows comparisons to be made between the observer's interpretations and those recorded in documents relating to single event (May, 2011). Scott (1990) proposed four criteria for assessing the quality of evidence available from document sources, and they are: authenticity-credibility-representativeness and meaning, as shown in Table 30.

	Criteria	Explanation	Action taken in research
1	Authenticity	Judgment of authenticity from the internal evidence of the text comes only when one is satisfied that it is technically possible that the document is genuine. Foster (1994) questioned: are the data from primary or secondary sources? Are they authentic copies of the original? Can authorship be validated? Are the document dated and placed? Are they accurate records of the real events or process described?	The entire reviewed documents were original official correspondences associated with flood infrastructure, compensation and technical studies. They were the property of four influential ministerial bodies, the SCP, MM, MRMWR and the MH
2	Credibility	Refers to the extent to which the evidence is undistorted and sincere, free from error and evasion.	All documents were original and acquired directly from the Directorate General of Social Sector Development at the SCP
3	Representativeness	Refers to the question of whether a document is typical depending on the aim of the research	The researcher is acquainted with the relevance of the document to the analysis and the documents were very well categorised to each service sector.
4	Meaning	Refers to the clarity and comprehensibility of a document to the analyst. What is it? What does it tell us?	The researcher's experience and familiarity with the document reviewed helped in distinguishing the prominent use gained from each type of document

Table 30: Assessment of the secondary document data

7.8 Assessment of interview questions

Creswell (2007, p.173) confirmed that, 'the researcher role in an interview is to record meaning that the participants hold about the problem not the other way around'. The interviewer bears the responsibility to pose questions that make it clear to the interviewee what is being asked (Patton, 2002). Getting the respondent's exact words is usually not important; instead, what they mean is important. A good interviewer can reconstruct the account and submit it to the respondent for accuracy and stylistic improvements (Stake, 1995, p.66). Meanwhile, Creswell (2007) mentioned that, in some cases, the research question changes in the middle of the study to better reflect the types of the question needed to understand the research problem.

Perhaps the researcher's greatest contribution is in working the research questions until they are just right (Stake, 1995, p.20). In terms of practice, the questions became more inclusive so that the participants can construct the meaning of a situation, a meaning typically forged in discussions or interactions with another person. The more open-ended the questioning, the better, as the researcher listens carefully to what people say or do in their life setting (Creswell, 2007, p.21). Yin (2003) recommended a pilot test to refine the data collection plan and to develop relevant lines of questioning. These pilot cases are selected on the basis of convenience, access, and geographic proximity. Therefore, the research questions were piloted, and from this, adjustments were made following participant feedback and reflection. Research questions were shaped to a state of better understanding, as shown in Table 31.

Interview questions	Feedback and adjustment from participants	Change
How urban design unit can incorporates physical measures to mitigate surface runoff?	How **can urban design introduce physical measures on the level of its morphological components of (plot, building, and street)** to mitigate surface runoff?	80%
How physical nexus of urban form features (blocks, street open space) and topographic features benefit surface runoff mitigation?	How **can** physical nexus **between** urban form features (building, block, street open space) and topographic features benefit surface runoff mitigation?	20%
How can mutual influence between urban form features and terrain features enrich urban space accessibility options?	How can mutual influence between urban form features and terrain features enrich urban space accessibility **alternatives**?	10%
What factors account for urban features (building, block, street, open space) redundancy?	Clear	0%
What are the possible ways the-safely redundant urban form feature-to assists runoff mitigation	**Due to inundation, how can** redundant urban form features **possibly functions to benefit** runoff mitigation	45%
To what extent a certain level of inundation can be accepted as a transitory phase?	How can a certain level of inundation be accepted as a transitory phase **considering duration and depth?**	25%

Table 31: Adjusting interview questions upon pilot interviews

7.9 Establish Linkages between interview questions and the reviewed literature

Stake (1995) mentioned that perhaps the most difficult task of the research is to design good research questions that will sufficiently direct the looking and thinking of the case. In qualitative studies, research questions typically orient to the case or phenomena, seeking patterns of unanticipated as well as expected relationships (Stake, 1995, p.41). "Stances on the use of literature in qualitative research vary widely, as do the stance on using prior theory. The literature may be fully reviewed and used to inform the questions actually asked, or it may be reviewed late in the process of research, or it may be used solely to help document the importance of the research problem" (Creswell, 2007, p.42). Table 33 displays the relevance of each of the interview questions to the theoretical framework of resilience on the one hand, and its relevance to the reviewed literature on the other.

7.10 Summary of quality criteria of data collection phase

As the interview will be the main source of primary data along with direct observations in the field, an important step is the author's preparation to conduct the interview. Therefore, exploring the literature in this area along with securing direction from author's supervisor will provide sufficient background knowledge for the author prior to conducting the interviews. Furthermore, the quality criteria in Table 32 have been used during the data collection phase to strengthen the solidity of the entire process.

No.	Criteria	Evidence
1	Using a variety of participants	Done (see Table 13 Chapter-4 & Appendix-2)
2	Using multiple data sources, such as interviews, government reports, consultancy studies, direct observations	Done (Chapter-4)
3	Linking the research questions with the reviewed literature	Done (see Table 33)
4	Recording and transcribing the interviews	All interviews will be audio recorded and transcribed by a third party
5	Maintaining the rigor of the research questions	Done (see Table 31)
6	Making the interview transcripts available for participants to review and comment on if necessary	Transcribed interviews sent to participants for a final check.

Table 32: Summary of data quality criteria of the data collection phase

Types of Resilience	Principles of Resilience	No	Research Questions	Literature relevance	
				Author	**Citation**
Inherent Resilience	Preparedness	1	How urban design unit can incorporates physical measures to mitigate surface runoff?	Ganor, 2003	Resilience is the ability to find unknown **inner strengths** and resources in order to cope effectively; The **measure** of adaptation and flexibility.
				Taylor, 2004	The idea of town planning was essentially about **physical design**, and hence involved the production of blueprint plans for **future urban form.** (p.17)
				Voogd, 2004	Achieving a **resilient built environment** is of paramount importance in achieving **resilient cities**.
		2	How physical nexus of urban form features (blocks, street open space) and topographic features benefit surface runoff mitigation?	Zevenbergen (2011)	Runoff and floods are themselves influenced by **geomorphological**, spatial and social factors. (p.39)
	Resourcefulness	3	How can mutual influence between urban form features and terrain features enrich urban space accessibility options?	Godschalk (2003)	Cities to be resilient; their **roads**, utilities, and other infrastructure systems must be designed to **continue functioning** under extreme hazard conditions.
				Chang (2014)	Increasing **resilience** can be accomplished through ex post actions such as **rerouting traffic**.
				Vale& Campanella 2005	Urban security and resilience are grounded in patterns of **connectivity**. (p.331)
				Ahern, 2011	When an urban landscape is understood as a system that performs functions, **connectivity** is often the critical parameter. (p.342)
				Vale& Campanella 2005	The simplest way to crash a network is to block or sever a crucial link. (p.315)
Adaptive Resilience	Redundancy	4	What factors account for urban feature (building, block, street, open space) redundancy?	Webber, 1990	The collapse of the Oakland expressway and the closure of the San Francisco bridge after an earthquake did not lead to disruption in the transport systems because of a high degree of **redundancy** in the transport network
				Zevenbergen (2011)	The capacity to **adapt** to changing conditions depends on their **substitution** rate. (p.16)
		5	What are the possible ways –the safely redundant urban form feature - to assist runoff mitigation?	Tierney&Bruneau 2007	Redundancy can be measured by the extent that alternative routes and modes of transportation can be employed if some elements lose function.
	Tolerance	6	To what extent a certain level of inundation can be accepted as a transitory phase?	Tierney&Bruneau 2007	Understanding the attributes and dimensions of resilience will define the acceptable levels of loss, disruption, and system performance.
				Zevenbergen (2011)	Floods are considered disasters because of the impact that they have on the functioning of human society. Floods are natural phenomena and it is a **human construct** to label flooding as **acceptable or not**.

Table 33: Linking interview questions to literature

7.11 Designate plausible rival explanations

Despite the wide range of application and contexts, resilience is not a universally accepted term, nor does it have a universally accepted definition, even for single geography fields, such as disaster risk reduction (DRR), climate change adaptation (CCA), humanitarian aid or spatial planning (Levine et al., 2012). Similarly, Weichselgartner and Kelman (2015) drew attention to the wide range of governmental and organisational views on resilience: 'resilience as a process, a state and a quality, ranging from a global focus on food and a national view on critical infrastructure to a sectorial view on business continuity and a local focus on climate change'. Sometimes the resilience of individual entities is focused on, and sometimes the resilience of systems. Weichselgartner and Kelman also referred to the current challenge for resilience in terms of the multitude of diverse definitions and approaches.

The above-mentioned concerns identify the problem of variance in approaching resilience from different disciplines. As seen in the literature, many scholars have urged the scientific effort to move forward to a more normative agenda, to specifically described resilience in selected fields in terms of developing measuring standards and definitions. From a researcher's point of view, this would ameliorate the problem. The more the idea of resilience is adopted within practice, the more the consensus would be achieved on what it means in different fields.

Mitchell and Harris (2012) referred to a drawback in how resilience works, observing that, while resilience may be important to support and maintain systems in a desirable state, it may also maintain a system in an undesirable state, making recovery or transformation difficult. They have termed this phenomenon the 'dark side of resilience', referring to undesirable systems that have become fixed, and are therefore less responsive to future threats or positive transformations. Likewise, Weichselgartner and Kelman (2015) referred to another related drawback of many resilience-building programs, namely that resilience is rarely acknowledged until a shock, stress or disaster has occurred. This makes resilience building on any scale and the evaluation of resilience investments challenging to measure and validate. Thus, Mitchell and Harris's concern is important; the reason for addressing resilience in this research was to identify it as a temporal action to facilitate systems coping with stressors through traumatic circumstances, and to start developing measures for the next event, building on the experience gained from previous events. This understanding eliminates Mitchell and Harris' concerns that, when the system relies on measures, they walk it through the harsh times and sustain the same status. The research addresses resilience as on-going practice reflected in the process of *design-learn-adapt*, shown in the instrumental framework (Chapter 5).

Weichselgartner and Kelman's concerns were a little more controversial in that the researcher believes that, to judge a resilience response, the comparison is not between two resilience states of before-and-after a stressor. Instead, the focus should be on a the comparison of the rapidity in which systems return to normality, or maintain minimum functionality, according to relevant definitions of such. One of the key concerns was expressed by MacKinnon and Derickson (2012), who heavily criticised the practice of resilience in the social domain. They accordingly offered a surrogate approach relying on preparedness instead of resilience. They were addressing the application ecological resilience within the social domain along with its associated political ramifications. They jump afterward to suggest an alternative for the idea of resilience within the conception of preparedness.

There were a lot of controversies in MacKinnon and Derickson's argument, in that they build their criticism on the practice of resilience in certain fields without identifying where they agreed or/and disagreed with the theoretical underpinning theory or assumptions. Nevertheless, contradictions were also evident in their argument; for example, they quoted (Evans, 2011) 'The abstract language of systems theory and complexity science **offers a mode of intellectual colonization which serves to objectify and depoliticize the spheres of urban and regional governance**, normalizing the emphasis on adaptation to prevailing environmental and economic conditions and foreclosing wider socio-political questions of power and representation. In the same sense they also quote Swanstrom (2008, p.15) who states that, 'The implication of the extension of ecological thinking to the social sphere is that human society **should mimic the decentralized and resilient processes of nature**.' Moreover, they confirmed that replicating the resilience process in nature is conditional to the decentralization and de-politicization of the spheres of urban and regional governance. They quoted that, (Evans, 2011; Swanstrom, 2008) 'Ecological models of resilience are fundamentally anti-political, viewing adaptation to change in terms of decentralized actors, systems and relationships and **failing** to accommodate the critical role of the state and politics.' Nevertheless, it is possible to stop their sequence by applying ecological resilience in the social domain and by posing the question, which is more important for the city's well being and safety: a political agenda or a natural process of resilience response? The researcher believes that, if a political system cannot accommodate benefits realised from '**mimicking the decentralized and resilient processes of nature'** then it is a liability and deserve replacement.

It is not the aim of this research to refute or confirm all the contesting interpretations and conceptualisations of resilience. However, most important points of view were demonstrated to indicate the depth and breadth of current thinking and the development of the concept of resilience notion for readers across wide range of opinions. This has helped to build a clearer picture and potentially eliminate bias. Nevertheless, the researcher was keen to engage with relevant contesting interpretations as much as practical to test and thence confirm or refute them methodologically.

7.12 Framework validation

This section explains the validation process of the previously developed instrumental framework. Discussion was held around the quality of the instrumental framework using a set of criteria developed through investigating the literature and through discussions with the focus group participants, Table 34. Selected participants from the S.C.P (the data provider) were asked to participate in the validation procedures. The reason for validation is to enable participants to judge the reliability of the framework structure, themes and variables and to respond where alterations and improvement are needed.

The framework validation process was caried out with five key participants from the SCP. The majority of participants were selected upon two criteria: the first was that nearly all of them were decision makers, whilst the second was their being the direct beneficiaries of the instrumental framework. In this sense, Wills, (2007, p.140) stated that "Interpretivism argues that knowledge is socially constructed, and therefore truth is relative to the groups that produce and consume the research". On the first day with the group, The researcher took particular time and effort to demonstrate and transfer sufficient knowledge about the framework's purpose, characteristics, and stages of crafting. A discussion was held with the participants for about two and a half hours, and all participants responded fairly equally across the process. The five participants in the focus group were asked to complete the same evaluation weighting forms at the end of first day's session; however, forms were left with participants to be collected the second day. This was to give participants ample time to evaluate the framework by reconsidering the discussion.

