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# EXPLORING SOCIAL RESILIENCE: INSIGHTS INTO CLIMATE CHANGE ADAPTATION GAPS FROM AN ESTUARINE REGION OF TAIWAN

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Key words: climate change adaptation, DPSIR, social resilience, vulnerability.

## ABSTRACT

The natural hazards and influence of climate change are uncertain. Supporting adaptation management strategies therefore requires a strong research basis, including prediction and vulnerability assessments. However, the practical value of research results tends to be under explored because of the lack of channel through which to apply the results. This study suggests means of strengthening local adaptation strategies and reducing social vulnerability by encouraging communities to work together to deal with the threat of climate change. We highlight the balance among built-environmental sensitivity and human adaptability dimensions, thereby emphasizing social vulnerability and addressing social resilience from risk perception perspectives. On the basis of the concept of vulnerability and the driver-pressure-state-impact-response (DPSIR) causal framework, semi-structured interviews were designed to explore social resilience. We discuss how a knowledge gap can lead to social vulnerability and maladaptation. In addition, we propose the prototype of a decision-making tool for facilitating adaptation by emphasizing a co-design process between residents and decision makers.

## I. INTRODUCTION

The natural hazards and influence of climate change are uncertain. Supporting adaptation management strategies therefore requires a strong research basis, including prediction and vulnerability assessments (Flüssel and Klein, 2006; de Bruin et al., 2009; Biesbroek et al., 2010). However, the practical value of research results tends to be under explored because of the lack of channel through which to apply the results. In addition, the lack of a proper communication platform often restricts sharing information to relevant issues, rather than providing the public with equal access to this information. The influence of climate change is closely related to each individual. However, differences in adaptation information and knowledge are the major cause of unequal public adaptability (Lahsen, 2010; Newsham and Thomas, 2011; IPCC, 2014). This gap also indicates the importance of including human adaptability as an indicator of social vulnerability when assessing the degree of external influence. Human adaptation ability reflects the influence of various impacts on individuals and is strongly related to individual knowledge and skills, socioeconomic structures, and institutional policies (Giddens, 2009). The development of Shetzu Island in Taipei is a typical example. The current study aims to suggest means of strengthening local adaptation strategies and reducing social vulnerability by encouraging communities to work together to deal with threat of climate change.

In the Methods section of this paper, we highlight the balance of built-environmental sensitivity and human adaptability dimensions to emphasize social vulnerability and address social resilience from risk perception perspectives (Kasperson et al., 1992; Scheraga and Grambsch, 1998; Cutter, 2003; Giddens, 2009; Henley, 2010). The definition of resilience adopted by the United Nations International Strategy for Disaster Reduction (UNISDR) states that 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” (UNISDR, 2005). The UNISDR definition stresses that resilience is a function of the degree to which a social system is capable of organizing itself to increase its capacity for learning from past disasters for improved future protection and to enhance risk reduction measures. On the basis of the concept of social vulnerability and the driver-pressure-state-impact-response (DPSIR) causal framework (EEA, 2007), semi-structured interviews were designed to explore social resilience. In the Discussions section, we focus on how the aforementioned knowledge gap leads to social vulnerability and maladaptation (Granberg and Glover, 2014). We then apply a set of adaptation tools to help bridge

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the gap. Finally, we propose the prototype of a decision-making tool for facilitating adaptation by emphasizing the co-design process between residents and decision makers.

## II. METHODS

### 1. Study Site

Shetzu Island is a flat sandbar in the suburbs of Taipei City, located in an estuarine region where the Keelung and Tamsui Rivers meet. In 1963, Typhoon Gloria generated heavy rainfall, which induced a surge of river water, flooding Shetzu Island. In light of this disaster, the national government of Taiwan began addressing flood risks in Taipei. In 1970, the Taipei Region Flood Control Project was completed, designating Shetzu Island as a detention basin to reduce flood risks in other parts of Taipei. However, as Shetzu Island rapidly developed and the population grew, the government subsequently developed disaster control infrastructure such as embankments and pumping stations. Regarding the functionality of the flood detention basin, the embankment in Shetzu Island exhibits the lowest protection height in Taipei. In addition, construction was banned to restrict population growth and land use. Although Shetzu Island has been restricted to low-density development, approximately 10,000 residents, whose families have lived there for generations, have continued to reside in the area. For more than four decades, these residents have lived in settlements and houses to which they are banned from major repairs and alterations. Because of low land prices and loose environmental regulations, in recent years, many plots of land using for farming in the area have been leased to unlicensed light industry factories, substantially reducing quality of life and increasing social vulnerability. After the embankment was built, Shetzu Island seemed to exhibit the capacity to cope with a 20-year flood. However, a close examination of resident environmental and sociocultural perception revealed that the current environmental risk is even greater than before. Generally, people acquire knowledge about the impacts of and adaptation to environmental threats on the basis of risk awareness (Smallman and Weir, 1999; Michael et al., 2010). In other words, people who experience related impacts exhibit more adaptability and knowledge compared with those who do not (Seery, 2011). However, Shetzu Island residents currently rely entirely on hardware infrastructure for flood control. The young generation even assumes that flood risks have been eliminated despite the influence of climate change and thus have difficulty imagining flood situations and adopting response measures. This phenomenon causes climate risk to increase (Smeets and Weterings, 1999).

