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Thesis title: Climate Adaptive Housing Transformation in Greenland Slum, Khulna: Utilizing Local Knowledge for Resilient Communities

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Summary

The most climate susceptible section of the city is the informal settlements, which is widely recognized. The inhabitants of the region endure the most severe consequences of climate change, including tremendous scarcity of resources. In that situation, Local knowledge (LK) is the most suitable entity to assist people in adapting to climate change given their limited capabilities because, LK is widely recognized as a crucial tool in combating climate change. However, there is a dearth of evidence on the efficacy of adopting LK in the process of transforming housing, particularly in urban informal settlements. This situation is significant since decisions made by local individuals are primarily based on their own knowledge, resulting in both positive and adverse consequences.

This study aims to investigate the impact of local knowledge on the process of housing transformation in an urban informal setting, utilizing the Greenland slum in Khulna as a specific case study. This research employs case study methodology to conduct qualitative research. Data is collected through interviews, focus group discussions, and in-depth observations at the household level mainly. The collected data is then analyzed using content analysis, specifically utilizing the Atlas ti. software. The aim of the analysis is to establish a clear and authentic relationship among related variables.

The research finds that the LK informed housing transformation process mostly focuses on short-term goals, economic efficiency, and physical interventions. This is mostly because the majority of their decisions are influenced by their economic limitations, and they assess the intensity and severity of weather incidents based on the physical damage inflicted on households as a result of these calamities. Due to their preference for fast decision-making, they may not address all difficulties. However, their commitment to incremental design solutions allows them to address most of the revealed inadequacies. They recently included housing maintenance cost in their list of climate risk indicators. This decision was made since they discovered that their short-term solutions were increasing their housing maintenance costs. Additionally, they recognized the importance of indoor living conditions on health, in addition to durability and cost-effectiveness. Prior to making any decisions, they still consider the fact that they lack tenure security, which raises the question of why they should invest in this place is still playing the key decision-making role and induce use of LK. Based on the findings of this research, several recommendations are made for residents, policymakers, and built environment specialists. These recommendations focus on four key indicators of housing transformation: material, labor, finance, and construction technique. By considering these indicators, a participatory upgradation policy can be developed for long-term improvement that is specifically tailored to this case.

Keywords

Climate Adaptation, Housing Transformation, Local Knowledge, Urban Informal Settlements, Greenland Slum, Khulna

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Abbreviations

Abbreviation	Full form
BRA	Bangladesh Railway Authority
CC	Climate Change
CCA	Climate Change Adaptation
FGD	Focussed Group Discussion
HH	Household
HT	Housing Transformation
IHS	Institute for Housing and Urban Development Studies
KCC	Khulna City Corporation
LK	Local Knowledge
NGO	Non-Government Organizations
NI	Natural Indicator
OKP	Orange Knowledge Program
PAR	Participatory Action Research
TEK	Traditional Ecological Knowledge

1. Introduction

1.1 Background

Bangladesh faces significant climate change vulnerabilities in its deltaic geography. According to the list of most susceptible climate devastation countries, Bangladesh ranked seventh (Ahmed & Kelman, 2018), as cyclones, floods, and storms frequently contend with Bangladesh (Eckstein et al., 2021). About 56% of the population resides in Bangladesh to some extent face climate change related vulnerabilities (Ahmed & Kelman, 2018). Additionally, 53 million Bangladeshis face "very high" climate risks, and among those 90 million live in highly climate-exposed areas (Eckstein et al., 2021). Furthermore, Ahmed & Kelman (2018) predict that climate change could internally displace approximately 13 million Bangladeshis, or one in seven, by 2050. Additionally, the coastal zones of Bangladesh are particularly vulnerable to natural disasters, which encompass 32% of the total land area. With its 1.5 million population, Khulna, a coastal city, exemplifies this heightened vulnerability due to its low elevation (only two to four meters above sea level) and frequent flooding exacerbated by climate change (Jabeen et al., 2010). Moreover, the Khulna region has witnessed notable climatic shifts in recent decades, including rising temperatures and humidity, a strengthening monsoon season, and an increase in annual rainy days (Mondal et al., 2013). These climate hazards multiply due to the increasing frequency and intensity of cyclones and storm surges, pluvial flooding and waterlogging, fluvial flooding from rivers, salinity intrusion into water sources, heatwaves, and water scarcity in Khulna City (Jabeen et al., 2010). Till 2022, 7.1 million people displaced from Khulna region due to climate issues and most of them take shelter in the urban informal settlements of Khulna, which is expected to soar up rapidly (Faysal et al., 2023).