No.	Evaluation criteria	Factors	Evidence in literature
1	Logic and sequence governed the framework	Structure clarity	The final product of an evaluation is a report, which can take many different forms, depending on the audiences and goals. The researcher should describe the applied procedures and explain in detail the results or outcomes of the study (Lynch, 1996, p.174).
2	Framework comprehensivness	Inclusive findings	The items in the instrument should be judged on their relevance and comprehensiveness (Scholtes et al, 2011, p.239) The researcher should try to expound the study, the results and interpretations as clearly as possible to the relevant audience. In this way, readers can make sense of the whole study and what the findings means to them as a whole (Brown, 2001)
3	Usability and applicability of framework	Utilization	Utility refers to the degree of usefulness the evaluation findings have for administrators, managers and other stakeholders (Lynch, 1996, p.63) The principles underlying naturalistic and/or qualitative research are based on the fact that validity is a matter of utility and dependability that the evaluator and the different stakeholders place into it (Zohrabi, p.258).
4	Potentials of positive change	Mitigation extent	These are the positive and negative changes produced by a development intervention, directly or indirectly, intended or unintended. This involves the main impacts and effects resulting from the activity on the local social, economic, environmental and other development indicators (OECD, 2000).
5	Scenario building and transferability	Actionable instrument	Criterion was suggested by members in the group as they were keen to see measurments in place.

Table 34: Coexistence of evaluation criteria in the literature

The framework was rated according to a combined calculation of scores and weights. A scale of 1-5 was used, where 1=poor, 2=fair, 3=average, 4=good and 5=excellent, which represented the range of minimum and maximum given scores. Meanwhile, the critera were given weights and rated by participants according to the importance and priority of each criterion over the others. Weights were given to each criterion, graded out of 100%, and the final participants'consensus upon the criteria weighing scheme is shown in Table 35.

	Evaluation criteria	Scores					Evaluation score	Criterion weight 100%	Total
		Poor	Fair	Average	Good	Excellent			
1	Logic and sequence governed the framework	1	2	3	4	5		**10%**	
2	Framework comprehensivness	1	2	3	4	5		**25%**	
3	Usability and applicability of the framework	1	2	3	4	5		**25%**	
4	Potentials of positive change	1	2	3	4	5		**20%**	
5	Scenario building and transferability	1	2	3	4	5		**20%**	
	Score for all criteria	5	10	15	20	25		**100%**	

Table 35: Framework validation analysis – one participant

Table 36 shows the detailed evaluation process of all participants in the focus group. The total mark assigned by the participant for the first criteria (the logic and sequence of the framework) was 22 out of 25, where two of the participants scored this as *Exellent* and three scored it as *Good*. The score was multiplied by the weight assigned for this criterion (10%) to gain a final evaluation index of 220 out of 250. The total marks awarded for the second criteria (framework comprehensivness) were 18 out of 25 and this yielded 450 out of 625, as the final index as two participants assigned *Average* and three selected *Good*.

By moving down to the third critera (the useability and aplicability of the framework) the total marks for this criteria were 20 out of 25, where all participants appeared to agreed on *Good*; thus, 500 out of 625 were noted as a final index. In the fourth evaluating criteria (the potential for positive change) the total weighting gained was 22 out of 25, where - like the first criteria - two of the participants scored *Exellent* and three were scored *Good,* and the final index was 440 out of 500. The final criteria (scenario building and the transformability of the framework) scored 21 out of 25, recording 420 out of 500, as one participant assigned *Average*, two selected *Good* and two were indicated *Excellent*.

Quality Criteria	Participants' responses					Score	Weight	Total
Logic & sequence of the framework	P1	P2	P3	P4	P5			
Poor						1	10%	
Fair						2		
Average						3		
Good	●		●	●		4		
Excellent		●			●	5		
sub-total	Out of 250					22	10%	220
Framework comprehensivness	P1	P2	P3	P4	P5	**score**	**weight**	**total**
Poor						1	25%	
Fair						2		
Average	●		●			3		
Good		●		●	●	4		
Excellent						5		
sub-total	Out of 625					18	25%	450
Usability & applicability of framework	P1	P2	P3	P4	P5	**score**	**weight**	**total**
Poor						1	25%	
Fair						2		
Average						3		
Good	●	●	●	●	●	4		
Excellent						5		
sub-total	Out of 625					20	25%	500
Potential for positive change	P1	P2	P3	P4	P5	**score**	**weight**	**total**
Poor						1	20%	
Fair						2		
Average						3		
Good	●		●		●	4		
Excellent		●		●		5		
sub-total	Out of 500					22	20%	440
Scenario building & transferability	P1	P2	P3	P4	P5	**score**	**weight**	**total**
Poor						1	20%	
Fair						2		
Average					●	3		
Good	●		●			4		
Excellent		●		●		5		
sub-total	Out of 500					21	20%	420
Grand Total	Out of 2500					103	100%	2030

Table 36: Summary of instrumental framework validation

At the end of the evaluation process, the overall combined score for the instrumental framework scores were 2030 out of 2500, which is equal to (81.2%) by considering total scores and weights. Participants were comfortable with the results; they commented accordingly on how to use the framework in diversifying intervention alternatives in different prone areas in Muscat and across Oman. The level of satisfaction reflected the the reliability and generalisability of the instrumental framewok.

7.13 Summary

This chapter summarised the validity of the adopted methodology in this research. It also displayed the testing procedure and the actions taken against each component within the evaluation methods. This includes, but is not limited to, the research validity (both internal and external), reliability and finally research generalisability. Moreover, content validity was applied to test the interview questions through a pilot interviews, as described in Table 31. The links between the interview questions with the reviewd literature were also highlighted in Table 33. Likewise, a methodological assessment was carried out for the secondary data and how it supported the main argument from the content analysis.

Generally, the use of multiple sources of data, represented in the interview, secondary data and the researcher's observations, helped to assess the integrity of the research findings, satisfied the internal validity and helped to eliminate potential internal threats. Using the logic of enquiry in performing more than one analysis across two case studies, each represents different ecological contexts, which helped to address the external validity. Reliability was achieved through the cohesiveness and flow of the research journey and the explantion of the research process and procedure diagrams. A diagram was drawn in Chapter 1 to visualise the logic that governed the sequential phases of the study. Finally, generalisability was clearly defined against what it exactly means in qualiative research and how it was met in the analysis account. The framework validation was carried out by performing a focus group activity with five experts at the Supreme council of Planning, as the SCP is the main beneficiary of the framework. The evaluation process was carried out using criteria developed from the literature and in discussion with the participants. A combined weighing scheme of scores and weights was applied to validate the frmework, and participants were satisfied with the framework's final outputs and evaluation.

Chapter 8: Conclusion and Recommendations

This chapter presents the research conclusions and recommendations. The chapter summarises the research aim and objectives, including how they were approached and achieved. The contribution of the field of urban resilience to flood highlighted in section 8.3. The research limitations and challenges are explained in sections 8.4 and 8.5, whilst the recommendations are presented in section 8.8 finally, potential future research is highlighted in 8.9

8.1 Summary of the research findings

The main aim of this research was develop an instrumental framework to guide ecologically compliant urban design to mitigate pluvial flood consequences in Muscat city. There is a consistent problem of pluvial flooding in the two areas under investigation in Muscat city. This problem has become increasingly problematic in the last ten years in Muscat area despite the continuous erection of flood protection projects by local authorities. This influenced the motive for exploring alternative solutions to this problem. The motive for this research was strengthened by an evidential lack in current knowledge on resilience from the perspective of urban design. Accordingly, **Chapter 1** focused on studying the potential resilience to floods from within the urban design discipline. Aside from identifying the **aim, objectives, motivation and gap in current knowledge**, this chapter showed how the research approached the problem and achieved the research objectives in terms of an appropriate **adopted method and methodology.**

Chapter 2 provided an in depth theoretical review of the resilience literature; this included a close examination of resilience in terms of types, domains, perspectives and principles. The researcher then developed a resilience framework to guide the following qualitative enquiry. Urban morphological approaches were also studied to understand the most relevant conception for urban morphology to address the physical aspect of urban design. The ecological paradigm that guides the research in addressing the ecological dimension in the city was also highlighted. Finally, the research clarified the main influencing flood factors in the area of study. The main deliverables of this chapter were **the resilience theoretical framework and the morphological unit of urban design.**

Chapter 3 addressed the research methodology. Qualitative-quantitative analysis was selected as the preferred research approach to explore the problem. The purpose behind the mixed method was to develop a rich description for the problem and test the reliability of the solutions identified. The main deliverables of this chapter were the identification of the **research approach, reasoning, and strategy along with the case study design and data collection methods.**

Chapter 4 addressed the content analysis and findings of the two case studies. Within-case analysis was carried out across two case study locations in the Muscat area. Semi structured interviews were performed to gain participants insights about the problem. The data were transcribed and analysed into areas, factors and influential variables. A cross case syntheses followed to identify agreements and differences in both cases. Consensus upon common influential variables led to the development of **the instrumental framework of physical interventions, which was the key deliverable in this chapter**.

In **chapter 5**, the instrumental framework helped to shape the design of the intervention scenarios. These scenarios were developed for each case study location according to a set of urban-ecological principles. The scenarios were driven by certain influential variables that arose from the case study analysis (see Tables, 24, 25, 26, and 27 in Chapter 6). These scenarios were prepared and tested across two interrelated stages of pre-processing and post processing situations. Arc GIS software was used in the pre-processing stage; meanwhile, simulation for the flood propagation was conducted through the HEC RAS flood simulation platform. Four scenarios for flood mitigation were developed and tested across the two case studies. Scenarios were discussed in terms of their implementation, reliability, and cost effectiveness with the data provider, the Supreme Council of Planning. The main outcome of this chapter was the **comparison made between the existing flood conditions with the extent of mitigation achieved by applying the intervention scenarios**.

Chapter 6 presented the validity of the adopted research methods as well as the validation of the results; thus, the research validity, reliability, and generalisability were discussed. Moreover, the research quality of the data collection was tested and plausible rival explanations were identified. Finally, the process of validating the instrumental framework was explained. This chapter delivers a range **of evidences that confirms the research validity**.

8.2 Achieving the research aim and objectives

The aim of this research was set to develop an instrumental framework to guide an ecologically compliant urban design to mitigate pluvial flood consequences in Muscat city. The research developed a resilience theoretical framework to achieve the research aim and objectives. The research aim was realised through four research objectives, stemming from the four research questions shown below:

Q1- What is the definition of resilience in urban design? How can resilience thinking contextually address urban design? (Resilience theoretical framework)

Q2- How can urban design incorporate physical measures to influence a state of urban form resilience against pluvial floods? (Operationalisation)

Q3- How can ecological-urban cohesion possibly achieve a resilient urban form to flood? (Eco-built resilient approach)

Q4- How can resilient-based urban design influence new approaches to looking at the urban design process? (Paradigmatic transformation)

The first question was about developing a relevant understanding for the concept of resilience in urban design (Resilience framework). The second was about the possibilities of incorporating resilient measures within the physical urban form (the operationalisation of the framework); whilst, the third related to the mutual cohesiveness between the built and the natural (an eco-built resilience approach). Finally, the fourth concerned the establishment of a new approach to handle urban floods within an ecological resilience perspective. The fulfillment of the final question was achieved through the realisation of all previous questions. Thus, the thesis calls for the establishment of new paradigm in the field of flood mitigation in urban areas, and examines its viability.

Both qualitative and quantitative data were collected in the form of face-to-face interviews, whilst secondary data were gathered the form of document analysis and project case reviews. Qualitative analysis for the geo data sets was conducted through the relevant software to enrich the findings from the qualitative enquiry. Creswell (1994, p.169) argued that the researcher should report the results based on the pre-agreed goals and objectives of the study. The following section displays the accomplishments of the research objectives.

8.2.1 Objective 1: To realise resilience conception that best fits urban design

There was range of definitions for resilience in the current literature; also identified in the literature was the methodological fear of turning the term into an empty signifier. Those fears were ascribed to the descriptive manner of approaching the term. The need for a normative agenda to address the term was also evident in the literature. The research therefore started with an in depth theoretical investigation of resilience identifying its various definitions, and the explanations that could best fit the urban design discipline to fill this epistemological gap. This research carried out on a theoretical investigation to develop an understanding of resilience from the descriptive approach to a normative agenda and finally towards successful practice.

The first objective was considered by achieving two goals; the first was to develop a conception that described the urban form's resilience to flood. This goal was achieved by developing a theoretical consensus on the chief commodity of an urban form. The first goal was addressed by identifying accessibility as the main commodity of the urban form, and developing urban resilience response is linked to maintain a minimum functionality level of this commodity, (section 2.6, Chapter 2). Through theoretical investigation, the second goal was to develop a theoretical framework for the domain of resilience, and its type and principles. An empirical consensus for the proposed resilience framework was achieved and made available through the Delphi study (Appendix-3). This was achieved by brainstorming the resilience principles throughout three turn-round sessions with experts. The resulting resilience theoretical framework guided the qualitative enquiry through the semi-structured interviews (Figure 29, Chapter 3).

8.2.2 Objective 2: To identify the urban design unit of the urban form through which physical interventions will be introduced.

A theoretical review was carried out across four key theoretical domains (Figure 3, Chapter 2). This objective was realised by investigating one of these theoretical domains, namely urban morphology (the internal context). Three morphological schools were examined to identify the most relevant conception of the urban design unit that serves the research purposes. Relevance to the physical dimension was a key factor in deciding the research choice between the three morphological schools. The Italian, British and French morphological schools were examined (section 3.2, Chapter-3). Despite the slight differences, these three schools were principally very close and relevant to the research orientation in focusing on the physical dimension of the urban form. Deeper investigations revealed the reliability of the British school, which centered on the thoughts of M.R.G. Conzen. The clear physical classification made by Conzen, represented in the three overlapping spatial levels of building, plot, and street, was convenient in meeting the intended physical analysis in this research. The three interrelated levels were taken directly to the interview, and remarkably, the interviewees commented on them extensively as they were very aware of their potential contribution, as recorded in the data analysis chapter.

The urban design unit (urban morphology), influenced by Conzen's morphological assumption, was the choice of this research as the urban morphological unit. Considering the natural unit of analysis, referred to as the geo-morphology, the two together formed the unit of analysis in this research, namely the generated morphology. Moreover, physical intervention-related comments made by participants across the interview process were set at the building, plot, and street levels in various manifestations. Insights from participants on each level significantly enriched the resulting physical instrumental framework, developed in Chapter 4. The second objective was realised by identifying the relevant urban morphological unit, Figure 102, and correspondingly, by identifying the generated morphology (section 3.4, Chapter 3)

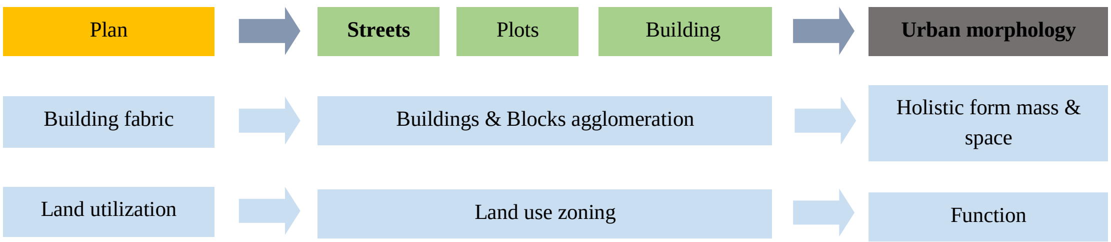


Figure 102: Adopted Conzenian urban morphology

8.2.3 Objective 3: To explore the influential ecological features that are associated with the urban design unit to promote resilient urban forms to pluvial flood.