### 2. DPSIR Framework

The European Environment Agency (EEA) proposed the DPSIR framework to clarify the interactions between the natural environment and human activities. This framework has been commonly applied in academic research to describe the causal relationship between society and the environment (EEA, 2007). The framework provides insights into climate change as driver

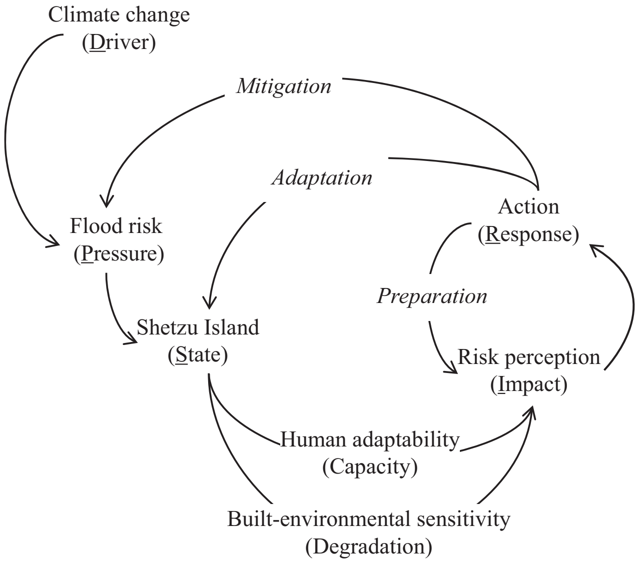



**Fig. 1. Research framework.**

and the resulting environmental pressures, the state of the environment and impacts resulting from changes in environmental quality, and the societal response to these changes (Smeets and Weterings, 1999). On the basis of social vulnerability, this study included the DPSIR to investigate the causes of events influencing the environment, specifically by analyzing the influence of human-environment interaction on the impact of climate change. In this study, climate change was regarded as a driving force (D), which generated a high level of both unpredictability and uncertainty that in turn caused pressure (P), thereby altering current public perception of the state (S) of the relationship between the environment and society. Subsequently, the impact (I) of climate change and risk pressure on the residents was explored thoroughly. Resident responses (R) to impacts were classified as positive, null, or negative. These responses generated feedback on the driver (D), which is expected to facilitate adjusting the current situation or mitigating impacts (Smeets and Weterings, 1999).

According to the aforementioned discussion, the research framework is described as follows (Fig. 1):

1. Driver (D): Challenges of climate change
2. Pressure (P): Increasing flood risks caused by environmental change
3. State (S): Resident awareness of both human adaptability (capacity) and built-environmental sensitivity (degradation) posed by floods
4. Impact (I): Resident risk perception explored under climate change
5. Response (R): Resident actions in response to risks, covering mitigation, adaptation, and preparation

### 3. Vulnerability Assessment

The risks of climate change are difficult to predict, and the

**Table 1. Dimensions, indices, and scale for vulnerability assessment of the study.**

| Dimension | Indices | 3-point scale |
|---|---|---|
| Built-environmental sensitivity | *Building, road, land use* | Degradation (–) 1, 2, 3 |
| Human adaptability | *Knowledge, skill, network* | Capacity (+) 1, 2, 3 |

**Table 2. Quantified survey results.**

| Driver → | Pressure → | State → | | Impact → | Response |
|---|---|---|---|---|---|
| Climate change | Flood | Environmental sensitivity (Degradation) | Human adaptability (Capacity) | Perceptions: Interviewee(s) | Actions (*n*)* |
| Simulation results: Shetzu Island is exposed to flood threat under climate change | | Low (–1) | Low (+1) | Neutral (0): C2a, C6a | Preparation (*n = 2*) |
| | | Low (–1) | Medium (+2) | Positive (+1): C6b | Adaptation (*n = 1*) |
| | | Low (–1) | High (+3) | Positive (+2): C8a, C1b | Adaptation (*n = 2*) |
| | | Medium (–2) | Low (+1) | Negative (–1): C3b, C4a, C7c | Mitigation (*n = 3*) |
| | | Medium (–2) | Medium (+2) | Neutral (0): C4b, C3a, C7a, C5b | Preparation (*n = 4*) |
| | | Medium (–2) | High (+3) | Positive (+1): C1a, C7b | Adaptation (*n = 2*) |
| | | High (–3) | Low (+1) | Negative (–2): C9a | Mitigation (*n = 1*) |
| | | High (–3) | Medium (+2) | Negative (–1): C2b, C4c, C5a | Mitigation (*n = 3*) |
| | | High (–3) | High (+3) | Neutral (0): C3c, C2c | Preparation (*n = 2*) |

* Number of interviewees on actions: Preparation (neutral perception; *n*(2 + 4 + 2) = *8*); Adaptation (positive perception; *n*(1 + 2 + 2) = *5*); Mitigation (negative perception; *n*(3 + 1 + 3) = *7*).

impact of climate change is diverse (EPA, 2015). In the context of close human-environmental interaction, impact is a cumulative result of such interaction. Therefore, when assessing the vulnerability of a particular area, examining social vulnerability is crucial because it addresses a more direct environmental impact on people. That is, social vulnerability is most directly reflected by the adaptive capacity of residents in responding to environmental impacts (Smit and Wandel, 2006; IPCC, 2007; Engle, 2011; Lankao and Qin, 2011; Sovacool et al., 2012). In addition, human adaptive capacity is based on human perception of environmental risks; however, perceptions of surroundings differ among individuals depending on upbringing, perceptual experience, and epistemological systems (Bickhard, 1992), from which subjective environmental images are constructed. The preferences, values, attitudes, behaviors, and decision models that individuals exhibit regarding environments differ on the basis of subjective environmental images (Obrist et al., 2010). These differences cannot be evaluated using physical geographical data. By analyzing resident risk perception, we can explore the influence of local culture, experiences, and environments on people (Adger et al., 2009; Giddens, 2009).

Therefore, when assessing social vulnerability, the risk perception of environmental sensitivity and human adaptability should be considered (Cutter, 2003). Index evaluation is based on environmental sensitivity and human adaptability (Rannow et al., 2010). This study adopted two dimensions, each defined using three indices:

1. Environmental sensitivity: building, road, and land use
2. Human adaptability: knowledge, skills, and networks

Each index is rated on a 3-point scale: 1 (low), 2 (medium), and 3 (high) (Tables 1 and 2). Risk perception generated through environmental sensitivity is attributed to anxiety and discontent regarding environmental conditions (Gilg, 2009). Because this type of risk perception reflects the vulnerability of people facing climate change, the index is calculated using negative points. By contrast, resident adaptation positively influences individual responses to climate change impacts. Consequently, its index is calculated using positive points. Integrating the evaluation results of negative environmental sensitivity and positive human adaptation capacity enables resident risk perception to be classified as negative (–2 and –1), neutral (0), or positive (+1 and +2).