However, urban informal settlements in Bangladesh's coastal zones like Khulna face unique challenges intensified by climate change because of their substandard and low-quality structures (Kabir et al., 2018). These informal settlements frequently become the refuge for many climate refugees displaced by river erosion and livelihood loss who migrate towards urban areas (Mondal et al., 2013; Adri & Simon, 2018). Apart from climate hazards such as flooding, extreme heat, and cyclones, these informal settlements exacerbate the vulnerabilities of their politically marginalized residents (Mondal et al., 2013). It's understandable that governments display apathy or even hostility towards these informal settlements due to their legal challenges. The absence of settlement legitimization and land tenure insecurity also create obstacles for dwellers to implementing long-term climate-resilient solutions (Mondal et al., 2013). In an overpopulated developing country like Bangladesh, the government faces immense challenges in providing adequate housing for the exponentially urban population; urban informal settlements are not an exception. Solely government-driven housing transformation is unable to meet the current housing demand, necessitating alternative approaches based on limited resources and competing priorities (Sowgat, 2012; Tasnim et al., 2019). As a result, the dwellers of informal settlements spontaneously resort to self-help strategies to fulfil their immediate necessities and to upgrade their living conditions (Mondal et al., 2013). The development of these self-help strategies is driven by the urgent needs and survival essentials of the individual dwelling in informal settlements.

Residents of a particular area possess valuable local knowledge (LK) about specific environments, cultural practices, and survival mechanisms. Leveraging this local knowledge, they develop adaptation strategies for dwellings to withstand floods, heat waves, and other climatic threats (Mondal et al., 2013). Moreover, formal housing solutions are often out of reach for the economic realities of marginalized populations. Self-help strategies developed based on their local knowledge allow residents to make incremental improvements within economic reality, fostering a sense of ownership and empowerment (Jabeen & Guy, 2020).

Engagement in the adaptation process of their dwellings through investing time, effort, and resources to enhance their living conditions reinforces their claim to the land.

Despite external threats, the proactive approach of residents in an informal settlement to adapt to the changing climate reflects the hidden potentialities of local knowledge for resiliency (Sultana & Luetz, 2022). In order to make housing investment decisions effectively and avoid maladaptation, it is crucial to combine formal and local knowledge to ensure the best use of resources (Satterthwaite et al., 2018). Experts' knowledge in architecture and engineering should evolve to meet local needs, maximizing resident buy-in.

1.2 Problem statement

With their inadequate infrastructure, precarious location, and limited resources, the highly vulnerable urban informal settlements face an increasing climate change threat than any other part of the urban area (Satterthwaite et al., 2007). Traditional disaster response from the government and NGOs often neglects the potentiality of local knowledge for long-term adaptation strategies, prioritizing immediate needs (Nyong et al., 2007). Local knowledge of any settlement is valuable as it evolves with environmental conditions, traditional practices, and disaster resiliency (Thornton & Bhagwat, 2021). Additionally, the conventional practice of local knowledge encompasses the generation of experiences adapting to challenging environments and improving self-esteem (Alam et al., 2019; Alam & Mondal, 2019). When it comes to integrating climate-adaptive local knowledge (LK) with effective climate change adaptation (CCA) strategies of scientific expertise in the field of housing design, there is a knowledge gap (Brink et al., 2023; Filho et al., 2022). Making informal settlements climate-adaptive is also challenging, as modern housing design often fails to recognize or incorporate undocumented LK systems (Wicaksono et al., 2023).

The Greenland slum is the most extensive area within the Khulna Railway slum area. Usually, the slums located in Bangladesh's coastal area is characterized by its dense population and endures very difficult conditions, distinguishing it from other urban informal communities around the world (Alam et al., 2019). Residents of the settlement are extremely vulnerable to the negative effects of climate change, such as flooding, heat stress, and diseases spread by vectors, due to their precarious living conditions in flimsy, inadequately protected shelters with inadequate sanitation facilities (Rahaman et al., 2018; Alam et al., 2019; Hossain & Rahman, 2021). As an informal settlement in a coastal urban region, the residents frequently experience traditional top-down after-disaster responses from the government and NGOs, including immediate relief overlooking valuable local knowledge (LK) held by the residents (French et al., 2020). With resource constraints, the Greenland Slum residents demonstrate remarkable self-reliance in employing local knowledge to improve their living conditions (Alam & Mili, 2018; Alam & Mondal, 2019). However, for long-term climate-adaptive housing transformation, it is necessary to minimize the gap between undocumented local knowledge and scientific expertise (Wicaksono et al., 2023). Despite external threats, the proactive approach of residents in an informal settlement to adapt to the changing climate reflects the hidden potentialities of local knowledge for resiliency. It is necessary to go hand in hand with the formal and local knowledge to ensure optimal utilization of resources and to prevent maladaptation in making housing investment decisions. Experts' knowledge in architecture and engineering should evolve on local needs, maximizing resident buy-in (Satterthwaite et al., 2018).