After identifying the unit of analysis in this research early in Chapter 3, the geo-morphology was clearly addressed as one of the two-combined components that eventually constituted the generated morphology (unit of analysis). The second stage in achieving this objective was realised by carrying out a critical theoretical investigation on urban ecology. The theoretical review revealed four interrelated components, which together constituted the ecology of the city. Those four components were: the physical, the biological, the built, and the social. In addition, since the orientation of this research leans towards the physical, the physical dimension of urban ecology, represented in terrestrial ecology (Topography), is targeted in an in-depth investigation, along with the physical aspects of the urban form.

The choice of the urban ecology paradigm involved 'ecology-of-cities' and the physical components of this paradigm were identified to explore the contribution of urban design and urban ecology to flood mitigation (shown in Figure 28, Chapter 3). The identification of the ecological paradigm was the first stage in achieving this objective, which was clearly reflected in the interview questions, which yielded a set of influential physical variables. The identification of these variables was the second stage in achieving this objective, (Table 23, Chapter 5).

8.2.4 Objective 4: To develop an eco-compliant urban design approach to pluvial flood within a flexible perspective of urban resilience against the existing thesis of urban resistance.

The literature revealed that the philosophical orientation of urban resilience to flood leans more towards the philosophy of safe-to-fail than fail-safe. This philosophical stance was methodologically embraced by the research across the different theoretical analysis stages. For example, when addressing the resilience perspectives, the virtues of ecological resilience allowed for a more stable character that confronted the breaking point within the engineering perspective. The resilience principles were also oriented theoretically towards meeting the research objectives by giving priority to particular principles, such as tolerance and redundancy, and so on.

The clear vision about the research method and methodology, along with the important milestones and deliverables detailed in Chapter 1, had assisted the research cohesion and clarity (Figure 2, Chapter 1). It also helped to build a dependable qualitative framework that could address the phenomena of flooding in Muscat city. After this, the developed instrumental framework was quantitatively tested throughout the scenario building process and virtual flood simulation. The calibration of the model was carried out through a comparison with the results taken from the ground at the time of flood event. The results were highly reliable in both cases, as explained in Chapter 6.

The previously explained process of moving from setting the research objectives, through the theoretical and content analysis and creating the framework and building the scenarios reflects one approach in building resilience measurers into the physical form to mitigate flood consequences. The cohesion of the process was determined from the start to the end of the study, along with the three main research deliverables; the resilience theoretical framework, the instrumental framework, and the build-and-test of intervention scenarios. These three were regarded as the achievements of the final objective of promoting a new ecological paradigm in looking at urban design resilience to pluvial floods.

8.3 Contribution to current thinking and practice

The research has methodologically bridged the gap in current knowledge by applying the principles of urban resilience to flooding. This was achieved by carrying an in depth theoretical investigation into current theory and practice, and evidence of a lack of proper knowledge in this field was highlighted in Chapter 1. Accordingly, this research could influence current knowledge and practice on two complementary levels; the first is on the theoretical level, by the streamlining of resilience thinking and its role in rethinking the ecological resilience of the city. The researcher built a theoretical framework to guide practice into more actionable approach. This was done by moving from the descriptive agenda of addressing resilience towards a more normative, applicable one.

The vital linkages that this research had established between resilience, urban design and ecology had set up a theoretical background for addressing resilience in the built environment. This was facilitated by displaying a full portrait of resilience attributes in general, and by identifying those key parameters to address the resilience of urban design to flood. The main contribution of this research was represented in the establishment of a theoretical background to address resilience in an urban context and to eliminate - at least - some of the methodological fears of turning the term resilience into an empty signifier or a political slogan.

The second level to which this study could contribute is in terms of current practice; was facilitated by feeding the key resilience principles into an empirical study. Guided by the resilience theoretical framework, the research empirical study yielded a set of variables. Results from the two cases were aligned, and this was clarified through the cross synthesis that developed from the formation of the instrumental framework and ultimately led to the scenario building. The simulation stage for the chosen scenarios was carried out to finalise the process. The quantitative results obtained on the extent of flood mitigation were realised by implementing the mitigation scenarios. This is one of the contributions of the research to current practice.

Aside from the research contribution to theory and practice, the process of building resilience principles into a flood responsive ecological urban design has attracted the attention of decision makers in Oman as to the viability of the method. This research mainly aims to build a future paradigm shift in flood management. This awareness was achieved in two different stages on the qualitative part of this research; the first was through the interview process when the participants engaged with the research questions with a noticeable level of enthusiasm, recording their insights on multidisciplinary areas, starting from the pure physical to the socio economic and political. Despite the placement of the research towards the physical aspects of ecology and urban design, the socio-cultural, socio-economic and politically natured insights were of significance in creating the intervention scenarios.

The second was experienced through the focus group with the main partner and data provider for this research, the Supreme **C**ouncil of **P**lanning in Oman. Experts reacted positively to the validation process of the instrumental framework through a focus group activity. They participated genuinely in shaping its final layout. Recorded comments and insights started from the general schemes of potential intervention scenarios to the detailed design levels. Eventually they expressed their anxiousness to have the results of the full study.

8.5 Research challenges

This research, as with any other study, has its challenges. The researcher arranged frequent visits to the field of the study in Muscat-Oman. Four field visits arranged from year one until the final year of the study with a considerable amount of time consumed in the field, (Appendix 2). However, it was highly beneficial, although stressful in terms of the time available for the research. Thus, the limitation of time was evident, as this research adopts a mixed method methodology with a quantitative part that was built totally around experimental traits embodied in relevant flood processing and simulation software. Indeed, mixed method researchers regularly carry on with the quantitative part by applying a questioner strategy on a larger sample and analysing the results returned in the statistical methods. During this research, the quantitative data collected for the second part of the enquiry was digital and geo-referenced that required hefty processing for pre-scenario and post-scenario situations. Despite facing some technical challenges throughout the quantitative analysis, issues were eventually solved through inventing ways to address issues in the software environment. These have arisen after calibration and after testing the research property methods; it adds robustness to the analysis as virtual simulation returns relatively dependable results. In addition, the availability of the digital data within the desired resolution was limited to some extent. This brought about an inherited challenge represented in the lengthy processing phase for the data.

Other challenges were associated with finding the appropriate participants for the interview in terms of relevant experience. However, a member of supporting team, (Appendix 2) was well aware of where to approach for the required expertise in the subject area of the research. They also suggested diversifying the orientation set by researcher for the interviewee population by adding experts from academia, aside from the government and private sectors, which was initially suggested by the researcher.

Eventually, the data provider was satisfied with the final diversified interviewee population. This satisfaction was strengthened later with the rich results of the variables yielded from the interview analysis. In addition, sharing the initial results from the pilot simulation had a positive impact and was very well received by focus group participants from whom satisfactory reflections were recorded for the framework.

8.6 Recommendations

This research concluded its journey with both qualitative and quantitative findings. In addition, the contributions to the current theory and practice were also identified. Yet the research listed a set of recommendations that were found and worth mentioning to complement the final picture of research outcomes. They are as follows:

8.6.1 Urban design (internal context)

- The current practice of urban design should incorporate parties wider than the conventional authorities. This can be extended to include expertise from universities, environmentalists and crowd sourcing. Feedback from external parties can be highly valuable in setting the vision for new urban expansions or existing urban regeneration.

- The urban design process should incorporate the physical characteristics of the natural landscape as significant influencers in shaping the urban form, and not only identified as natural hazard zones or sometimes places of natural conservation.
- In considering the durability of the urban structure when they are created, urban design practice should develop advanced strategies of future plan evaluation that are consistent with the changing nature of flood occurrences. Audit trails and transparency in displaying the targeted objectives, along with predicted flood dissemination, are broader than the current circles of decision makers and execution parties. This can help to steer the practice of urban design towards a more resilient path.

8.6.2 Ecology (external context)

- Knowledge dissemination about the natural landscape features within the city should be maintained amongst city dwellers. Identifying their enormous power in times of natural stress along with their benefit to the quality of life within the city can hinder the continuous violation of natural features. This can be a task of local government; NGO's or even sole speakers and green activists.
- Specialised natural maps for all natural settings, both within and around cities, should be provided. A decision concerning any physical interaction across these maps should be a highly central responsibility beyond the local government and communities. This can resonated through two factors; the first is through the natural extensions of these features as cross-location and affected by flooding in upstream areas. They can establish wider links than the administrative boundaries of a town or even a city. The second is to eliminate bias, personal benefits and/or, in some places, political corruption.

8.6.3 Resilience (system quality or content)

- Resilience as an emerging idea in the field of urban design should be equally embraced on both theoretical and empirical levels. Efforts to theorise and investigate what the term might represent in different fields should be accompanied with experimental traits. This would help to balance the epistemological efforts against the applicability of the idea. Steps towards actionable science in applying resilience measures to floods are required; in other words, seeking a theoretical consensus around an emerging idea is required at some point to move that idea forward to practice. This would realise the theoretical inferences and harvest benefits of scientific efforts.

- Resilience is a system property. It could be a character of a highly specialised field or a small entity. Thus, it might be more appropriate to develop it locally through bottom-up reasoning. A comprehensive approach to developing the idea on broad levels can bring complexities that originate from different acting systems. Thus, achieving it on a smaller level can lead to a process of realising resilience all the way up towards complex adaptive systems in the city. Nevertheless, the literature revealed that the bottom-up approach best describes flood occurrence as site-specific phenomena.

8.6.4 Flood (change agent)

- Floods should be seen as part of the natural process that happens at the site of any city well before the city exists. This vision can alter the whole action taken in confronting the issue of flooding. Efforts should be spent on maintaining this natural process as equal as maintaining and upgrading a city’s structures and services. Negligence in this natural process can drive a reversal impact.
- In the context, where the study took place, government documents revealed that urban floods in specific, and disaster management in general is not yet represented by a distinguished authority or public sector body in Oman. Rather, protection measures and planning dispersed across different authorities. There is a need to identify a natural hazard management body working collaboratively with all relevant partners. The main objective of such entity is to draw national vision for disaster management and set aims and objective for short and long-term targets.
- Aside from identifying a distinguished body to deal with disaster management, the field of flood management should be envisaged as a multi-disciplinary. Experts from economy, sociology, hydrology, and other urban specialities should engage in one complementary process to draw comprehensive policies for disaster management and flood mitigation in specific.

8.7 Generalisability and contextualisation of the findings

This research carried two case studies, each with significant urban and ecological settings. A set of influential variables resulted from the analysis of the two cases. These variables shaped the instrumental framework, which was the backbone of the intervention scenarios. The research is able to generalise the findings by applying the instrumental framework in any area prone to pluvial floods in Oman. This was assured through the study’s external validity achieved by applying a multiple case study design. The results of mitigation gained from the intervention scenarios were found to be reliable in both cases. However, the general logic that governs the instrumental framework, represented in the main components of ecology and urban design, and the implementation of solutions through the urban design unit could be suitable for application elsewhere. These are the circumstances of an environment that incorporates clear urban settings with a distinguished ecological footprint.

This is a contextual study where the phenomenon was studied in its real boundaries. As such, generalisability has different meaning here, as mentioned earlier. However, it is useful to recall the views of Creswell (2007) who stated that the focus of a qualitative generalisation is on the particularity, not generalisability. In addition, Leung (2015) mentioned that the approach to generalisation in qualitative enquiry is based on judging the extent to which the findings in one study can be generalised to another under similar theoretical foundations, and through a proximal similarity model. Nevertheless, the method and methodology followed from start-to-end in this research could be globally generalised. This is applicable considering that the process moves more towards the highly contextualised, and vice versa, shown in Figure 103.

8.8 Research limitations

This research was the product of previously determined areas in ecology and urban design. The ecological paradigm of ecology-of-cities was chosen to lead the ecological association with this research. On the one hand, the research focused on the physical dimension in this paradigm, represented in the terrestrial ecology (topography). On the other hand, the research focused on the physical characteristics of the urban design unit (plot-building-street). These two choices were legitimated in place in Chapter 3. However, they both draw the boundaries of this research within the fields of ecology and urban design.

The consideration given to resilience was intimately connected to these two choices. Thus, the relevant resilience measures and principles were very much connected to the characteristics of the choices made for urban design and ecological paradigms. In addition, with respect to the nature of the problem under investigation, pluvial floods were studied across two case studies; coastal and flush floods were beyond the boundaries of this research. Other socio-cultural limitations were experienced in the case of this research in the scenario building stage. The research identified one of the viable scenarios to develop in CS-1;

however, further discussions with the data provider, SCP, revealed that such scenarios could be viable technically, although very difficult empirically. The reasons explained by SCP revealed that the difficulties are associated with the property evacuation and compensation process that this scenario would require. Meanwhile, the area was occupied by a single extended clan historically linked to the location with close social ties. The majority of the residents in the area resisted the change, even with generous compensations made by the government, in a similar practice in the same area; this was potentially due to their cultural routes and social ties.

Other contextual limitations are associated with the application of the instrumental framework outside the Muscat area. The instrumental framework was influenced by the urban-ecological significance at each area. Accordingly, with flat prone areas with no topographic potential, for example geomorphological, variables will be no longer of influence. The reliance of the instrumental framework will be mostly on the urban morphological unit. However, this is mostly not the case in the majority of the prone areas in Oman. This is because topographic diversity is the footprint of the ecological scene across Muscat specifically and Oman in general.