### 4. Semi-Structured Interviews

We emphasize that risk events occur in a societal context and suggest that residents, as key stakeholders, are able to tell a "story" about environmental impacts and responses in collaboration with researchers (Kok et al., 2011). As such, we conducted semi-structured interview activity and used DPSIR framework to guide the interview process, enabling the general public to explore their risk perception. It addresses residents' reactive awareness, their proactive actions in response to climate change, and their inextricable blend of face and feeling, reason and gut reaction, cognition and intuition (Ropeik, 2011). The interview format helped us understand residents' stories in a systematic manner and enabled us to have an open dialogue with residents and explore how risk events interact with psychological, social, and cultural processes (Chiang et al., 2014). The semi-structured interviews consisted of several key questions that helped to define the areas to be explored and enabled us and the residents to diverge from the interview guide to pursue an idea or response in more detail. The key questions in the semi-structured interview are listed as follows:

*Stage 1 (the interviewer will indicate climate extremes and an increase in flood risk)*

1. Has your *building* ever been flooded (if "yes", note "–1")?
2. Have the *roads* nearby ever been flooded? (if "yes", note "–1")
3. Have the flood degraded the *land use* (if "yes", note "–1")

*Stage 2 (the interviewer will ask the following questions when one "yes" is given at Stage 1.)*

1. Have you ever gained any knowledge to protect your building from flooding? (if "yes", note "+1")
2. Have you ever used any skills? (if "yes", note "+1")
3. Have you ever shared the knowledge or skills in your neighbor network? (if "yes", note "+1")

We selected residents with diverse backgrounds and interviewed them until no new relevant information could be obtained (tools4dev, 2015). When conducting these in-depth semi-structured interviews with Shetzu Island residents, we avoided contact with local politicians such as village heads or local representatives and did not reveal our backgrounds or objectives.

The DPSIR framework was adopted to facilitate the interview process, during which we placed additional emphasis on flood risks and climate change such that the residents could express their opinions about the environment and society. In particular, researchers recorded resident evaluations of current measures when potential risks were considered. These comments were then arranged according to environmental (i.e., building, road, and land use) and social (i.e., knowledge, skills, and networks) indices. Subsequently, the integral perception was determined to be negative, neutral, or positive. The levels of environmental sensitivity and human adaptability were thus obtained.

### 5. Adaptation Support Platform

The researchers adopted semi-structured field surveys to investigate the adaptation capacity of local communities. In addition, simple and public adaptation support platform was provided to Shetzu Island residents, enabling them to conduct self-assessments. The obtained data were subsequently integrated into this platform and developed to provide the public with equal access to climate change and adaptation information, thereby assisting them to understand related information, potential risks, and the importance of adaptation. We used the three-dimensional (3D) modeling software program by ESRI, CityEngine as the adaptation support platform. This program offers more flexible control over the modeling of design elements on site. In addition, it is equipped with the procedural modeling approach and a strong online model-sharing service, which we employ for communicating and interacting with members of the local community as well as stakeholders. The adaptation support platform addresses the following points:

1. This platform provided simulation scenarios of potential risks in people's daily surroundings, focusing on the buildings, roads, and land use. Adaptation options were also discussed in conjunction with these risks, prompting people to reflect on which types of adaptation capacity they possessed and which adaptation measures that were implemented or offered could reduce risks.
2. The flood potential maps illustrated how climate impacts are likely to affect both built-environmental sensitivity and human adaptability to adapt to climate change, facilitating the identification of factors that cause high vulnerability, such as geographical places, space, policies, socioeconomic conditions, and infrastructure. Therefore, the general public, planners, and decision-making units can easily identify potential risks in their own regions or other regions that face similar risks. Appropriate adjustment mechanisms could subsequently be developed.
3. Through the use of CityEngine 3D modeling software, the adaptation support platform was developed. With this platform, two-dimensional (2D) geographical data were rapidly converted into visual models of cities or building complexes. Simulations of different adaptation strategy projects were controlled by adjusting land use, road, or building rule parameters such as pattern, height, and age. The platform provided unique interactive design and procedural modeling capacities for the efficient creation of 3D cities and, enabling both decision makers and the general public to easily plan and assess regional development projects.

## III. RESULTS

We conducted the semi-structured interviews until no new relevant information could be obtained. We randomly interviewed 20 residents from several locations, engaging in extensive discussions with them regarding their environmental sensitivity and adaptability to flood risks. The simulation model