The LK informed climate adaption strategy is widely regarded as a means to achieve long-term sustainability. However, it's effectiveness is not extensively studied in the context of housing transformation in urban informality (French et al., 2020; Wicaksono et al., 2023). This research aims to systematically document how resident-driven housing transformation, informed by local knowledge (LK), evolved from threat identification to address in the urban informal context of Greenland Slum, Khulna. The research will focus on understanding the socio-cultural and socio-political factors that influence housing decisions at the grassroots level and contribute to long-term sustainability.

1.3 Research objective

This research investigates the potential of local knowledge (LK) for transforming housing in Greenland Slum, Khulna, to enhance climate resilience. The specific objectives are:

- To understand the way of perceiving climate change-related threats using LK among residents of Greenland Slum.
- To explain the utilization of LK related to materials and construction technique in improving functionality and liveability of dwellings in Greenland slum.
- To examine the effectiveness of LK-informed housing transformation in terms of adapting to perceived CC threats in Greenland slum.

1.4 Research Question

The main research question is:

How does the local knowledge (LK) contribute to climate-adaptive housing transformations in Greenland Slum, Khulna, Bangladesh?

The sub-questions are:

1. How do residents in Greenland Slum perceive climate threats based on their local knowledge?
2. How do residents utilize local knowledge of materials and construction methods to adapt their dwellings for improved functionality and liveability?
3. How effective are resident-driven housing transformations, informed by local knowledge, in adapting climate change threats in Greenland Slum?

1.5 Social & Scientific relevance towards policymakers and local residents

This study aims to bridge the gap between undocumented local knowledge and scientific competence in order to facilitate a collaborative approach to climate-adaptive home transformation (Wicaksono et al., 2023). This research endeavors to provide valuable insights into the potential of local knowledge for the construction of climate-adaptive housing in informal settlements, such as the Khulna Greenland Slum, by attaining the research objectives.

The housing policymakers, NGOs, architects and all the sectors related to settlement and climate design will benefit from the outcome of the research. Additionally, this research will try to explore an effective relationship between local and scientific knowledge for designing climate-context-culture-sensitive housing solutions thus empowering the residents of informal settlements and fostering a sustainable future. This Participatory Action Research (PAR) principles and contributes to the decolonization of knowledge by empowering residents and validating their practices. Aiming for a culturally appropriate housing solution which is

climate-adaptive simultaneously and offers valuable insights for urban planning, particularly regarding climate change vulnerabilities in urban informal settlements (Satterthwaite et al., 2007; Elias, 2011). By analysing local knowledge that evolves with the local environments, this research offers deeper insights into environmental management especially in informal context (Bruchac, 2014). Furthermore, this integrated knowledge can lead to more vigorous adaptation strategies by combining traditional ecological knowledge (TEK) with scientific approaches (Filho et al., 2022). This research holds important social scientific importance and provides policymakers with valuable insights for evidence-based decision-making. In addition, it examines the potential of utilizing local resources and expertise to develop cost-efficient solutions (Wicaksono et al., 2023). Furthermore, the cooperative method enhances the self-confidence of inhabitants and promotes community support, resulting in long-lasting results and the development of skills through the acquisition of new abilities (Senanayake, 2006; Shaffril et al., 2020;). This project establishes a connection between local knowledge and scientific competence, leading to the development of sustainable and fair solutions for climate adaptation. These solutions benefit both policymakers and the residents of Greenland Slum, Khulna.

1.6 Scope & Limitation

This thesis aims to explore the true potential of informal settlement residents in housing transformation, drawing from their local and experiential knowledge. Moreover, this will be documentation of how they perceive and utilize their knowledge about housing. From this limited longitudinal study, we can draw a brief evolution of their understanding of housing. Although the primary focus of this empirical study is on material and construction methods, it also considers individual perceptions of finance and labor. Based on this, it may be difficult to draw a definitive conclusion about residents' satisfaction, particularly in terms of whether they lack tenure security. For this reason, the results of their housing transformation may not accurately reflect their true capabilities. Furthermore, drawing a general conclusion from this single case analysis may not be feasible for the broader urban informal context. That's why the outcome of this research can only enlighten policymakers and urban professionals about the true potential of local knowledge and their possessive role in housing and settlement transformation.