8.9 Future studies

As mentioned previously, research boundaries were limited to one ecological paradigm. Urban design characteristics were studied through an urban morphology lens. This research boundary was the product of previously determined areas in ecology and urban design, due to predefined objectives associated with the problem under consideration. Nevertheless, the research revealed an interesting arena of multiple dimensions in resilience, ecology and relative new employment for urban design characters. Those areas and dimensions could be the construct of future research. Some of the subject areas that the researcher considers worth visiting are as follows:

1- Despite the challenges associated with the ecological paradigm of ecology-of-cities, it could be efficiently deployed to address the inherited problems with multi acting systems in the city. Nevertheless, the author believes that this task will be broader than one PhD study; however, in relying on the capabilities of multidisciplinary state agencies and other research institutions and collaborators, such studies would be applicable through the availability of appropriate scientific capacities and logistics.

2- This research has addressed the problem of flooding from within an urban-ecological perspective; it also highlights some insights from the hydrology discipline. However, the multi-disciplinary perspective in envisaging urban design practice is yet to be discussed. An exploratory study about the appropriate practice of urban design could be very timely, where all key disciplines could contribute to shaping the structure of future cities. This can successfully confront the conventional urban design paradigm, which tends to involve one individual more comprehensively visualized and technically consistent with current and future environmental challenges.

3- From a socioeconomic perspective, further research can attribute to various aspects that relate to the people, their governing entities, as well as the inclusiveness of policies for flood mitigation. Firstly, social awareness of individuals and communities to behavioural responses to floods is a field that needs expanding upon in relation to a given community's distinctive culture and citizen behavioural patterns, which varies regionally as well as locally (different cities or smaller semi-urban agglomerations). Awareness of social coherence strategies and synergy in response to floods can intensely boost the effects of physical urban mitigation design interventions. Secondly, from a governance point of view, a required attention needed at the level of local municipalities in terms of inclusiveness of all aspects that are affected by floods and/or need mitigation measures.

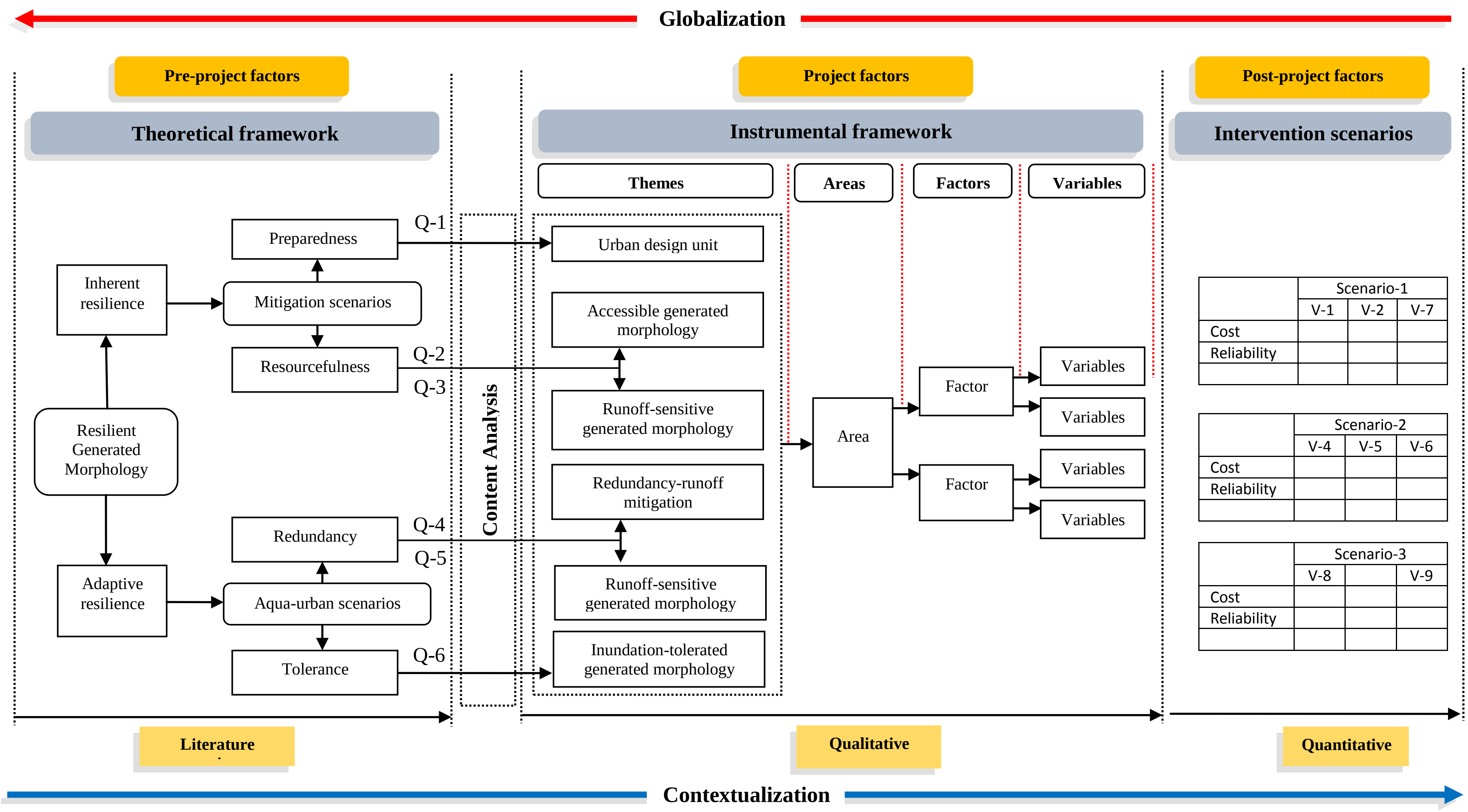


Figure 103: Project factors and generalizability

Appendix 1: Description of Case study area

Muscat city:

Geography

Muscat is located in northeast Oman, at 24°00′N 57°00′E. The Tropic of Cancer passes south of the area. It is bordered to its west by the plains of the Al Batinah Region and to its east by Ash Sharqiyah Region. The interior plains of the Ad Dakhiliyah Region border Muscat to the south, while the Gulf of Oman forms the northern and western periphery of the city. The water along to coast of Muscat runs deep, forming two natural harbours, in Muttrah and Muscat. The Western Al Hajar Mountains run through the northern coastline of the city (www.scp.gov.om).

Volcanic rocks are apparent in the Muscat area, and are composed of serpentine and diorite, extending along the Gulf of Oman coast for ten or twelve 16 kilometres (9.9 mi) from the district of Darsait to Yiti. Plutonic rocks constitute the hills and mountains of Muscat and span approximately 30 miles (48 km) from Darsait to Ras Jissah. These igneous rocks consists of serpentine, greenstone and basalt, typical of rocks in Southeastern regions of the Arabian Peninsula. South of Muscat, the volcanic rock strata is broken up and distorted, rising to a maximum height of 6,000 feet (1,800 m), in Al Dakhiliyah, a region which includes Jebel Akhdar, the country's highest range. The hills in Muscat are mostly devoid of vegetation but are rich in iron.

Figure (1) Muscat administrative boarders (SCP)

Figure (2) Muscat urban areas (SCP)

Climate:

Muscat features a hot, arid climate with long and very hot summers and warm "winters". Annual rainfall in Muscat is about 10 cm (4 in), falling mostly from December to April. In general precipitation is scarce in Muscat, with several months on average seeing only a trace of rainfall. However, in recent years, heavy precipitation events from tropical systems originating in the Arabian Sea have affected the city. Cyclone Gonu in June 2007 and Cyclone Phet in June 2010 affected the city with damaging winds and rainfall amounts exceeding 100 mm (4 in) in just a single day. The climate generally is very hot, with temperatures frequently reaching as high as 40°C (104°F) in the summer. Humidity in the summer is at 40-60%, which is quite high for such hot temperatures.

Climate data of Muscat													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	34.2 (93.6)	37.0 (98.6)	41.4 (106.5)	44.0 (111.2)	47.0 (116.6)	48.3 (118.9)	49.2 (120.6)	46.8 (116.2)	43.6 (110.5)	42.0 (107.6)	37.8 (100)	33.0 (91.4)	49.2 (120.6)
Average high °C (°F)	23.5 (74.3)	26.1 (79)	29.8 (85.6)	34.7 (94.5)	37.5 (99.5)	40.4 (104.7)	38.6 (101.5)	36.2 (97.2)	35.3 (95.5)	34.0 (93.2)	29.5 (85.1)	27.1 (80.8)	32.73 (90.91)
Daily mean °C (°F)	19.4 (66.9)	21.9 (71.4)	24.8 (76.6)	28.7 (83.7)	32.3 (90.1)	35.5 (95.9)	34.0 (93.2)	32.3 (90.1)	30.4 (86.7)	29.5 (85.1)	24.7 (76.5)	22.0 (71.6)	27.96 (82.32)
Average low °C (°F)	15.3 (59.5)	17.6 (63.7)	19.7 (67.5)	22.7 (72.9)	27.1 (80.8)	30.6 (87.1)	29.4 (84.9)	28.4 (83.1)	25.5 (77.9)	24.9 (76.8)	19.9 (67.8)	16.9 (62.4)	23.17 (73.7)
Record low °C (°F)	11.5 (52.7)	12.5 (54.5)	14.4 (57.9)	17.5 (63.5)	19.6 (67.3)	24.5 (76.1)	25.0 (77)	23.3 (73.9)	23.0 (73.4)	17.5 (63.5)	14.3 (57.7)	14.4 (57.9)	11.5 (52.7)
Precipitation mm (inches)	12.8 (0.504)	24.5 (0.965)	15.9 (0.626)	17.1 (0.673)	7.0 (0.276)	0.9 (0.035)	0.2 (0.008)	0.8 (0.031)	0.0 (0)	1.0 (0.039)	6.8 (0.268)	13.3 (0.524)	100.3 (3.949)
Average relative humidity (%)	63	64	58	45	42	49	60	67	63	55	60	65	57.6
Mean monthly sunshine hours	268.6	244.8	278.3	292.5	347.4	325.7	277.7	278.6	303.9	316.9	291.9	267.0	3,493.3
Source: NOAA (1961-1990)													

Figure (3) climate data of Muscat NOAA

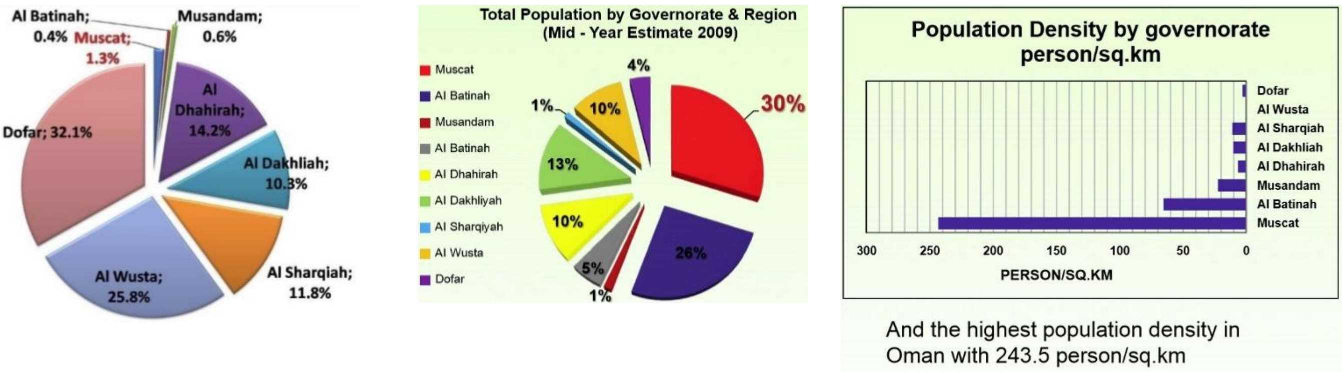


Figure 4: Oman population distribution (Al Garibi, 2014)

Muscat urban area:

The Al Sultan Qaboos Street forms the main artery of Muscat, running west-to-east through the city. The street eventually becomes Al Nahdah Street near Al Wattayah. Several inter-city roads such as Nizwa Road and Al Amrat Road intersect with Al Sultan Qaboos Road (in Rusail and Ruwi, respectively). Muttrah, with the Muscat Harbour, Corniche, and Mina Qaboos is located in the north-eastern coastline of the city, adjacent to the Gulf of Oman. Other coastal districts of Muscat include Darsait, Mina Al Fahal, Ras Al Hamar, Al Qurum Heights, Al Khuwair and Al Seeb. Residential and commercial districts further inland includeAl Hamriyah, Al Wadi Al Kabir, Ruwi, Al Wattayah, Madinat Qaboos, Al Azaiba and Al Ghubra.

Urban growth in Muscat is characterized by the following attributes (Al Gharibi H.2014):

- Extreme land consumption;
- Low densities particularly at peripheries;
- Private automobile dependency with absence of viable public transport;
- Fragmented open space, wide gaps between development and scattered appearance;
- Lack of choice in housing types and prices;
- Separation of uses into distinct areas;
- One to two story buildings as a default form of development;
- Large lots;
- Commercial buildings surrounded by acres of parking and
- Life style patterns are oriented towards the single villa on a walled plot as the most favourite residential building type.

These trends however meet limited resources mainly related to land.

The urban morphological situation had witness three crucial turning points, from the prospect of the plot size of the residential use, it was 150 sq. m before the oil revolution in 1970, and it end up to 1200 sq. m in nowadays, this can explain how much land is consumed, the rapid urbanization invades vacant lands, farm lands and other ecologically vulnerable lands. The figure shows the morphological leaps of rapid urbanization. (Al Gharibi H.2014)

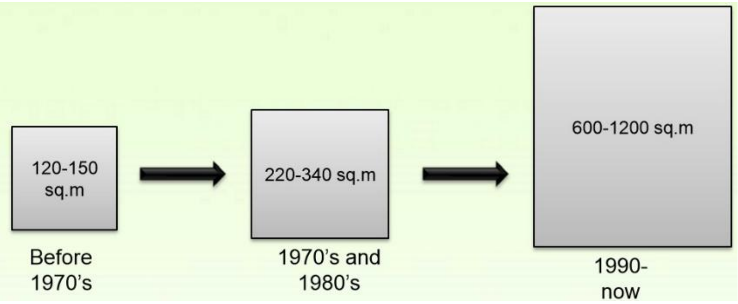


Figure 5: Residential plots development (Al Gharibi, 2014)

Rapid urbanization:

Due to the rapid urbanization driven by high demand on new plot of land, patch developments along the high ways and aside of linking roads has come to emerge more and more in the urban life producing more pressure on the urban infrastructure and invading more ecologically critical lands to which the of floods become increasingly evident.