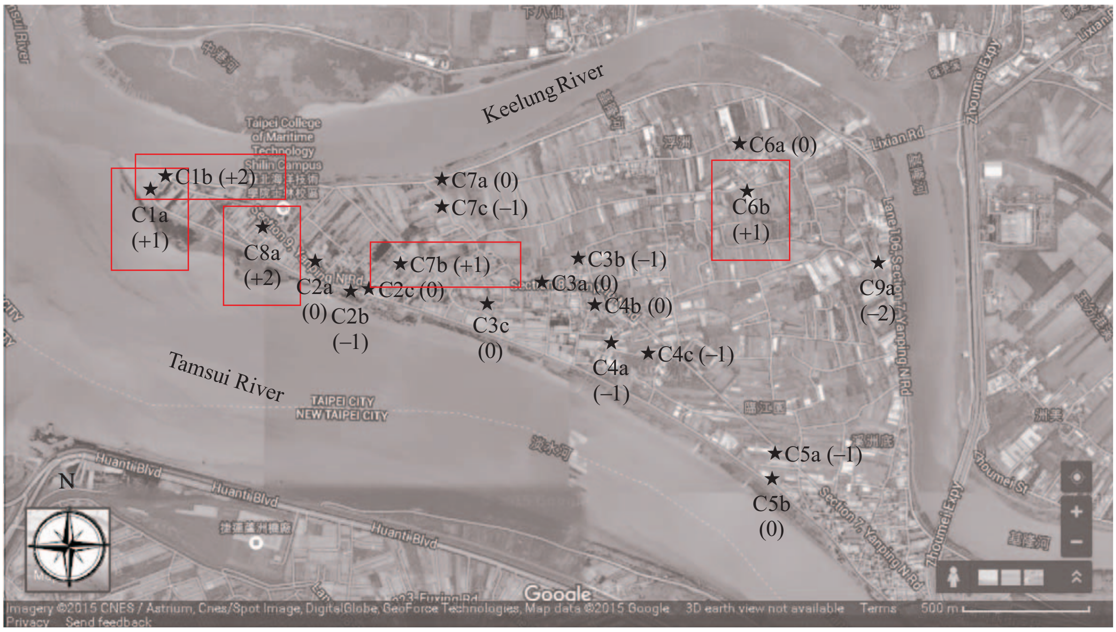



**Fig. 2. Locations of the interviewees.**

enabled the interviewees to more clearly understand the flood potential map and the influence of different adaptation plans. Furthermore, we evaluated environmental sensitivity, resident adaptability, and related response measures according to the DPSIR framework (Table 2). The base model and flooding scenario were utilized as tools to help the residents visualize risk. Using simulated models with which the interviewees could interact ensured that the interviews were conducted on the basis of adequate equalized information and knowledge.

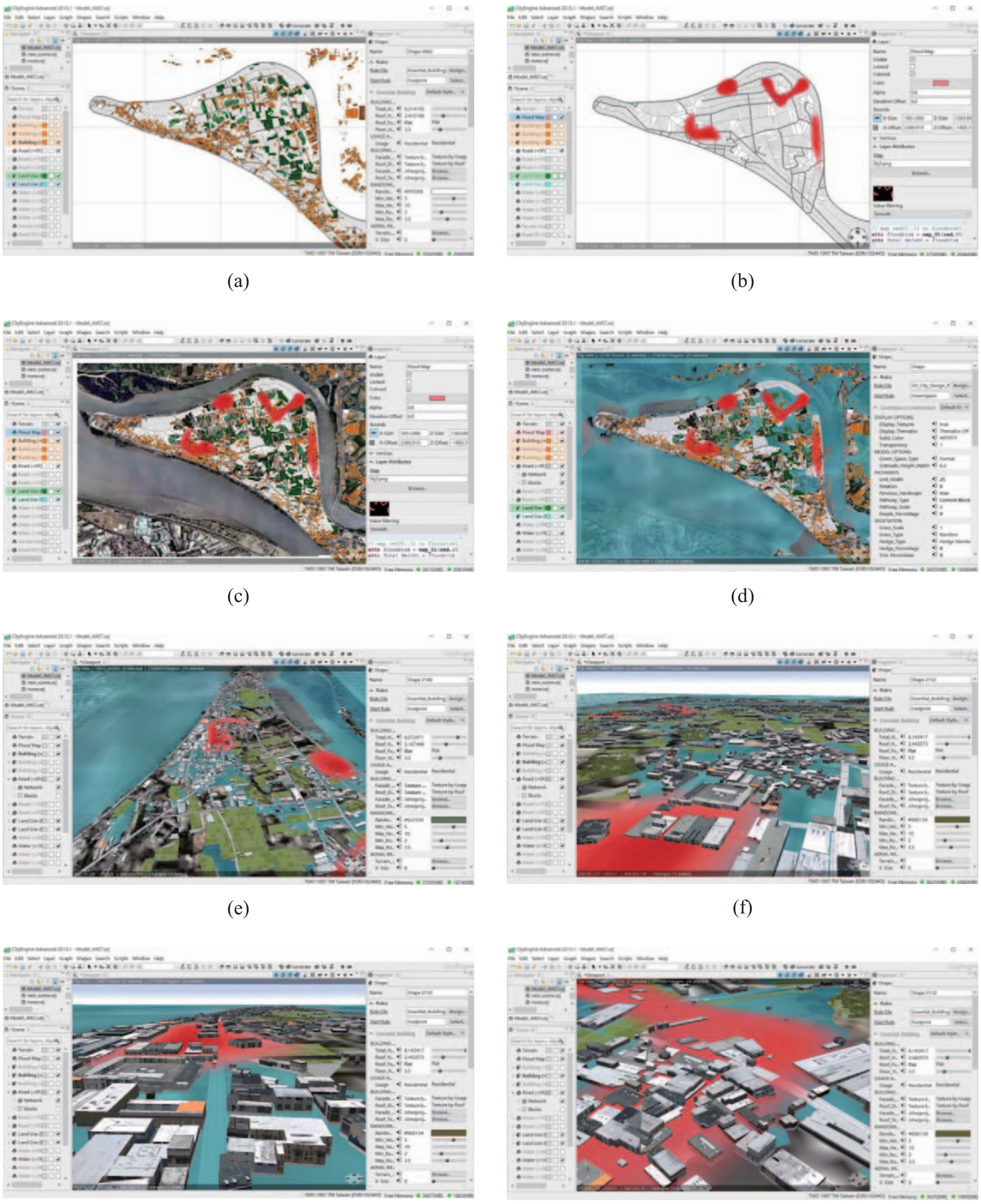
The systematic framework allowed us (researchers) to conduct interviews face-to-face with the interviewees (residents) selecting the location. The flooding scenarios were shown to the interviewees after they had elaborated on their impression of the current locations that have the high potential of flooding. Using scenarios in a model helped the interviewees easily observe the risk they were exposed to by climate change. Their perception and awareness of flood risk were recorded. That is, the state of the study site represents both built-environmental sensitivity and human adaptability. Given environmental degradation, human capacity addresses the ability to cope with change.

The mitigation, adaptation, and preparation presented in the interviewees' responses were determined through their perception index (positive, neutral, or negative). We also identified some relationships between the results and where the interviewees lived; as shown in Fig. 2, more positive responses were acquired at the end of the peninsula. Through the interviews, we discovered that this area was previously the site of more flooding than were other parts of Shetzu Island, accounting for the higher risk perception of these specific residents. These results confirm the close association between risk perception and social vulnerability.