2. Literature review and hypotheses

2.1 Introduction

This chapter will examine previous research and theoretical frameworks about the significance of local knowledge (LK) in the process of adapting dwellings to climate change. This inquiry will focus on emphasizing the dynamic role of LK in the informal urban context, as well as determining if the perspective of local residents remains the central theme. To explore that, how they identify climate threats and vulnerabilities and, based on that, how they take decisions are closely related. This chapter will also clarify the relationship between these two key phenomena, and subsequently address the measurement of their context-bound effectiveness. Furthermore, this chapter contextualizes the key theme of the research: LK's contribution to climate-adaptive housing based on indigenous knowledge systems (IKS), community-based adaptation (CBA), and co-production theories. This chapter's discussion will identify the key insights and current gaps, leading to the development of a concept that will propel this study forward.

2.2 Climate vulnerability in informal settlements:

With inadequate facilities and a lack of formal infrastructure, informal settlements are always vulnerable to climate change and CC threats. Informal settlements, often developed without formal planning measures and situated in perilous locations such as water retention zones or coastal flood plains, are considered the most vulnerable part of any urban area, exacerbating their suffering by exposing them to climate change-related risks (Dodman et al., 2019). Those who live in this type of settlement frequently face extreme weather events such as flooding, heat stress, fire hazards, and seasonal storms, which have an intense impact on their living conditions because of their substandard lifestyle (Roy, Hulme, & Jahan, 2013). The lack of formal infrastructure, such as roads, drainage, sanitation services, and durable housing, boosts their vulnerability to climatic hazards. This makes them more susceptible to the compounding effect of poverty (Adelekan et al., 2015; Satterthwaite et al., 2020). Because they lack formal infrastructure and live in substandard housing in hazardous locations with elevated poverty due to climate change, they used to use informal adaptive strategies as a bottom-up approach to mitigate those climate threats (Jabeen et al., 2010; Nightingale et al., 2020). Applying interventions at the community level is beneficial because it takes into account the individual circumstances of each community, such as their level of exposure, susceptibility, and hazard. The effectiveness of these interventions may vary depending on these factors (Satterthwaite et al., 2020). Based on that the adaptation measurements differ from one dwelling to another, as each household's adaptation measure varies (see figure 1).

2.3 Climate threat perception:

Residents of informal settlements are bound to live with inadequate infrastructure and extreme poverty, so they must develop their perceptions about climate threats based on local knowledge. Ford et al. (2016) recognize indigenous and local knowledge as key indicators of climate change. However, residents of informal settlements typically develop a nuanced understanding of changing weather patterns, which they refer to as climate knowledge, based on their lived experiences of climate events and everyday sufferings (Chaudhari et al, 2012). This knowledge helps them to understand and identify the severity of climate change as they experience the change in frequency and intensity of a particular weather event like heavy rainfall, flooding, heat waves, etc. (Adger et al., 2013). Despite their lack of familiarity with scientific data, their extensive observation of long-term trends enables them to accurately pinpoint the current climate threat (Howe et al., 2013). In informal settlements, both living experience and traditional knowledge play a critical role in developing their understanding of climate change