Figure 6: Rapid urbanization between 2001 and 2008 (Al Garibi, 2014)

History of flooding:

Muscat and Oman in general had frequently witnessed an increasing occurrence rate of flood driven by cyclones and heavy rain falls due to the climate change, the rapid urbanization jointly performed as a factor that worsen the situation and the consequences of these climate events, having a large urban expansions to intervene with sensitive ecological territories had exacerbate the problem by increasing the physical exposure to flood streams and prone areas. Table (1) exhibits a brief history for the extreme events in Oman (Al-Barwani, 2011).

Natural Event	Date	Precipitation Levels in mm	Place of occurrence
Tropical cyclone	1890	285	Muscat and Sohar
Tropical cyclone	1963	269	Salalah
Tropical cyclone	1966	202	Salalah
Cyclone storm	1971	99	Masirah
Tropical cyclone	1977	430	Salalah
Low pressure	1999	--	Sur
Deep low pressure	1999	69	Salalah
Cyclone storm	2002	58	Salalah
Low pressure	2004	116	Oman
Cyclone Gonu	2007	626	Oman
Cyclone Phet	2010	603	Oman

Table 1: History for the extreme events in Oman Al-Barwani (2011)

Figure (8) Muscat city cyclone Gonu 2007 (SCP)

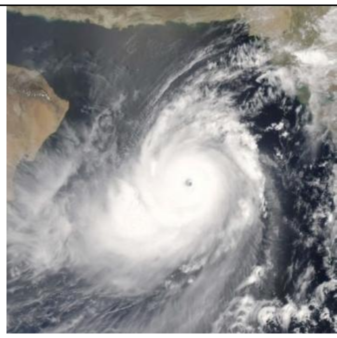
Cyclone Gonu 2007	
On the 5th of June 2007 tropical cyclone Gonu approached the coast of Sharqiya near reass-Alhad in east Oman.	
The most disastrous tropical cyclone ever recorded in the history of Oman TC records.	
Tropical cyclone Gonu was associated with heavy thunder storms, strong winds, high sea tides and flooding	
Surface wind reached to category 4 :211-250 km/h.	
Casualties of this event was (49) people died and estimated loss of (1.5) billion Rial Omani = (4) billion $	

Figure 9: Cyclone Gonu (Al-Barwani 2011)

Figure (10) Muscat city cyclone Phet 2010 (SCP)

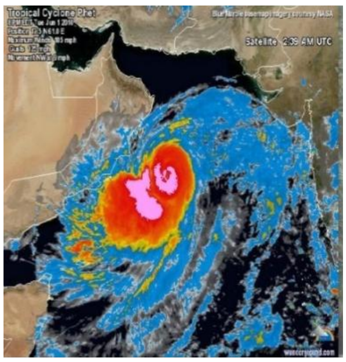
Cyclone Gonu 2007	
On the 4th of June 2010 tropical cyclone Phet approached the coast of Oman near Qalhat and proceeded to Muscat and Batinah region.	
The second most disastrous tropical cyclone ever recorded in the history of Oman TC records.	
Tropical cyclone Phet was associated with heavy thunder storms, strong winds, high sea tides and flooding	
Surface wind reached to category 4:211-250 km/h.at sea, however reduced to category 1 when approached the land.	
Casualties of this event was (6) people died and estimated loss of (780) million Rial Omani = (2) billion $	

Figure 11: Cyclone Phet (Al-Barwani 2011)

Appendix 2: Summary of field visits

2.1 First field visit:

Two visits were arranged to the study areas in Muscat city during the second year of the research 2015, the first took place between 1st August 2015 and the 15th September 2015, and this visit was dedicated to achieve two targets:

1- Introducing the project objectives and potential outcomes of flood mitigation.

2- Maintaining initial access to the study areas, data collection, and possible interviewees.

A meeting was arranged with the deputy chairman of the supreme council of planning-minister of commerce, during which an approval was obtained for the two carry on with the study at the two prone locations and required data to be provided to the researcher. He also suggested establishing teamwork from the SCP to facilitate and support the researcher's mission. Accordingly, a teamwork was formed consist of the head of the minister's office, the adviser of the SCP, the deputy secretary general of the SCP. Followed meeting was held with teamwork members and four key governmental bodies and two private consultancy companies were suggested to be approached for data collection, Table (2).

	Governmental sector	Private sector
1	Supreme Counsel of Planning	Consultancy company (Infrastructure)
2	Muscat Municipality	Consultancy company (rods, bridges & dams)
3	Ministry of water resources	--
4	Ministry of housing	--

Table (2) initial candidate's classification

Aside from this achievement, and by the time the researcher was in the field, a heavy downpour took place in Muscat on August. Heavy rainfall that last for (45) minutes caused a significant inundation on CS-2, Al-kuwair catchment, (Figure 12 shows the location-though the event in the image related to the 2010 Phet cyclone). The main street in CS-2 area was inundated for a bout ten hours with a (30-50) cm of runoff water. The same day the researcher was contacted by one of the team work, he was encouraging the researcher to visit the area in order to witness the real time situation. The researcher had set to the site, there was a (40) cm depth of runoff water in one location on the path of Sultan Qaboos Street.

Figure (12) SQS in CS-2 flood of 2010 SCP, 2010

The experience of being in the site during the event was overwhelming, witnessing a real time flood situation. this was, in a great extent, resembling Patton's (2002. p.48) description of qualitative inquiry when stating that; “Qualitative inquiry means going into the field, into the real world of programs, organizations, neighborhoods, streets corners, and getting close enough to the people and circumstances there to capture what is happening”.

2.1.1 Achievement of the first visit:

- Introducing the project, its objective and its potential outcomes to the data provider.
- Gaining initial access to the two sites of the study.
- Gaining initial access to relevant hydrologic and land uses data.
- The data provider was very satisfied for the choice of the two case study locations.
- Experiencing a real time pluvial flood event.

2.1.2 Challenges faced during this phase:

The process of introducing the project and gaining approval to access both sites and the relevant data was a time consuming process. Key people whom the researcher should approach were very busy and always on travel inside or outside the country. The researcher spent a month on achieving this important milestone in the research journey.

2.2 Second field visit:

Second visit was arranged to the field of study between the 9^{th} of December 2015 and the 8^{th} of February 2016. The researcher made a round trip to Baghdad and then to Muscat before back to UK, the purpose of visiting Baghdad was to confirm the unavailability of the data required for the case study analysis as the researcher’s sponsor principally preferred to have a case study in Iraq. A meeting with the director general of spatial planning in the ministry of planning in Iraq was arranged. Resourceful face to face meeting revealed the inappropriateness of the available data to conduct the research analysis. Part of the data was unavailable and the other was outdated, also the Arial photo and the digital elevation files (DEM) were both in coarse inappropriate resolution.

On the 19th of December the researcher left Baghdad and arrived to Muscat city and the second phase of data collection was launched. A meeting with the team work was arranged to manage the second face of data collection, a list of targets were placed as follow:

- Checking availability and source of hydraulic data including rain gauge stations.
- Checking availability and source of land use data.
- Checking the availability and source of hazard prone areas, water sheds and terrestrial ecology maps.
- Checking availability, source, and resolution of the Arial photo.
- Checking availability, source, and resolution of the digital elevation model (DEM).
- Reviewing and revising the list of potential interviewees.

A meeting was arranged with the director general of water resources in the ministry of water resources through which the picture was cleared about the availability of hydraulic data. The readings of rain gages in the area of study for about 30 years back were confirmed available; he welcomed the idea of conducting the project and promised to make the data available for the researcher on time.

All land use maps, water shades, hazard prone areas, and terrestrial ecology maps are sourced in the digital elevation file for Muscat city, and the supreme council of planning asked the researcher to provide letters from his university assuring the exclusivity of the use of the (DEM) files for the purpose of this research only. The required letters were asked to be issued addressing two key people, the first is the deputy secretary general of the supreme council of planning as he is one of the team work formed to assist the researcher. The second is the supreme council of planning advisor for planning affairs.

Accordingly, two letters where issued from the University of Salford to the mentioned people, assuring the confidentiality of the data and the exclusivity of the data to be used for the scientific and applied purposes of this research (Appendix 7). Based on these two letters hydraulic experts in the directorate general of spatial planning make the data available for the researcher , also advised the researcher about the proper boundaries for the two catchments to meet the purpose, objectives and the technique of the analysis that the researcher is going to use. An e-mail including a (KMZ) file for the two revised case study catchments was received accordingly from the directorate general of spatial planning at the SCP.

Regarding the Arial photo of the study area, the researcher was advised to coordinate with ministry of housing as they own the Arial photo for Muscat governorate. Meeting with the ministry adviser was arranged, and due to technical reasons, the Arial photo was not ready at that time, the researcher thanked the effort paid from the ministry of housing as they promise to provide the Arial photo when it will be ready. On the 23rd of March 2016 the researcher received the air born Arial photo for the two case study locations from the ministry of housing. By having that, all digital data required for the case study analysis were satisfied.

2.3 Third field visit:

Two field visits were arranged to the area of the study in 2016. The first was in June and the second was in August. Purpose of the visits is to perform the interviews with the participants. All (16) interviews were accomplished during these two visits. There were some challenges witnessed during the first field visit in June, as some participants could not make themselves available to the interview due to some changes in final examination at universities in Muscat. This had led to the necessity of the second visit within just two months, where all the university professors were having fewer loads. This was one of the financial and logistics burdens that the researcher had to deal with during the phase of primary data collection. However, all interviewed were performed and transcribed.

2.4 Fourth field visit:

The researcher arranged a final visit to the study area to accomplish two important tasks:

1- To perform the real geo data set validation.

2- To conduct the focus group activity of validating the instrumental framework at the SCP.

2.4.1 Validating the geo data set

The date of the (DEM), and the aerial photo acquisition was in 2014. Hence, a process of validating those digital files is required. This is important to check for any significant changes or modifications in the urban-ecological context in the study areas. The process was carried out manually by a real survey in the field. Paper maps for the prone area were used to validate the geo data set with the existing urban-ecological context in the study area. The researcher had employed one survey consultant and two architect's students. The job was divided to four tasks at each area where each one of the team covered a certain part of the surveyed area. The job was carried on with CS-1 site and took (4) hours to finish the job as the urban context was quite simple and not that dense, while, the process took (7) hours in covering CS-2 next day. The method by which the two areas were covered was by driving in the car slowly through the main streets of the prone area and recording any changes or construction activities was how this validation took place. There were few minimal changes in some buildings, other changes represented in demolishing of old building and construction was going on in an alternative project of multi story boiling with the same municipal specifications of height and number of floors.

No significant urban or ecological change witnessed in the two study areas that might affect the hydrological performance in the two areas. However, the geo data set was validated and the researcher had a good opportunity to speak face to face with few people whom were affected by the cyclone of 2007 in the two areas of the study.

2.4.2 Focus group activity:

The researcher had arranged the focus group to be done at the SCP. The SCP is the end user and the prime beneficiary from the study in general and the instrumental framework in specific. five experts were approached to contribute in the two days activity. In the first day an introduction session to circulate knowledge about the project was conducted. In depth discussions followed with the participants promote better understanding and shaped the framework into more actionable instrument. Participant were provided with the evaluation forms and asked to make it ready next day. This gave the participants more time in considering framework potentials. The next day, a brief face to face sessions with each one of the participants were accomplished, during those sessions forms were collected, some participants added valuable further insights. Eventually, Forms were analyzed for the final instrumental framework validation as seen in chapter-7.

Appendix 3: Delphi study in developing resilience principles

1. Development of resilience principle frame work from expert judgment:

A Delphi study was conducted among a number of six experts from different backgrounds, there was a common factor among most of them that they were in managerial positions in the SCP. The design of the questioner consists of three stages each of which with a thematic question displayed across three turn rounds of anonymous experts' response. Table 3 below demonstrates the study design:

Stage	Thematic question	Consensus through Turn rounds		Outcome
Stage -1	Principles homogeneity	1	50%	Homogeneous principles
		2	90%	
		3	95%	
Stage -2	Principles orientation	1	30%	Hard systems resilient-based principles
		2	70%	
		3	100%	
Stage -3	Principles integration & representativeness	1	20%	Hybrid framework
		2	70%	
		3	100%	

Table 3: percentage of consensus through turn-rounds

1.2 Stage one: Principles Homogeneity

The discussed approaches of resilience principles are stemmed from various disciplines. some of which were laid to specify resilience in social aspect, other describing the economic resilience while other addressed infrastructural systems, among all of which, there were other referring to managerial and organizational aspects. In this first stage, a thematic question laid across three questioner turn-rounds led the experts' responses towards grouping principles upon homogeneity, Table 4:

No.	Grouping similar principles			Principles Homogeneity
1	**Redundancy**	Diversity-Redundancy		Redundancy
2	Feedback	Homeostasis	**Reflective**	Reflective
3	**Learning**			Learning
4	**Adaptive** thinking			Adaptive thinking
5	**Participation**	Inclusive		Participation
6	**Resourcefulness**	Omnivory		Resourcefulness
7	**Robustness**			Robustness
8	**Resistance**			Resistance
9	**Rapidity**	Response-Recovery	High flux	Rapidity
10	**Flatness**			Flatness
11	**Reliability**			Reliability
12	**Connectivity**	Buffering		Connectivity
13	Flexibility	Flexibility v stiffness	**flexibility**	flexibility
14	Integration	**Cohesion**		Cohesion
15	**Margin**			Margin
16	**Tolerance**			Tolerance
17	**Capacity**	Buffering capacity		Capacity

Table 4: Total population of resilience principles grouped upon similarities

1.3 Stage two: Principles orientation

The second stage was designed for a reductionist purpose as well, Experts were asked to identify those most relevant principles to the notion of resilience in urban design. To facilitate responses clarity and correspondence to the objective, thematic question set to differentiate between four confronting characters identified as soft systems versus hard systems and resilience (safe-to-fail) thesis versus resistance (fail-safe) thesis.

The physical aspect of urban design- as it is the focus of this research- will line up under the hard system as the first selected criteria. On the other hand, resilience will be chosen over the resistance as the second selected criteria. These two filter-like criteria helped in reducing the plenitude of resilience principles to the most relevant to research area of interest which is resilient thinking in urban design as a hard system, figure (13).