## 1. Mapping

To create basic data for adaptation strategy simulation, we superimposed the layers of 2D local map data to build a GIS database for the buildings, roads, and land use. Different adaptation strategy projects were simulated by adjusting rule parameters such as the pattern, height, and age of buildings. Subsequently, these data were converted into CityEngine 3D modeling software. With these models, the adaptation support platform was established and various adaptation strategies could be used for simulation, enabling the public and planners to understand the influence of different adaptation plans on the local environment as well as potential hazardous situations. For Shetzu Island, the flood potential map was superimposed on the basic model to serve as a prerequisite for all adaptation strategies, thereby facilitating the adaptation of various areas to flood risks. The operation process is shown in Fig. 3 that addresses the following points regarding the process:

1. Layers of 2D geographic data and information were mapped into a GIS database using ArcGIS software, including roads, buildings, blocks, and land use (farm and pond), and input into CityEngine (Fig. 3(a)).
2. Flood potential map modified based on NCDR (2016) was input into CityEngine (Fig. 3(b)).
3. Aforementioned GIS database and flood potential map were laid out on the satellite image with defined coordinates (Fig. 3(c)).
4. The flooding potential of sea level rise was also demonstrated and mapped as a control factor layer (Fig. 3(d)).
5. 3D building models and massive urban environments of the study were created, edited and shared using CityEngine as the adaptation support platform (Figs. 3(e)-(g)).



(a) (b) (c) (d) (e) (f) (g) (h)

**Fig. 3. CityEngine was used as the adaptation support platform of the study, which offers more flexible control over the modeling of design elements on site: (a) layers of building, road, and land use; (b) layer of flood potential map; (c) all layers laid out on the satellite image; (d) flooding potential of sea level rise; (e)(f)(g)(h) 3D building models and massive urban environments demonstrated on the adaptation support platform. The right side of the panel introduces a shape (an associated parameter list) or a layer (for adding a map using image data or creating mappings of image data to various attributes).**

6. By importing and visualizing the control factor layer into the base model, flooding scenarios were simulated for the existing buildings and infrastructure.
7. The base model and flooding scenarios were utilized as tools to visualize risks and communicate with the locals to acquire more accurate social vulnerability survey results; the vulnerability indices analyzed using the DPSIR framework were visualized as a 2D map with red indicating higher vulnerability.
8. Simulated building foundation height and other urban design elements were defined by referring to the flooding potential

layer and vulnerability map through parametric control.

## 2. Environmental Sensitivity

The interview results (Table 2) revealed that resident perception of environmental sensitivity was neutral on average. However, when the building, road, and land use indices were analyzed separately, resident evaluations of the buildings and roads were substantially negative, whereas those regarding land use were highly positive. During the interviews, the Shetzu Island residents exhibited considerable identification with and attachment to the environment, even though they commented negatively on various aspects of the living environment. This phenomenon could be attributed to intense familial and communal ties among the residents developed over generations. The environmental sensitivity of the three indices is discussed as follows.

*a) Buildings*

The construction ban prohibits extensions and reconstructions. As houses age, they subside. New increased space was constructed with corrugated iron sheets to circumvent the construction ban. However, these inadequate housing and factory buildings rendered the residents discontent and anxious about their living quality. The building index score for environmental sensitivity was approximately −3.

*b) Roads*

The main road problem reported was that no proper drainage system was installed. Therefore, the roads were prone to flooding after heavy rain. The drainage of the entire region was dependent on pumping stations. In addition, the road system was insufficient. Old roads that were built to support agricultural activities could not support current light industrial uses. Currently, only the area (Sections 7-9 of Yanping North Road) and bypasses inside the embankments exhibit a standard width for two-lane roads. Other roads on which trucks travel are only 4 meters wide. Consequently, when vehicles approach each other from opposite directions, problems often occur regarding right of way, affecting the safety and usability of these roads. In addition, the width of lanes between residential houses does not meet the requirements for fire lanes, affecting safety. Even the widest two-way road (Section 7 of Yanping North Road) on Shetzu Island is often congested at peak hours. Accordingly, the interviewees expressed concerned about road quality, stating that regardless of future risks, if they were to continue living on Shetzu Island, the government should first lift the work ban to enable the improvement of buildings and roads.

*c) Land Use*

Resident evaluation of land use was neutral. Agriculture, which was still the major use of land, was viewed positively. The residents still rely on agriculture as their main source of income; in addition, they recognize the positive effect of agriculture on the environment. Specifically, agriculture creates unique urban spaces, causing residents to identify with and become attached to the local environment. In addition, the residents commonly believed that the vulnerability to flood risks in the agricultural areas was low, and that though floods could be harmful for crops, the costs are not excessive and the restoration work after floods is not complex.

## 3. Residents' Adaptability

During the interviews, we explored interviewees' perceptions using human adaptability indices (knowledge, skills, and networks) and provided insights into the interviewees' actions: preparation (neutral perception; $n = 8$), adaptation (positive perception; $n = 5$), and mitigation (negative perception; $n = 7$) (Table 2). We argue that resident skills and local network connections generated positive results and originated from the accumulation and dissemination of knowledge regarding past flooding experiences. Though the actions have been adopted, there are still limited adaptation ($n = 5$), compared to preparation ($n = 8$) and mitigation ($n = 7$), on how to respond to and manage the uncertainties in a changing climate. The aforementioned DPSIR framework can be utilized to address the issues and enables adaptive management, because of its iterative process. Due to the adaptation gap, we discuss the three human adaptability indices as follows:

*a) Knowledge*

The main obstacle to enhancing local adaptability was found to be the knowledge gap. The residents lacked knowledge on the influence of climate change, and assumed that the existing embankment and water pumps were sufficient to withstand the adverse effects of climate change, such as floods and heavy rains. Therefore, although local vulnerability was high; the residents did not emphasize enhancing adaptability and merely depended on the existing infrastructure to mitigate flood risks.