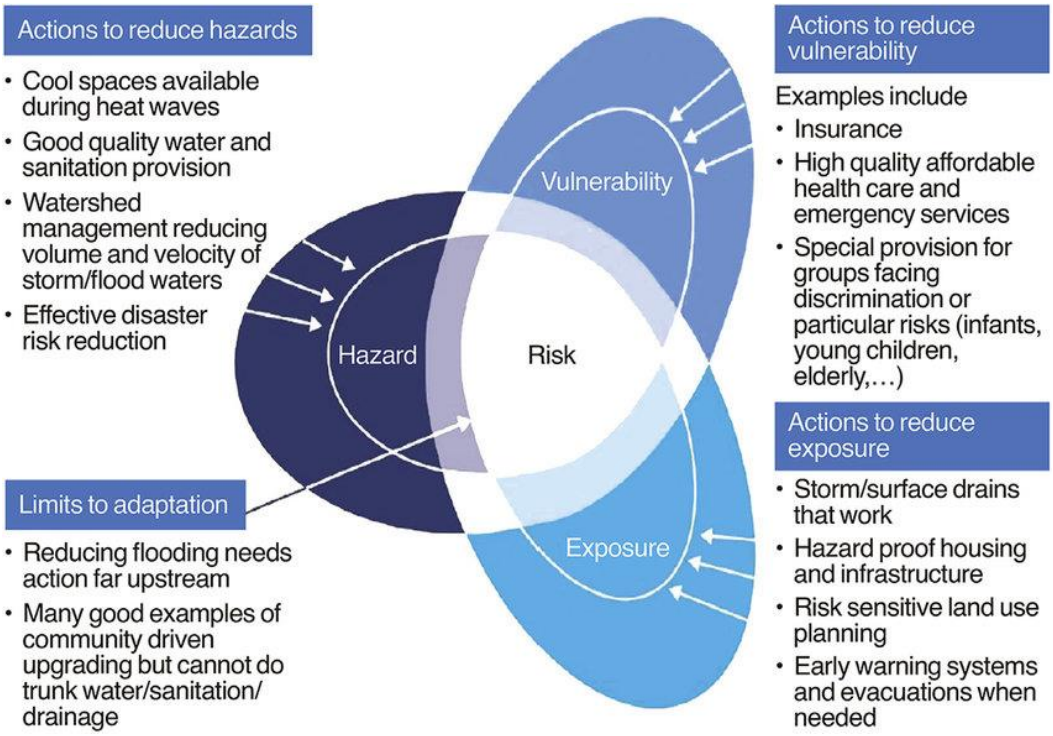


Figure 1: Identifying climate vulnerability (Source: Source: Satterthwaite et al., 2020).

and whether the local people detect it as environmental change (Alam, Alam, & Mushtaq, 2017). This lived experience and knowledge-based perception help them prepare for future decisions about how to cope with climate change issues. While they understand that resource constraints are the primary obstacle to transforming this perception into effective action, they are also compelled to adopt a bottom-up approach based on these constraints (Moser & Ekstrom, 2010, Nightingale et al., 2020). In informal settlements, residents every day convert their perceptions into reality in the form of housing transformation.

2.3.1 Natural indicator-based detection of climate change:

Local knowledge-driven climate change detection relies on natural indicators, which have been created through centuries of experience and are considered the most reliable source. Climate change can be indicated by considerable alterations in weather patterns, cloud formation, local plant and animal behavior, as well as the extinction of flora and animals (Crate, 2011; Rahman et al., 2021). Among the residents, there must be someone, especially the seniors, who often carry the sophisticated capacity to decode and interpret this natural sign language of possible changes in weather (Adger et al., 2013). Usually, generation after generation passes down the long-term climate trend knowledge developed through observation and experience, aiding the young generation in visualizing a collective memory of the long-term climate trend (Nyong et al., 2007). Most of the indigenous communities have a traditional calendar with seasonal indicators of natural phenomena, so they can easily detect any observable variation in timing and duration of the season, like a delayed monsoon or prolonged drought (Berkes, 2009; Crate, 2011). Berkes (2009) asserts that local people often interpret changes in resource-based livelihood patterns, such as crop yields or fishing patterns, as a key signal for a shift in weather patterns. This knowledge is very context-specific, which is a clear indication of residents' tight relationship with nature. However, in urban informal settlements, our ability to predict or perceive changes in weather patterns is limited due to limited access to environmental resources and rapid environmental change (Satterthwaite et al., 2018).

2.3.2 Experience based detection of climate change:

Residents of informal settlements gained deep insight about the context-specific pattern of climate and the risks associated with it from their lived experience of a particular space. Residents develop this knowledge through prolonged exposure to specific weather patterns and their ability to adapt to their changes (Douglas et al., 2008). Based on this experience, residents develop an integrated learning approach. Usually, residents who have firsthand experience with climate change-related events develop a clear understanding when they compare it to other events in terms of frequency and intensity. When they find the difference to be greater, they can easily make decisions about weather changes (Satterthwaite et al., 2020). Moreover, cultural memory and long-term observations help to understand this issue (Adger et al., 2013). Residents can also detect changes in the overall health condition of the community, like the presence of any particular disease, for example, vector-borne disease, at a particular time, or any new kind of health issue that arises all of a sudden, like heatstroke due to heat stress, which could be the first noticeable change, especially in urban informal settlements (Revi et al., 2014). Even the visible change in housing patterns is also a good indicator of climate change (Roy et al., 2018). based on the process of detecting climate change in urban informal settlements involves a combination of personal experience, recollections, and visible impacts on residents' daily lives.