Looking at the total population of resilience principles generated to describe social, economic, technological or infrastructural systems. The discrimination tool used to address principles relevance demonstrated on the (X) axis as hard-Soft characteristics and (Y) axis as Resistance-resilience characteristics. This three turn-round stage yielded into four areas of interest on both sides of the X axis and the Y axis shown in figure (13).

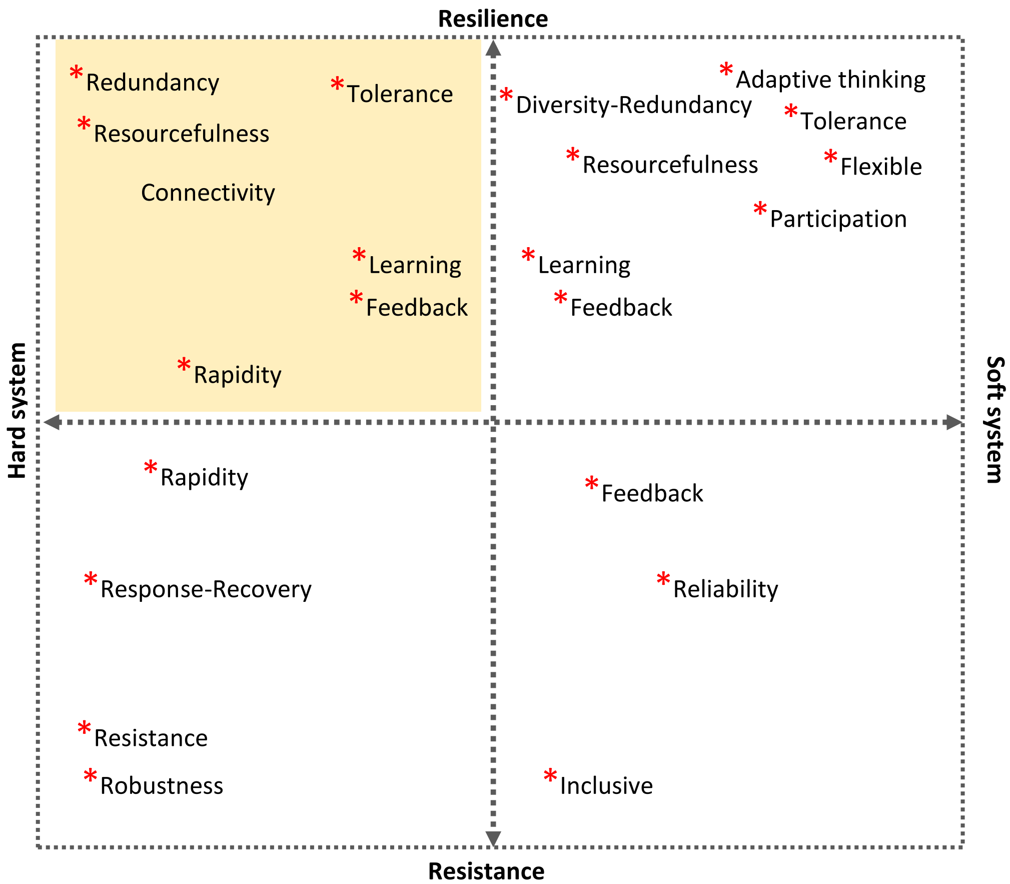


Figure (13) resilience principle orientation

The area formed between hard system on the X axis and the resilience on the Y axis in figure (13) represents the area that accommodates principles of resilient urban design. The principles of Resourcefulness, Redundancy, connectivity, learning, feedback, Tolerance and rapidity are the initial principles that resulted from the analysis of stage two.

1.4 Stage three: principles reduction and representativeness

Experts were asked to integrate and reduce the principles resulted from stage two as a fine tuning step to produce the final resilience framework. This is going to be through merging upon similarities in nature to conduct and develop a hybrid framework of resilience principles, figure (14).

By examining the initial questioner turn-rounds, Resourcefulness and redundancy were taken straight forward to final hybrid model. They are among the most principles that clearly exist in the five discussed approaches of resilience principles. Learning and feedback were represented in one principle, as they are exemplifying a process of preparatory future response based on previous events, hence were jointly referred to as; preparedness principle.

Rapidity in which time consumed to return to the normal state is the main character, though it is an important character of the resilience thesis, but it is not the pivotal one. Experts were previously educated about difference between resilience thesis (safe-to-fail) and resistance theses (fail-safe), accordingly, time dimension envisioned as the longest the system can undergo disturbance before collapsing or shifting to another state. Hence, this principle was replaced by tolerance. Finally, connectivity was linked under the principle of resourcefulness. The resulted resilience principles will constitute the backbone of the resilience theoretical frame work.

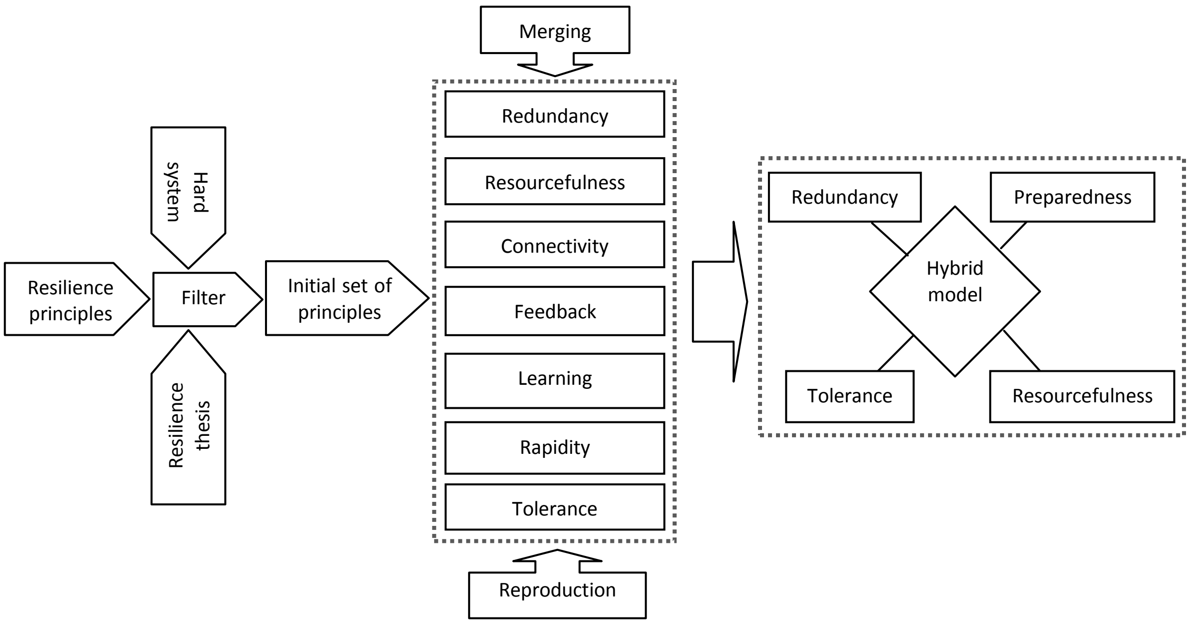


Figure (14) Resilience principles' hybrid model

Appendix 4: Resilience definition in various fields

Author, year	Domain	Definition
Gordon, 1978	Physical	The ability to store strain energy and deflect elastically under a load without breaking or being deformed
Bodin, 2004	Physical	The speed with which a system returns to equilibrium after displacement irrespective of how many oscillations are required
Holling, 1973	Ecological system	The persistence of relationships within a system; a measure of the ability of systems to absorb changes of state variables, driving variables, and parameters, and still persist.
Holling, 1995	Ecological system	Buffer capacity or the ability of a system to absorb perturbation, or the magnitude of disturbance that can be absorbed before a system changes its structure
Abel, 2001	Ecological system	The ability to persist through future disturbances
Waller, 2001	Ecological system	Positive adaptation in response to adversity; it is not the absence of Vulnerability, not an inherent characteristic, and not static.
Brock, 2002	Ecological system	The transition probability between states as a function of the consumption and production activities of decision makers
Klein, 2003	Ecological system	The ability of a system that has undergone stress to recover and return to its original state; more precisely (i) the amount of disturbance a system can absorb and still remain within the same state or domain of attraction and (ii) the degree to which the system is capable of self-organization
Anderies, 2004	Ecological system	The amount of change or disruption that is required to transform the maintenance of a system from one set of mutually reinforcing processes and structures to a different set of processes and structures
Ott, 2004	Ecological system	Maintenance of natural capital (as the basis for social systems' functioning) in the long run
Walker, 2004	Ecological system	The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks
Adger, 2005	Ecological system	The capacity of linked social-ecological systems to absorb recurrent disturbances ... so as to retain essential structures, functions, and feedbacks
Longstaff, 2005	Ecological system	The ability by an individual, group, or organization to continue its existence (or remain more or less stable) in the face of some sort of surprise….Resilience is found in systems that are highly adaptable (not locked into specific strategies)

		and have diverse resources
Resilience alliance, 2006	Ecological system	The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks-and therefore the same identity.
Resilience alliance, 2009	Ecological system	The capacity of a system to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes.
Adger, 2000	Ecological and social systems	The ability of communities to withstand external shocks to their social infrastructure
Adger, 2003	Ecological and social systems	The ability to persist (i.e., to absorb shocks and stresses and still maintain the functioning of society and the integrity of ecological systems) and the ability to adapt to change, unforeseen circumstances, and risks
Comfort, 1999	Community	The capacity to adapt existing resources and skills to new systems and operating conditions
Meleti, 1999	Community	(The ability to) withstand an extreme event without suffering devastating losses, damage, diminished productivity, or quality of life without a large amount of assistance from outside the community
Bruneau, 2003	Community	The ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes
Godschalk, 2003	Community	The ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes
Timmerman,1981	Community	A system capacity to absorb and recover from the occurrence of hazardous event; reflective of a society ability to cope and to continue to cope in the future.
Wildavsky, 1991	Community	The capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back
Brown, 1996	Community	The ability to recover from or adjust easily to misfortune or sustained life stress
Sonn, 1998	Community	The process through which mediating structures (schools, peer groups, family) and activity settings moderate the impact of oppressive systems
Paton, 2001	Community	The capability to bounce back and to use physical and economic resources effectively to aid recovery following exposure to hazards
Center of community	Community	intentional action to enhance the personal and collective capacity of its citizens and institutions to respond to, and influence the

enterprise, 2000		course of social and economic change
Chenoweth, 2001	Community	The ability to respond to crises in ways that strengthen community bonds, resources, and the community's capacity to cope
Ganor, 2003	Community	The ability of individuals and communities to deal with a state of continuous long term stress; the ability to find unknown inner strengths and resources in order to cope effectively; the measure of adaptation and flexibility
Kofinas, 2003	Community social resilience	Two types of social resilience: (1) a social system's capacity to facilitate human efforts to deduce the trends of change, reduce vulnerabilities, and facilitate adaptation; and (2) the capacity of a [social-ecological system] to sustain preferred modes of economic activity
Quinlan, 2003	Community	Resilience consist of (1) the amount of change a system can undergo and still retain essentially the same structure, function, identity, and feedback on function and structure, (2) the degree to which a system is capable of self organization (and reorganize after a disturbance), and (3) the degree to which a system expresses capacity for learning and adaptation.
Ahmed, 2004	Community	The development of material, physical, sociopolitical, socio-cultural, and psychological resources that promote safety of residents and buffer adversity
Kimhi, 2004	Community	Individuals' sense of the ability of their own community to deal successfully with the ongoing political violence
Coles, 2004	Community	A community's capacities, skills, and knowledge that allow it to participate fully in recovery from disasters
Allenby, 2005	Community	The capability of a system to maintain its function and structure in the face of internal and external change and to degrade gracefully when it must
Gunderson, 2005	Community	The return or recovery time of a social-ecological system, determined by (1) that system's capacity for renewal in a dynamic environment and (2) people's ability to learn and change (which, in turn, is partially determined by the institutional context for knowledge sharing, learning, and management, and partially by the social capital among people)
Pfefferbaum, 2005	Community	The ability of community members to take meaningful, deliberate, collective action to remedy the impact of a problem, including the ability to interpret the environment, intervene, and

		move on
Subcommittee on disaster reduction, 2005	Community society	The capacity of a system, community or a society potentially exposed to hazards to adapt, by resisting or changing, in order to reach and maintain an acceptable level of functioning and structure
UN/ISDR, 2005	Community	The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure
Perrings, 2006	Community	The ability of the system to withstand either market or environmental shocks without losing the capacity to allocate resources efficiently
Liu, 2007	Community	The capability to retain similar structures and functioning after disturbances for continuous development
Norris, 2008	Community individual	A process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance
Rose, 2007	Economic	(Dynamic) Resilience: the speed at which an entity or system recovers from a severe shock to achieve a desired state Static economic resilience: the ability of an entity or system to maintain function (e.g., continue producing) when shocked Inherent resilience: the ability to deal with crises Adaptive resilience: the ability (of an entity or system) in crisis situations to maintain function on the basis of ingenuity or extra effort
Masten, 1990	Individual	The process of, capacity for, or outcome of successful adaptation despite challenging or threatening circumstances Individual
Egeland, 1993	Individual	The capacity of successful adaptation, positive functioning, or competence … despite high risk status, chronic stress, or following prolonged or sever trauma
Butler, 2007	Individual	Good adaptation under extenuating circumstances; a recovery trajectory that returns to baseline functioning following a challenge

Table 5: Resilience definitions in various fields

Appendix 5: Ethical approval, Participant Invitation Letters and information sheet

College Ethics Panel
Ethical Approval Form for Post-Graduates

Ethical approval must be obtained by all postgraduate research students (PGR) prior to starting research with human subjects, animals or human tissue.

A PGR is defined as anyone undertaking a Research rather than a Taught master's degree, and includes for example MSc by Research, MRes by Research, MPhil and PhD. The student must discuss the content of the form with their dissertation supervisor who will advise them about revisions. A final copy of the summary will then be agreed and the student and supervisor will 'sign it off'.