*b) Skills*

The residents developed flood-control skills from past flooding experiences. The older residents in settlements retained clear memories of frequent flooding, in response to which flood-control skills were developed. For example, many fields and structural foundations were elevated, and this phenomenon was increasingly common in settlements close to the Keelung Riverbank. Some fields were even elevated by a height equivalent to one story. In addition to elevated foundations, the houses on Shetzu Island were constructed as unique two-story traditional three-compound complexes, in which the main living space and ancestral shrine were located on the second floor, with the first floor serving as a semi-open space. However, the development of these flood-control skills stagnated after the embankment was built. As the experienced residents aged, floods that occurred 40 years prior were gradually forgotten. The younger generation possessed little knowledge of flooding hazards or related skills.

*c) Networks*

Under the construction ban, Shetzu Island unintentionally retained local familial and communal ties typical of traditional settlements. Close settlement networks facilitated the dissemination of adaptation methods to address climate change impacts and enabled the creation of several mutual aid mechanisms as well as the establishment of community shelters. However, the residents generally lacked knowledge of handling future climate change risks, revealing a gap in adaptability.

### 4. Residents' Perceptions

Social resilience is built on human risk perception. Statements regarding this perception enabled us to thoroughly understand local situations and assess social vulnerability. Therefore, during the interviews, we focused on both built-environmental sensitivity and residents' self-perceived adaptability. Subsequently, information regarding resident perceptions of the environment and society were arranged and analyzed using the DPSIR framework. The impacts (I) of climate change on the local community were retrieved and derived according to the perceptions of various residents. We divided perceptual information collected from the interviews into three types: positive, negative, and neutral. One point of environmental sensitivity (marked using negative numbers) offset one point of adaptability (marked using positive numbers). Calculating all of the aforementioned environmental sensitivity (−1 to −3) and adaptability (+1 to +3) points yielded the overall risk perceptions of the interviewees. The perceptions were classified as positive or negative and are discussed as follows:

*a) Positive Perception*

After the scores of environmental sensitivity and adaptability were integrated, positive overall scores indicated that the interviewee exhibited positive risk perception. The interview content revealed that this resident possessed Medium (+2) or High (+3) adaptability and lived in a location with Low (−1) or Medium (−2) environmental sensitivity (Table 2). The result indicated that this resident possessed a moderate knowledge of the impacts of climate change, was capable of addressing these impacts, and was satisfied with the living environment.

*b) Negative Perception:*

After the scores of environmental sensitivity and adaptability were integrated, negative overall scores indicated that the interviewed resident exhibited negative risk perception. The interview content revealed that this resident possessed Low (+1) or Medium (+2) adaptability and lived in a location with Medium (−2) or High (−3) environmental sensitivity (Table 2). This resident was unsatisfied with the living environment; this was reflected by the greater environmental sensitivity. Moreover, this resident showed inadequate adaptability, possessed little knowledge of climate change impacts, and lacked the knowledge and capacity required for addressing these impacts. Therefore, when floods occur, this resident and his or her living area are likely to be severely affected.

### 5. Residents' Actions

The response actions that residents take when impacts occur can be inferred from their risk perception. Whether resident risk perception is positive or negative determines their response attitudes, which range from active to passive. In our investigation, resident responsive behavior was classified into three types: preparation, mitigation, and adaptation:

*a) Preparation*

A neutral interviewee risk perception rating indicated that these interviewees exhibited similar levels of perception regarding environmental sensitivity and their adaptability. The high environmental sensitivity of the environment in which they lived was counterbalanced by their optimal adaptability, thereby reducing the impact level, or the advantage of a less sensitive environment was counterbalanced by unsatisfactory resident adaptability, thereby increasing the impact level. We anticipated that the impact exerted on this type of resident was not particularly evident. Therefore, this study inferred that these residents would not engage in response measures but were prepared when facing the flood risks posed by climate change.

*b) Mitigation*

A negative interviewee risk perception rating referred to mitigation ($n = 7$) suggested that these interviewees exhibited a high level of risk perception regarding higher environmental sensitivity but lower human adaptability. These residents passively responded to increasing risks; they merely attempted to follow the traditional flood control measures such as elevating embankments or increasing the number of pumping stations to mitigate the impact of flooding. It is argued that the government flood control measures have limited utility. Some residents also pointed out that the dikes exacerbated the floods. When there were floods, most residents were accustomed to observing and measuring water levels in the drainage ditches, setting up water control gates in front of their own houses, and elevating living spaces on the ground floors. Early warnings were also broadcast in the communities.

*c) Adaptation*

A positive interviewee risk perception rating indicated that interviewees exhibited a low level of perception regarding environmental sensitivity, and that they possessed knowledge of climate change impacts that enabled them to predict the conditions and level of these impacts. Therefore, these residents can engage in response actions in advance. In an environment with risks, these residents developed relevant skills, engaged in appropriate response, and even constructed a built environment for adaptation. With climate change and adaptation knowledge, the level of local social resilience could be substantially enhanced.

The investigation results showed that older residents who lived in this environment had relatively positive risk perception than did the younger residents. Furthermore, the older residents showed more familiarity with the environment, and their experience in responding to floods greatly enhanced their adaptability. When encountering flood risks caused by climate change, the older residents confidently narrated response measures according to past experiences. They were anticipated to adopt an active responsive behavior. However, the younger residents had little memory of past floods and exhibited weak identification with the local environment. Consequently, they were unsatisfied with the environment in which they lived and lacked adaptation experience. Although these younger residents showed a greater understanding of climate change than the older residents did, most of them believed that climate change impacts progressed slowly and posed no immediate risks. Therefore, these younger residents tended to engage in no or passive risk response actions and thus exhibited higher vulnerability.