2.3.3 Exposure and Vulnerability to climate change:

Residents of informal settlements are prone to the impact of climate change due to their location, financial condition, and limited access to resources. It makes them vulnerable to climate change, but it also helps them detect and be aware of changing weather patterns by developing an early warning system and sometimes preparing a vulnerability-based emergency plan to cope with it (Jabeen et al., 2010). Residents prepare by adopting adaptive housing transformation strategies based on their exposure to the vulnerabilities created by specific climate threats, such as searching for additional ventilation systems in heat-stress-prone areas (Nightingale et al., 2020). When this issue escalates to a communal level and necessitates community-wide preparation, it can transform into a community-wide adaptive system to mitigate the impact of climate change (Dodman and Mitlin, 2013). According to Adger (2003), these vulnerabilities push them to create social networks and resource pools that help them grow collective resilience. This dependency developed based on their resource deficiency and their attempts to efficiently use limited resources, which is evident in ensuring utilities like water, sanitation, and electricity in informal urban settlements (Satterthwaite et al., 2020). In these settlements, this efficient resource usage practice resulted in effective adaptive strategies for housing transformation. In addition, residents often alter their livelihood patterns to mitigate the risks associated with climate change (Roy et al., 2018). Sometimes climate change vulnerability emerges as environmental degradation, and residents take an ecosystem-based approach to tackle these issues, like local reforestation or at least roof gardening (Munang et al., 2013). Informal settlements, which represent the changing climate, use these things as catalysts for developing adaptive strategies characterized by locally developed experiential knowledge.

2.3.4 Perceived impact of climate change:

As urban informal settlements are the most vulnerable part of the community to any climate change threat, they have to take proper measures based on these physical and non-physical impacts, which are clear indicators of climate change in related contexts. In informal settlements, structural damages and community-wise infrastructural failure are typically the key physical indicators for CC (Satterthwaite et al., 2020). Green infrastructure, when present in urban informal settlements, signifies extreme resilience and the severe impact of climate change together (Munang et al., 2013). Besides that, livelihood diversification and arising

climate-related health issues, especially in vulnerable communities, are non-physical cues of CC (Roy et al., 2018; Revi et al., 2014). Occasionally, intensified climate change issues lead to the incurred trauma people experience and the cultural practices they adopt to mitigate the impact of disasters (Adger et al., 2013). These factors lead to the development of community-wide adaptation measures, which acknowledge the reality of climate change and its early manifestation in urban informal settlements (Dodman and Mitlin, 2013). In informal settlements, residents typically implement preventive or adaptive measures to address the physical and non-physical issues arising from climate change.

2.3.5 Implication of climate change perception:

CC perception directs adaptation strategy through understanding the vulnerabilities (see figure 2). Previous debates have revealed that climate change affects households differently depending on their geographical location and resource limitations, a phenomenon known as exposure to climate change (Nightingale et al., 2020). Households are being affected by both physical and non-physical factors that contribute to their lived experience, as a result of their exposure. By quantifying this influence, one may accurately determine the level of vulnerability of a dwelling, and individuals with expertise can readily recognize this (Jabeen et al., 2010). Climate change impacts can be recognized by both natural phenomena and social interactions. It is crucial for individuals to detect and manage these hazards in advance in order to minimize damage, particularly in informal settlements (Adger et al., 2013). CC perception played a significant role in making decisions related to housing transformation and changes in livelihood (Revi et al., 2014).

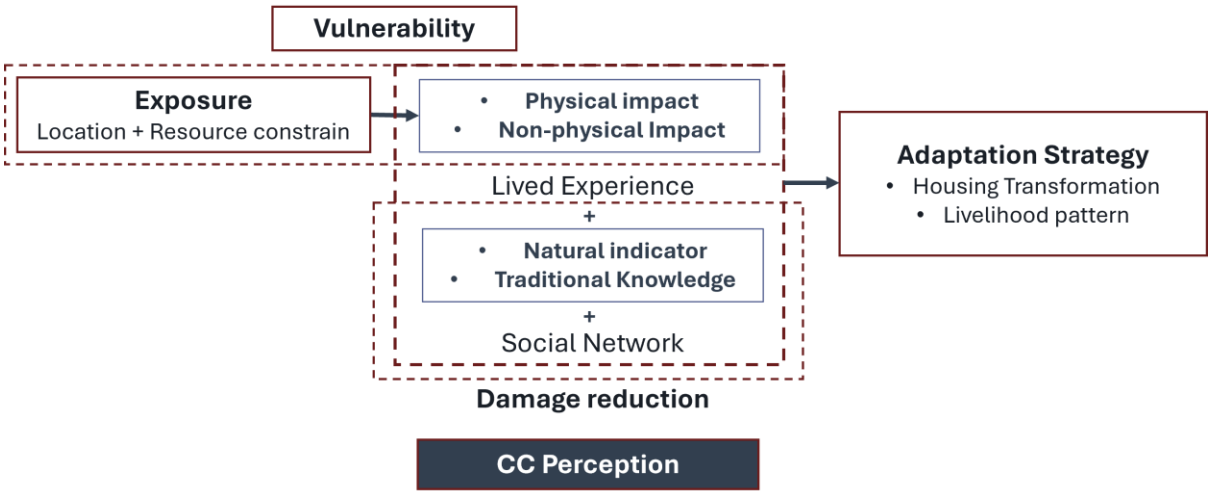


Figure 2: Implication of CC perception (Source: Jabeen et al., 2010; Adger et al., 2013; Revi et al., 2014; Nightingale et al., 2020).