The signed Ethical Approval Form and application checklist must be forwarded to your College Support Office and also an electronic copy MUST be e-mailed to the contacts below at your College Support Office;

CASS:	Deborah Woodman	d.woodman@salford.ac.uk
CHSC:	Jill Potter	j.potter@salford.ac.uk
	Rachel Shuttleworth	r.shuttleworth@salford.ac.uk
CST:	Nathalie Audren-Howarth	n.audren@salford.ac.uk

The forms are processed online therefore without the electronic version, the application cannot progress. Please note that the form must be signed by both the student and supervisor.

Please ensure that the electronic version of this form only contains your name and your supervisor's name on this page, where it has been requested.

All other references to you or anyone else involved in the project must be removed from the electronic version as the form has to be anonymised before the panel considers it.

Where you have removed your name, you can replace with a suitable marker such as […..] Or [Xyz], [Yyz] and so on for other names you have removed too.

You should retain names and contact details on the hardcopies as these will be kept in a separate file for potential audit purposes.

Please refer to the 'Notes for Guidance' if there is doubt whether ethical approval is required
The form can be completed electronically; the sections can be expanded to the size required.

College Ethics Panel:

University of Salford MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

7 March 2016

Mohanad Abdulkareem

Dear Mohanad

<u>RE: ETHICS APPLICATION ST15/75</u> – The resilience of urban design to pluvial flood.

Based on the information you provided, I am pleased to inform you that your application ST 15/75 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Prof Mohammed Arif
Chair of the Science & Technology Research Ethics Panel
Professor of Sustainability and Process Management,
School of Built Environment
University of Salford
Maxwell Building, The Crescent
Greater Manchester, UK M5 4WT
Phone: + 44 161 295 6829
Email: m.arif@salford.ac.uk

Participant Invitation Letter

PhD research student
Room 314
School of Built Environment
3rd Floor, Maxwell Building,
The Crescent,
University of Salford, Salford
United Kingdom
M5 4WT
Tel: + 44 (0) 161 295 5000
Email: m.m.abdulkareem@edu.salford.ac.uk

The resilience of urban design to pluvial flood

Dear Madam/Sir,

My name is ……………and I am currently studying PhD at the School of the Built Environment, The University of Salford in the UK under the supervision of………..

As part of my PhD study, you are kindly invited to participate in a semi-structured interview about my research titled "The resilience of urban design to pluvial flood". The research aims to develop an instrumental framework for professionals to guide them in producing resilient urban design that mitigates the pluvial flood consequences in Muscat city.

Your cooperation is most essential as the deliverable of the case study could be beneficial to the future of the city. All responses, opinions and point of views placed to this interview would be kept strictly confidential and will only be used for academic purposes only. Once an appropriate data collection will be completed and analysed, the original data will be shredded.

Unless requested, the data collected may appear anonymously in the PhD dissertation and other related publications such as local and international journal. However, no personal details or details about the organisation will be disclosed.

Thank you.

Participant Consent Form

University of Salford MANCHESTER

Title of Project: The resilience of urban design to pluvial flood.
Ethics Ref No.: ETHICS APPLICATION ST15/75
Name of Researcher: Mohanad Mahdi Abdulkareem
Name of Supervisor: Professor Hisham Elkadi
Name of co supervisor: Dr. Nicholas Davies

(Delete as appropriate)

➢ I confirm that I have read and understood the information sheet for the above study (version x- date) and what my contribution will be.	**Yes**	**No**	
➢ I have been given the opportunity to ask questions (face to face, via telephone and e-mail)	**Yes**	**No**	
➢ I agree to take part in the interview	**Yes**	**No**	**NA**
➢ I agree to the interview being tape recorded	**Yes**	**No**	**NA**
➢ I understand that my participation is voluntary and that I can withdraw from the research at any time without giving any reason	**Yes**	**No**	
➢ I understand how the researcher will use my responses, who will see them and how the data will be stored.	**Yes**	**No**	
➢ I agree to take part in the above study	**Yes**	**No**	

Name of participant: ………………………………………………………………

Signature: Date:

Name of researcher taking consent: Mohanad Mahdi Abdulkareem

Researcher's e-mail address:
School of Built Environment
University of Salford,
Maxwell Building 3rd Floor,
Salford, M54WT, United Kingdom
Email: m.m.abdulkareem@edu.salford.ac.uk
Tel: + 44 (0) 161 295 5000

Participant Information Sheet

Research Title: The resilience of urban design to pluvial flood

I would like to invite you to take part in a research study. Before you decide, you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Ask questions if anything you read is not clear or need more information. Take time to decide whether or not to take part.

This study is part of a PhD research; the research will focus on developing an (echo-built) instrumental framework which would reveal the contribution of the urban design discipline correspondingly with the local terrestrial topography to mitigate pluvial flood based on surface runoff responsive design.

What is the purpose of the study?

Develop an (eco-built) instrumental framework for urban flood management professionals to guide them in producing resilient urban design to mitigate surface runoff that generates from heavy precipitation conditions.

Why have I been invited?

Two case studies are chosen to be part of this study; they are the most important prone areas among a total of four areas in Muscat administrative boundaries, they both include a mix of important commercial, residential and public services activities. The problem of storm water inundation in the two areas are addressed as the most critical flood related issues during extreme weather of 2007 and 2010 in Muscat city, and working to solve the problem in these two areas will add value to the city's resilience to flood and save or rationalize the increasing Governmental investments in expensive flood infrastructure, and as an ultimate goal of generalization the solution to other regional and international flood resilient practices.

Do I have to take part?

It is up to you to decide. We will describe the study and go through the information sheet, which we will give you. We will then ask you to sign a consent form to show your agreement to take part. You are free to withdraw at any time, without giving a reason.

What will happen to me if I take part?

- There will be face to face interview.
- This interview will happen twice within one year of the study.
- Each interview session will take up to 1:30 hours.
- Each interview will be audio recorded, the main reason for that is help the researcher to take more important notes by replaying the interview.
- All electronic data will be password protected. While the hardcopy data will stored in safe and secure place with exclusive access to me and my supervisor. Also all data will be backed up on DVD and stored in another safe place in case of losing some of the data.
- During the interview you will answer some questions. Your answers will be treated as qualitative data and will be analysed through one of the analysis methods.

What are the possible disadvantages and risks of taking part?

There are not any disadvantages or risks in this study.

What are the possible benefits of taking part?

The study is set to realize best knowledge in city resilience to pluvial flood following the state of art approaches and theories, though there will be no guarantee to which extent it can be relevant or beneficial to you, but it will hold at least the latest thinking in resilience approach which is one of the most debatable adaptation approaches nowadays.

The study will amplify the understanding of city resilience to pluvial flood from an ecological perspective; it will also identify new thinking of urban design that autonomously incorporates the resilience values within the city physical form and development process.

What if there is a problem?

If you have a concern about any aspect of this study, you are welcomed to speak to the researcher who will do his best to answer your questions.

Will my taking part in the study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential, and any information about your name and address will be removed, the whole process will maintain the anonymity of the participants.

What will happen if I don't carry on with the study?

If you withdraw from the study all the information and data collected from you, to date, will be destroyed and your name removed from all the study files.

What will happen to the results of the research study?

All the results will be used to develop the initial conceptual framework. Part of the result will be published. You will not be identified in any report/publication unless you have given your consent.

Who is organising or sponsoring the research?

University of Salford
Contact details:
The Crescent, Salford, M5 4WT, UK
Researcher Name: Mohanad Abdulkareem
Phone No: +44 (0)161 295 5000
E-mail: m.m.abdulkareem@edu.salford.ac.uk

Interview questions:

No.	Questions
1	How urban design unit can incorporates physical measures to mitigate surface runoff
2	How physical nexus of urban form features (blocks, street open space) and topographic features benefit surface runoff mitigation
3	How can mutual influence between urban form features and terrain features enrich urban space accessibility options
4	what factors account for urban feature (building, block, street, open space) redundancy
5	What are the possible ways the safely redundant urban form feature to assists runoff mitigation
6	To what extent a certain level of inundation can be accepted as a transitory phase

Table 6: Interview questions

Appendix 6: (QSR Nvivo) Coding analysis, two pilot interviews (candidates A1 & B3)

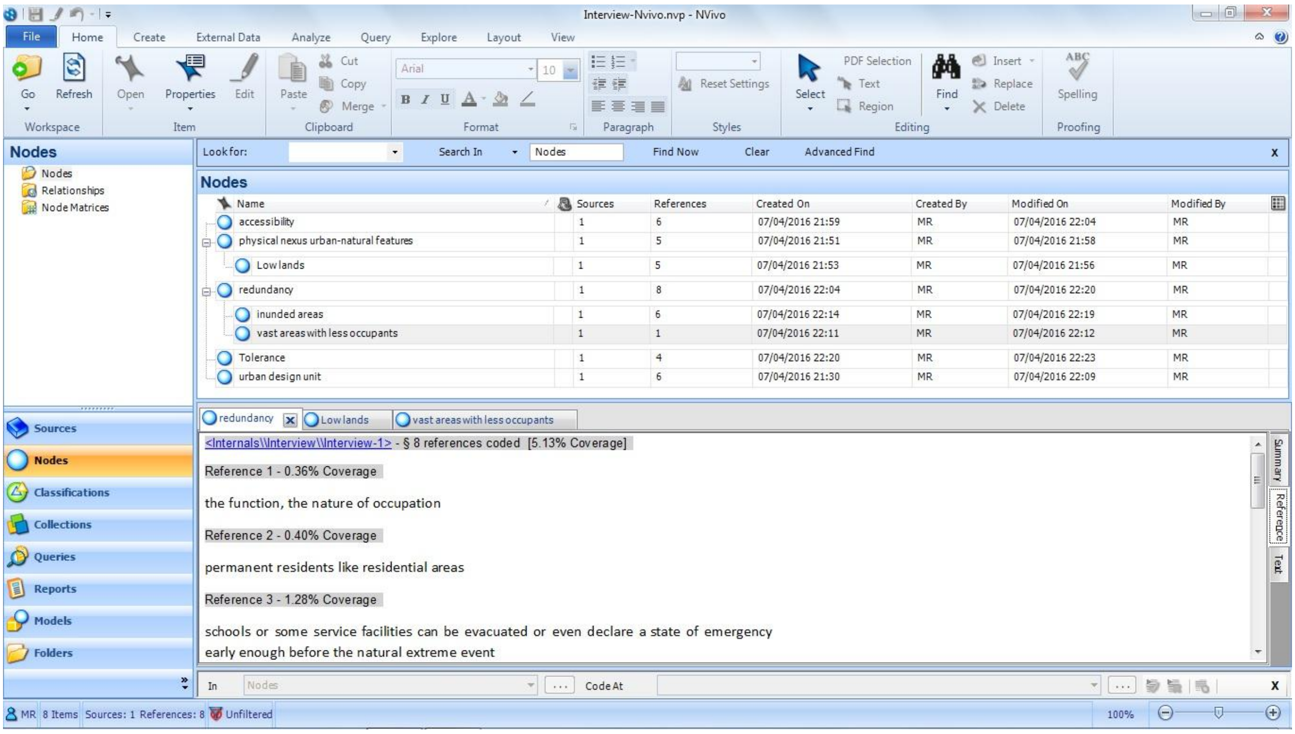


Figure 15: Nvivo interface

Candidate A1

Theme 1: **Urban design unit**

6 references coded [3.95% Coverage] Reference 1 - 0.25% Coverage)

Reference 1 - 0.25% Coverage
Concept: Ratio of space to building.
Code1: (Space-Mass ratio)
Reference 2 - 0.77% Coverage
Concept: Space will accommodate the flow of people, vehicles and even surface. water runoff
Code2 (people, vehicles & water flow)
Reference 3 - 1.02% Coverage
Concept: Directional design for the urban open spaces to favor the direction where the water normally tends to flow.
Code3 (urban space-water flow direction)
Reference 4 - 0.61% Coverage
Concept: Redesigning the horizontal levels of buildings, plot and streets
Code4 (building, plot & street elevations)
Reference 5 - 0.61% Coverage
Concept: Effective spatial linkage for the safely elevated urban features.
Code5 (linking safe spaces)
Reference 6 - 0.68% Coverage
Concept: Efficient allocation for the land uses that occupy vulnerable occupants.
Code6 (land use-occupants allocation)

Theme2: **physical nexus urban-natural features**

5 references coded [1.55% Coverage]

Reference 1 - 0.29% Coverage
Concept: Variations in ground elevation.
Code1 (elevations variation)
Reference 2 - 0.32% Coverage
Concept: Unique topography in each location.