## IV. DISCUSSIONS

In summary, the investigation results showed that the fundamental reason for the social vulnerability of Shetzu Island is the gap in climate change knowledge among its residents. Knowledge asymmetry is existing, rendering the residents and governmental planning units unable to identify appropriate development mechanisms. In response to flood risks, several maladaptation measures were executed. We found that knowledge asymmetry created two types of gaps. First, regarding climate change risks, the residents exhibited a notable gap in their knowledge of impacts and adaptation. Therefore, the residents showed low risk perception, lacking adaptation ideas and capacity. Second, the planning units developed maladaptation strategies that were inconsistent with the needs of local residents, thus failing to properly address vulnerability problems. Therefore, new adaptation strategies should primarily focus on bridging the gaps in these two aspects to solve the problem of information asymmetry as well as the challenges of climate change impacts.

### 1. Knowledge Gap

The long-term progression of climate change is incremental, showing few instantaneous impacts. The investigation results indicated that most of the interviewed residents could not accurately perceive the risks of climate change and were not active in developing adaptability. Moreover, these residents did not emphasize environmental sensitivity. Knowledge of climate change was acquired mainly through news coverage. Therefore, a knowledge-communicating technology platform should be established to provide the public with comprehensible, professional, and accurate information. Relevant information could be collected from academic research, case studies, news coverage, international conferences, and related workshops. Through technological applications such as situation simulation and interactive maps, users of this platform would understand the type, scale, and extent of impacts caused by climate change to local areas, thereby enhancing public perception of climate change risks. In addition to knowledge, the technology platform should also offer model adaptation methods and strategies, prompting users to assess their vulnerability referred to both built-environmental sensitivity (degradation) and human adaptability (capacity). Consequently, social resilience would no longer be enhanced only through a top-down approach but also through individual, familial, communal, and settlement collaborations.

### 2. Maladaptation

The major reason for increased social vulnerability is maladaptation, defined as adaptation measures that are implemented to reduce vulnerability to climate change but instead produce the opposite effects, thereby causing increased vulnerability in other systems, sectors, or social groups (Barnett and O'Neill, 2010). Maladaptation often occurs when adaptation measures merely focus on short-term objectives and overlook long-term and overall considerations (IPCC, 2013). Currently, the measures implemented on Shetzu Island by the local government are building embankments and pumping stations, prohibiting construction, and maintaining low-density development. However, the perception investigation results revealed that these measures caused social vulnerability to increase; it was also increased because of overdependence on the embankment. A new development project proposed in recent years, namely a high-density project that requires leveling the entire Shetzu region and elevating its height by using filling soil, clearly lacked a field survey and overall vulnerability analysis. The project showed inconsistency with the residents' needs and was thus extensively delayed. In addition, the project design dismissed the flood detention function, which is likely to result in the increased vulnerability of Taipei as a whole. Planning should be conducted on a local and overall basis to avoid maladaptation. In the early planning stages, construction of a knowledge platform is required to integrate local geographic data such as that on built-environmental sensitivity, human adaptability, and risk perceptions. Subsequently, different policies can be examined from multiple perspectives to facilitate generating planning methods that can be adapted to local levels of risk and resilience. In addition, by using the communicating mechanisms built into the co-design platform to involve the stakeholders, the planners could infer the appropriateness of various adaptation methods with the assistance of the general public.

### 3. Adaptation Planning

The case of Shetzu Island reflects a planning obstacle common in Taiwan. Specifically, planning units were disconnected from local expectations; therefore, the adaptation measures could not fill the vulnerability gap. When risks arose, the planning units sought to continually enhance infrastructure and failed to adapt strategies according to local needs; in addition, the general public lacked related knowledge, rendering a delay in reaching consensus for appropriate development plans and obstructing the improvement of local resilience. To bridge the aforementioned gaps, we developed a set of adaptation instruments to serve as references in the development of future adaptation plans. In addition to addressing environmental problems, the instrument set examines social vulnerability, facilitating the bottom-up enhancement of local adaptability by incorporating the residents as actors. The instruments aim to fill the knowledge gaps, build an online knowledge platform, integrate information, and publicize related information by offering local residents equal access to this information. Furthermore, the set of instruments aid the public to understand the content and level of impacts closely related to them, guide them in discerning vulnerability gaps, and enable them to investigate adaptation measures suitable for local conditions. Regarding adaptation measures for various locations, the proposed platform provides adaptation decision-making instruments to facilitate integrated simulation and situation analysis for various adaptation strategies. Through this platform, adaptation strategies can be communicated to the people publicly and transparently, enabling the concerned public to become part of the decision-making process and thereby establishing holistic and localized adaptation strategies. According to the aforementioned functions, these instruments are divided into a knowledge platform and decision-making support, which are discussed as follows:

*a) Knowledge Platform*

Data sources include research, cases, and media coverage of climate change impacts, forecasts, and adaptations. Related knowledge and applicable adaptation methods were compiled and shared with the public through information technology. The platform is aimed at presenting information in a universal, understandable, and credible manner to assist people in enhancing self-adaptability and developing new adaptation instruments. Eventually, all city residents are anticipated to be able to investigate and execute adaptation strategies (Faust and Smardon, 2011). Two main types of knowledge are presented. (1) Climate change impacts: The platform provides the public with information related to climate change impacts and forecasts, highlighting the challenges and opportunities created by environmental changes, thereby emphasizing the importance of adaptability. (2) Adaptation strategy searches: Different supporting measures can be retrieved by using various types of land use and terrain as keywords. These supporting measures are represented visually to assist people in understanding the adaptation principles and methods suitable for their type of land use. For example, on Shetzu Island, the major knowledge gap faced by residents related to the scale of flood hazards. By using this platform, statistics on the frequency and scale of sea-level rise, extreme downpours, and typhoons obtained through measurements by other international institutions could be superimposed onto the hydraulic models of the Keelung and Tamsui Rivers. Subsequently, flood areas under several extreme climate situations and the relationships between water level and environmental factors such as embankments, houses, fields, and roads are displayed through interactive maps.