2.4 Adaptive strategies in housing transformation:

Residents of informal settlements take effective measures to adapt to climate change based on their local knowledge and available resources (see figure 3). They develop these measures based on their perceptions of specific climate threats, as well as their individual and community perceptions, as informed by LK. Satterthwaite et al. (2020) assert that local perception plays a more effective role in adapting to the CC issue in an ingenious and resourceful manner. Though these strategies help address climate issues, their scale of implementation due to resource constraints is questionable.

2.4.1 Local material and construction method:

The most common response to any kind of adaptation strategy in housing transformation in an informal settlement context is the use of local materials and construction techniques, which

express a dynamic nature. In terms of material selection, the availability and cost-effectiveness of locally available materials are crucial indicators of the right material for the residents of informal settlements. Choosing this kind of material for housing transformation is considered a grass-roots coping strategy for climate change (Jabeen et al., 2010). Locally available materials are believed to be the most suitable to withstand the local climate (Ahmed, 2018). In addition to these indicators, durability is another issue that can extend the effectiveness and resilience of housing. Bamboo, tin, and recycled or reused materials are considered to be resilient and efficient when used in an informal setting, taking into account their cost-effectiveness and availability. Nevertheless, there are instances when this notion may conflict with the ideal characteristics of climate resilience, especially in terms of their efficacy in extreme heat or floods events (Santamouris, 2020). According to Pelling (2011), besides the locally available material, LK-informed traditional construction techniques are highly effective in the adaptation process. The community continuously evolves this LK-based construction method through rigorous trial-and-error, sharing and applying knowledge to enhance the adaptive capacity of local people (Roy, Hulme, & Jahan, 2013). For example, in any of the informal settlements prone to flooding, people usually raise their plinth, adapt to houses on stilts, or even find floating platforms, but end up solving problems based on their experience and observations (Khan et al., 2019).

Together, applying local materials and techniques ensures climate resilience and economic sustainability, which is crucial for informal settlements because of their long-lasting fight with financial constraints (Sharma et al., 2011). Moreover, while these strategies undoubtedly guarantee short-term success, further investigation is necessary to determine their long-term effectiveness. For instance, the use of tin could provide protection against rain, but what about its impact on heat stress?

2.4.2 Labor and Finance:

Residents in informal settlements encounter substantial obstacles in terms of labor and finance due to their low resources while confronting climate change challenges. Residents in these scenarios frequently find themselves compelled to rely on their own capabilities, drawing upon their local expertise, in innovative manners, which unequivocally demonstrates their resilience.

Labor: Typically, community adaptation projects such as road upgradation and water edge reconstruction rely on the collective efforts of their labor force (Jabeen et al., 2010). As a result, they save time, share knowledge and skills, and enhance local capacity to manage climate change which are effectively used at household level (Ensor et al., 2018). Usually, when it is necessary, they assist each other and exchange this critical resource, increasing community bonding (Adger, 2003).

Finance: To manage financial resources, they typically rely on community funds created collaboratively with savings groups, or they attempt to access any microcredit fund for individual and communal adaptation (Archer, 2012). To handle this issue more efficiently by spreading the cost over a long period of time, most of the decisions they take are incremental (Adger, 2003). In response to the ever-increasing costs of housing maintenance and the impact of climate change on regular livelihoods, they strive to diversify their income sources by establishing home-based enterprises (HBEs) or leveraging other informal income sources that are less susceptible to climate change issues (Roy et al., 2018). Moreover, to reduce financial burden, they used to recycle and reuse locally available and low-cost materials for construction, which further exacerbated maintenance costs (Alam et al., 2018; Satterthwaite et al., 2020). Sometimes, they have to depend on an informal money lending network in the form of a high interest loan, which elongates their financial sufferings (Moser and Satterthwaite, 2008).

It is evident that the residents of informal settlements approach labor and financial issues in a genuine manner, unlike other people who handle these issues through collective action based on limited resource usage. However, the scale of implementation may not always address the overall climate-related challenges, as they are always in short supply.