Code2 (consider distinctive topography)
Reference 3 - 0.28% Coverage
Concept: Potential areas of inundation should be identified.
Code3 (delineation of inundation areas)
Reference 4 - 0.27% Coverage
Concept: Directions of possible flows.
Code4 (Flow directions)
Reference 5 - 0.39% Coverage
Concept: Places that might be dry or well drained.
Code5 (delineation dry-well drained areas)

Theme2: sub-theme1: **Low lands**
5 references coded [3.27% Coverage]
Reference 1 - 1.39% Coverage
Concept: Open space design and ratio to the building mass can be considered to allow space for water to move through and transferred rather than accumulate.
Code1: (space-mass ratio)
Reference 2 - 0.39% Coverage
Concept: Vertical expansion verses than horizontal expansion.
Code2: (vertical expansion)
Reference 3 - 0.72% Coverage
Concept: Reduce the intensity of the building mass for the favor of the urban space.
Code3: (mass intensity)
Reference 4 - 0.35% Coverage
Concept: Unpaved surfaces in the lower areas.
Code4: (surface sealing)
~~Reference 5 - 0.41% Coverage~~
~~Increase the chances of ground permeability~~
~~Code5: (surface sealing)~~

Theme 3: **Accessibility**
6 references coded [3.14% Coverage]
Reference 1 - 0.61% Coverage
Concept: Redesigning the horizontal levels of buildings, plot and streets.
Code1 (elevation's design-urban unit)
Reference 2 - 0.52% Coverage
Concept: Variation in horizontal elevations creates safer levels.
Code2 (elevation's variation-safer levels)
Reference 3 - 0.21% Coverage
Concept: Linking elevated areas
Code3 (linking safe places)
Reference 4 - 0.52% Coverage
Concept: Network of pathways for people and even small vehicles.
Code4 (pathways network)
Reference 5 - 0.68% Coverage
Concept: Emergency network for accessibility during surface runoff circumstances.
Code5 (emergency pathway network)
Reference 6 - 0.61% Coverage
Concept: Effective spatial linkage for the safely elevated urban features.
Code6 (linking safely elevated featured)

Theme4: **Redundancy**
8 references coded [5.13% Coverage]
Reference 1 - 0.36% Coverage
Concept: The function, the nature of occupation.
Code1 (feature's occupancy nature)
Reference 2 - 0.40% Coverage
Concept: Permanent residents like residential areas.
Code2 (permanent occupancy)
Reference 3 - 1.28% Coverage

Concept: Schools or some public service facilities can be evacuated or even declare a state of emergency early enough before the natural extreme event.
Code3 (alternating occupancy-impermanent)
Reference 4 - 0.79% Coverage
Concept: Evacuating a residential neighborhood or a hospital is a matter of sheer difficulty.
Code4 (evacuation difficulty-permanent occupancy)
Reference 5 - 0.30% Coverage
Concept: In the first place the land use.
Code5 (priority for land use)
Reference 6 - 0.68% Coverage
Concept: Efficient allocation for the land uses that occupy vulnerable occupants.
Code6 (allocating vulnerable occupant)
Reference 7 - 0.53% Coverage
Concept: Vast areas of land and relatively less numbers of users.
Code7 (vast areas-low occupancy rate)
Reference 8 - 0.79% Coverage
Concept: Re-identify those urban features and recognize their multi functionality properties.
Code8 (reconsidering multi functionality for redunded features)

Theme4: sub-theme1: **inundated areas**
6 references coded [3.28% Coverage]
Reference 1 - 0.62% Coverage
Concept: Collecting water and safely transfer it to its final destinations.
Code1 (runoff transfer)
Reference 2 - 0.89% Coverage
Concept: Those urban features can act as part of the drainage infrastructure but on contemporary basis.
Code2 (function as temporal urban drainage system)
Reference 3 - 0.67% Coverage
Concept: Collect the surface runoff water or to act as a transitory water paths.
Code3 (function as temporal runoff pathways)
Reference 4 - 0.44% Coverage
Concept: Orientate the runoff to water courses or wetlands.
Code4 (linkages with wetlands)
Reference 5 - 0.40% Coverage
Concept: Supports the urban drainage infrastructure.
Code5 (ease the discharge of surface drainage network)
Reference 6 - 0.26% Coverage
Concept: Play another important role.
Code6 (shift function)

Theme4: sub-theme: **vast area-low occupancy rate**
Reference coded [1.10% Coverage]
Reference 1 - 1.10% Coverage
Concept: Protected from surface runoff by elevating entrances levels and floors to higher than the expected levels of runoff.
Code (minimum accessibility by adjusting elevations)

Theme5: **Tolerance**
4 references coded [1.95% Coverage]
Reference 1 - 0.75% Coverage
Concept: Land use and the type of service that the urban form provides in certain areas.
Code1 (land use type)
Reference 2 - 0.30% Coverage
Concept: Large places with few occupants.
Code2 (vast areas-low occupancy rate)
Reference 3 - 0.45% Coverage
Concept: Tolerable to the minimum level of accessibility.
Code3 (minimum required accessibility)
Reference 4 - 0.46% Coverage
Concept: Runoff exposure in terms of depth and the duration.

Code4 (Maximum acceptable depth and duration)

Candidate B3
Theme1: **urban design unit**
17 references coded [22.61% Coverage]
Reference 1 - 1.64% Coverage
Concept: Physical barriers are one of the most important issues to deal with when considering how urban design –within the physical dimension- can contribute reducing the generated runoff.
Code1 (urban design unit considers physical barriers)
Reference 2 - 0.79% Coverage
Concept: Wrong urban practice like the urban expansion in the flood prone areas or flood plains.
Code2 (informal urbanization-increase flood exposure)
Reference 3 - 1.02% Coverage
Concept: Urbanization can be barrier for the water to infiltrate through the soil, increasing the rate of surface runoff.
Code3 (urbanization influence soil geotechnical)
Reference 4 - 0.83% Coverage
Concept: Underground structure can reduce or say considered as a barrier against water infiltration.
Code4 (underground structures influence soil geotechnical)
Reference 5 - 0.65% Coverage
Concept: Slop is very important, and it can be natural or artificially increased.
Code5 (natural and artificially created sloop)
Reference 6 - 1.51% Coverage
Concept: Deepening the bed of the urban streams or the low land but should not conflict with the elevations of the final destination down streams to avoid water accumulation.
Code6 (design effort on natural streams-maintain good flow)
Reference 7 - 0.71% Coverage
Concept: Maintain building codes to prevent any construction in these natural features.
Code7 (building codes to protect natural features)
Reference 8 - 1.52% Coverage
Concept: And if you consider in your design any type of construction crossing these natural features the ultimate concern should be not to block or reduce the flow underneath.
Code8 (construction crossing natural features - natural features capacities)
Reference 9 - 1.10% Coverage
Concept: Orientation, so either you have street that comes perpendicular on the slop or parallel to the slop direction or incline.
Code9 (roads direction versus slop direction)
Reference 10 - 1.12% Coverage
Concept~~: Problem when have your street network perpendicular on the slop direction or say in Muscat parallel to the sea coast line.~~
Code10 ~~(street network perpendicular on the slop direction can be problematic)~~
Reference 11 - 1.77% Coverage
Concept: An urban designer to consider two options: either lifting the whole corridor of the street or creating so many tunnels underneath and in this case you will be liable to the cost of construction.
Code11 (lifting prone features –cost liable)
Reference 12 - 1.74% Coverage
Concept: Place the street as flat as with the level of the ground in order not to perform as an obstacle or a barrier for the surface runoff, and in this case you will be liable to maintenance coast.
Code12 (flatten urban features to reduce barriers-maintenance liable)
Reference 13 - 3.32% Coverage
Concept: If the street orientation runs parallel with the slop of the ground the case is kind of easier, you just have to shape the street doom wise to have drain collectors on both sides that facilitates the accumulation and flow of the surface runoff to the desired direction, and with a little investment this can be done and reduce the impact of runoff efficiently.
Code13 (slop related design to favor runoff drainage)
Reference 14 - 0.73% Coverage
Concept: Elevating the zero level of his plot significantly higher than the street level.
Code14 (elevation's individual alteration-barrier)
Reference 15 - 1.74% Coverage
Concept: Fill in loose soil and then compact it, this widely followed technique will reduce water permeability,

reduce water content and the entire plot will also act as a barrier for surface runoff.
Code15 (plots preparation for individual housing-influence soil geotechnical)
Reference 16 - 0.65% Coverage
Concept: Elevate your plot area the neighboring areas will become like a pounds.
Code16 (elevation's individual alteration-surrounding pounds)
Reference 17 - 1.78% Coverage
Concept: Conflict of interest on the issue of surface runoff mitigation between the micro level of single individual's plot of land and the aggregate or macro level of the neighborhood or city district.
Code17 (conflict in mitigation between micro-macro levels)

Theme2: **physical nexus urban-natural features**
6 references coded [7.87% Coverage]
Reference 1 - 1.14% Coverage
Concept: The design in the case of significant topography should respect the natural water paths, water streams, wet lands, lowlands.
Code1 (significant topography)
Reference 2 - 1.09% Coverage
Concept: I think what we said earlier implies hear, the slop I suppose is a key characteristics of the morphology of the ground.
Code2 (slop is key characteristic of geomorphology)
Reference 3 - 1.22% Coverage
Concept: The geomorphology, have this characteristic we mentioned, slop, the design can benefit from this in terms of desired water flow paths.
Code3 (slop benefits flow path)
Reference 4 - 1.28% Coverage
Concept: Urban design should avoid those paths or support their performance in the physical design to enhance the flow capacity for instance.
Codde4 (designers should mind for flow paths)
Reference 5 - 2.09% Coverage
Concept: I think we still can rely on the elevations, contour lines that represent different level heights that can eventually tell where will be the low land that are potentially prone for the accumulation of surface runoff.
Code5 (delineation of elevated-low elevated areas)
Reference 6 - 1.05% Coverage
Concept: In the case of higher elevation areas where generated runoff runs out of it to downstream. Your design should consider that.
Code6 (runoff generated areas-runoff accumulated areas)

Theme3: **accessibility**
6 references coded [9.70% Coverage]
Reference 1 - 1.80% Coverage
Concept: Main traffic nodes can be allocated in higher areas, main routes should run parallel to the gradient as the generated flow can run through and trans-passing to its final destinations downstream.

Code1 (allocation of traffic nodes)

Reference 2 - 2.25% Coverage
Concept: If the layout of a main street comes perpendicular on the slop or gradient line it will be facing the flow of the surface runoff and building on both sides of the street will be barriers leading may be to an increase in the level of runoff water.

Code2 (flow path-perpendicular road layout can be considered a barrier)

Reference 3 - 1.35% Coverage
Concept: It is about the space; do not exhaust all the space for building, sufficient open spaces within building blocks allow always for good accessibility.

Code3 (sufficient space respect to mass-spaces accessibility)

Reference 4 - 1.52% Coverage
Concept: Evacuation squads, to access a relatively wide open space with certain level of inundation rather than getting through narrow road with the same level of water depth.

Code4 (open space accessed easier than narrower ones in same inundation depth)

Reference 5 - 1.54% Coverage
Concept: A balance should be maintained between open space and building mass- if it is correct to call it like that- especially in areas that are liable for frequent floods.

Code5 (a special balance between open and built in prone areas)
Reference 6 - 0.49% Coverage
Concept: Ensure safe connection between important destinations.
Code6 (key areas safely connected)
Reference 7 - 0.71% Coverage
Concept: Design safe pedestrian paths that survive inundation in highly occupied areas.
Code7 (safe pedestrian paths-highly occupant areas)

Theme4: **redundancy**
7 references coded [7.91% Coverage]
Reference 1 - 1.92% Coverage
Concept: In an urban area, the volume of traffic in certain area reflects its importance and then its possibility to be considered as a redundant area, the more traffic it serves the less it is likely to be redunded.
Code1 (volume of traffic reflects redundancy rate)
Reference 2 - 0.56% Coverage
Concept: Essential route serving most of the important destinations.
Code2 (essential routes)
Reference 3 - 1.67% Coverage
Concept: Areas of vulnerable occupant, or highly populated, also need to be focused on redirecting the runoff away from them, you can't compromise on the function disturbance of these places.
Code3 (type of occupants-occupancy rate)
Reference 4 - 1.18% Coverage
Concept: Also places of 911, emergency services need to be prioritized in mitigation effort to be the last area to accept surface runoff.
Coce4 (priority for supportive service during floods)
~~Reference 5 - 0.62% Coverage~~
Concept~~: of highly importance to other affected areas during flooding times.~~
Code5~~ (priority for supportive service during floods)~~
Reference 6 - 0.52% Coverage
Concept: In the first place the land use, and the occupancy rate.

Code6 (land use-occupancy rate)
Reference 7 - 1.44% Coverage
Concept: If we can't keep it dry, we better recruit it to serve surface runoff, getting the urban feature to be a problem solving rather than a problem suffering.
Code7 (function shift)

Theme5: **Tolerance**
6 references coded [4.43% Coverage]
Reference 1 - 0.37% Coverage
Concept: To which level and to how long I believe.

Code1 (depth and duration of flood-important)

Reference 2 - 0.98% Coverage
Concept: Three days were too long and very harsh, so it varies, from culture to culture and from context to context.

Code2 (duration tolerance is culture-context related)

Reference 3 - 1.03% Coverage
Concept: From my point of view the more the area is urbanized and sophisticated the shorter it can tolerate inundation.

Code3 (the more urbanized the less tolerated)

Reference 4 - 0.63% Coverage
Concept: First consideration from this prospect is the availability of water.

Code4 (drinking water availability-extends tolerance)

Reference 5 - 0.83% Coverage
Concept: Even water tankers served only accessible areas; food was not that big issue at that time.

Code5 (drinking water in the first place)

Reference 6 - 0.61% Coverage
Concept: Preparedness for people can prolong their tolerance for inundation.

Code6 (the ready the people-the longer they tolerate)

Appendix 7: Samples from the data collection request letters

University of Salford
MANCHESTER

11 January 2016

Sultan Salim Al Habsi
Secretary General of the Supreme
Council of Planning
P.O. Box 881
Muscat
Postal Code: 100
Sultanate of Oman

Your Highness Sultan Salim Al-Habsi

On behalf of the University of Salford, I would like to express my gratitude for the kind support that the Supreme Council of Planning has shown to our PhD researcher, Mohanad Abdulkareem. I believe that Mohanad has worked for the Ministry of National Economy and then the Supreme Council of Planning for about ten years as an urban and infrastructure planner. He is currently researching a very important area in considering "How efficient urban design can contribute to mitigating the impact of floods in urban areas". I am confident that this study will deliver valuable solutions or alternative approaches for managing this problem, not only in Oman, but also in the UK as well.

As the research requires some GIS data for flood prone areas within the Muscat governorate, I would like to assure you that the University of Salford takes the issues of data security and confidentiality very seriously and that all areas and streets names will be anonymised and will be exclusively used for the purposes of this research only.

Please do not hesitate to contact me if you require any additional information.

Yours sincerely

[redacted]

Professor Hisham Elkadi Ph.D. (Liv), FRICS, FAIB, ARIBA
Dean | School of Built Environment
Room 426a, Maxwell Building, University of Salford,
Salford, M5 4WT, UK

University of
Salford
MANCHESTER

11 January 2016

His Excellency Eng. Sultan Hamdoon Al Harthi
P.O Box 881
P.C. 100 Muscat
Oman

Your Excellency Eng. Sultan Hamdoon Al Harthi

On behalf of the University of Salford I would like to express my gratitude for the kind support you have shown to our PhD researcher, Mohanad Abdulkareem. I believe that Mohanad is researching a very important area by considering "How efficient urban design can contribute to mitigating the impact of floods in urban areas". I am confident that this study will deliver valuable solutions and alternative approaches for managing this problem, not only for Oman, but for the UK and Iraq as well.

I would also like to assure you that the University takes the issues of data security and confidentiality very seriously and that participants' input will be anonymised unless their explicit consent is obtained in advance.

Please do not hesitate to contact me if you require any additional information.

Yours sincerely

[redacted]

Professor Hisham Elkadi Ph.D. (Liv), FRICS, FAIB, ARIBA
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