*b) Decision-Making Support:*

The 3D interactive adaptation support platform can be used to build an effective communication medium between planners and people and can thus become a discussion tool in the decision-making process (Fig. 3). The platform underscores a design and planning method that tightly couples the creation of design proposals with impact simulations informed by geographic contexts (Flaxman, 2010) in terms of geodesign. We argue that it provides a design framework and supporting technology for professionals to leverage geographic information, emphasizing environmental evidence-based data, design, and decision. That is, the platform helps to fill the gap in climate change adaptation warrants understanding climate impact as well as collaborative design and planning processes across sectors, actors, and levels. Simple adjustment mechanisms, such as shapes (associated parameter lists) and layers (for adding maps using image data or creating mappings of image data to various attributes) are provided using the platform, facilitating the visualization of the space adaptation projects proposed by planners using 3D models. These models can present design project situations after environmental impacts. Therefore, public discussions on various projects can be incorporated into the decision-making process, taking into account how planning and management can be improved and implemented to resolve conflicts between stakeholders. (Liu et al., 2011; Chang and Lin, 2016). For development plans in different areas, we can provide individual project platforms that compile related projects, proposals, reports, and the work content of different units. The aforementioned information can be integrated into a specific file and posted for public access. Moreover, data disclosure and cooperation among various units can also be increased. The objective is to encourage citizens to engage in co-design. All data are permanently preserved in a project file for public review.

## 4. Resilience Thinking

The goal of resilience perception is to reduce the vulnerability of regions with high disaster risks and potential by developing responsive capacity for various types of disasters. Since the 1980s, the notion of resilience has been gradually applied to managing risks, analyzing the causes of disasters, identifying social vulnerability, investigating methods to reduce vulnerability, enhancing impact resistance, and examining the possible damage, response measures, and speed of venue restoration after impacts (Henley, 2010; IPCC, 2012). In addition to hardware (e.g., urban planning and facilities), resilience focuses more on software, such as social capital, economics, resources, and disaster-control policy mechanisms. Resilience through software is more connected to people because when people are stricken by natural disasters, they rely on social capital to help restore and maintain basic living standards. Consequently, risk-control strategies no longer adopt the conventional prevention methods. Current risk-control strategies propose the building of resilience before impacts occur and the use of the impacts to develop adaptation methods. Such strategies emphasize absorptive coping, adaptive, and transformative capacity.

In the face of global climate change, response measures should be developed on the basis of national-level, systematic, strategic, and overall planning. Moreover, national boundaries should be surpassed to enable countries to learn from one another. Urban planning should return to being human-and-environmentcentered rather than vehicular or industrial location-oriented. Furthermore, the rights and capacity of disadvantaged groups should also be protected and strengthened. Therefore, social vulnerability can be reduced, and a sustainable resilient city can be created. In addition, considering economic cost benefits, interdisciplinary adaptation strategies should focus on systematic integration, long-term planning, environmental ecosystems, opportunity diversity, high mobility, experiments, and reviews of implementation plans. Moreover, each measure should be reduced in size and implemented incrementally. Additionally, each minor strategy should adhere to local conditions and be established as living labs, proceeding in innovative steps that are continually modified and corrected according to reviews. Mutual learning among each local strategic component and among various countries should also be strengthened.

Presenting a strong discourse that reflects the complete situation facilitates public recognition and enables a consensus to be formed. Therefore, all citizens can engage in the decision-making process, thus maximizing the effectiveness of adaptation strategies. Compared with water-control technology and flood-control policies, cross-regional experience sharing is underlined. Plans, decisions, and principles can be derived from the adaptation experiences of various countries, facilitating the availability of various guidelines following exposure to different risks. In Taiwan, the development of resilient cities is still in an emerging state. Two major obstacles remain in the development of resilient cities in Taiwan. First, adaptation mechanisms and designs are not sufficiently flexible to respond to various potential risks. Therefore, when effects and costs have been evaluated in the past, criticisms have often arisen. Currently, numerous disaster-control engineering designs merely focus on single partial risks. For example, on Shetzu Island, embankment construction only considered the local flood risks but overlooked the flood control of the entire system of Keelung and Tamsui Rivers and local drainage problems. If basic facilities were designed with multiple functions from a large-scale perspective, their effects would be substantially enhanced. Second, the development of adaptation strategies in Taiwan differed between the government and the public. In particular, although the government and scholars have promoted policy co-design, this concept has not been implemented effectively because public awareness of this mechanism is lacking. Moreover, public consensus regarding appropriate solutions has been lacking. Therefore, this study suggested that the government adopt the storyline policy method, incorporating communication and promotion into policy development, thereby engaging all citizens in the decision-making process and facilitating the development of resilient cities in Taiwan.

## V. CONCLUSION

In general, adjustment strategy planning focuses on the exposure of visible environmental damage. Although social vulnerability directly reflects people's risk impact level, no close examination of social vulnerability is usually included in such strategy planning. Moreover, residents tend to lack related knowledge on the relevant impacts and changes, and they rarely participate in planning. Therefore, adjustment strategies are often irrelevant to local problems (Cash, 2003; Cash et al., 2006).

The case of Shetzu Island exemplifies the typical adaptation obstacles found in areas facing similar risks. Specifically, residents are overly dependent on hardware facilities, lack risk awareness, and have gradually lost adaptability. Planning units tend to cause maladaptation because they fail to closely assess social vulnerability factors before designing adaptation strategies. The residents and planning units also have difficulty reaching a consensus on new development projects. The fundamental reason for this problem is information gaps. Predicting and preventing climate change impacts requires substantial research. Because most people are not aware of the types and levels of climate change impacts they directly face, the primary task of adaptation should build an integrated platform that collects and shares information with the public and provides the public with equal access to information in a universal and comprehensible manner (Eikelboom and Janssen, 2015). Therefore, people can easily determine the relationship between impacts and themselves, the sensitivity of the environments in which they live, their adaptability, and other adaptation measures that can serve as references. Social resilience can thus be strengthened individually and collectively. Furthermore, communication with planning units enables the cooperative design of localized adaptation strategies. The DPSIR cycle combining risk perception framework evaluates the risk event by highlighting the interaction between environmental and social vulnerability. The current results demonstrate that climate adaptation knowledge and technology gaps are the key to the social amplification of risk and maladaptation, which determine the adaptive responses to the impact of climate change from both residents and decision makers.

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