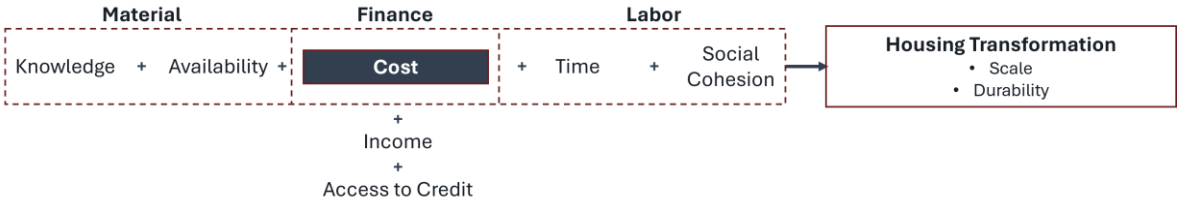


Figure 3:The indicators of HT (Source: Jabeen et al., 2010; Archer, 2012; Ahmed, 2018).

2.4.3 Constrains of adaptation in informal settlement:

The adaptation strategies that are taken by residents themselves to cope with climate threats in informal settlements are usually driven by the constraints. Sometimes these constraints limit their capacity, forcing them to maladapt to climate issues, exacerbate their existing suffering, or create new problems altogether.

Physical: Due to locational disadvantages, such as living in a hazard-prone area, they are often forced to remain in the same location and face the same problems over and over because there is limited space left to expand or rethink the housing transformation (Dodman et al., 2019). The lack of drainage, sanitation, and other essential services and infrastructure typically worsens the situation, escalating water-related issues and disease outbreaks (Satterthwaite et al., 2020). In addition to this geographical constraint, they build their homes using inferior materials, and their construction techniques further degrade the quality of their dwellings (Alam et al., 2018). Furthermore, due to their location in a hazard-prone area and the substandard housing they use to adapt to climate change, they occasionally have to degrade the environment by cutting trees, polluting waters, and encroaching on green areas, which further complicates their living conditions (Roy et al., 2018).

Non-physical: Among the non-physical issues, tenure plays a vital role, as most of them have no formal tenure, along with the eviction threat and legal regulations that keep them away from long-term investment and reduce the adaptivity of their dwellings (Archer, 2012). This also keeps them from receiving government support because they are living outside of a legal framework (Dodman and Mitlin, 2013). Furthermore, their financial inability exacerbates the situation, forcing them to live a measurable life without adopting any adaptation measures (Moser and Satterthwaite, 2008). This further exacerbates their climate anxiety, leading them to prioritize short-term solutions, which significantly hinders the implementation of long-term proactive measures. Moreover, a lack of effective technical knowledge, cultural practices, social stigma, security issues, and behavioral norms can sometimes lead to maladaptation or stagnation in any backward condition (Jabeen et al., 2010; Adger et al., 2013).

In terms of adapting to climate change, residents of informal settlements face a complex mixture of physical and non-physical issues. Most of the time, they energize each other and pose a severe threat to achieving resilience. That also indicates that to figure out this challenge, not only physical but also non-physical issues have to be taken care of together.

2.5 Effectiveness of housing transformation

Informal settlements usually prioritize LK-based dwelling modification methods as the most effective approach for dealing with climate change threats. These grassroots techniques have become essential in informal settlements for minimizing the impacts of climate change at the household level through improving housing resilience and reducing vulnerability to climate-related issues (Satterthwaite and Dodman, 2013). For ensuring sustainable adaptation in resource-constrained settlements, this dual-benefit approach is the ultimate solution (Ayers & Forsyth, 2009). Considering climatic vulnerabilities such as flooding and heat waves, elevating foundations, altering roofing materials, and enhancing the natural ventilation system can significantly enhance the living conditions in specific settlements. However, the effectiveness of these measures varies depending on the local knowledge of residents (Revi et al., 2014). Most of the time, these transformational measures increase the functionality and liveability of dwellings by improving the lighting, ventilation, and insulation conditions and raising the overall comfort level (Roy et al., 2018). Living standards in informal settlements always remain below average, but due to the climate change issue, local residents forcefully take some decisions that protect them from climatic impacts while also improving living standards as a co-benefit. But sometimes forced adaptation measures could end up leading to maladaptation (Barnett & O'Neill, 2013).

2.5.1 Adaptive capacity of transformed dwelling:

Residents typically take various steps to adapt to climate threats, demonstrating greater effectiveness in building adaptive capacity through local knowledge such as elevating platforms, improving drainage, and using durable materials (Chowdhury, 2020).

Resilience to threats: The effectiveness of resident-driven housing transformation is highly dependent on the performance of specific measures taken based on perceived threats like heat waves, flooding, etc. (Jabeen et al., 2010). Typically, the user's personal experience allows for an easy measurement by comparing the damage rates they report from similar events. However, shifting weather patterns can render this approach ineffective when the event's intensity drastically alters. To address this, incremental adaptation strategies are useful (Adger, 2003). Alam et al. (2018) suggest that we can precisely measure efficiency among different decisions based on cost and time. Moser and Satterthwaite (2008) assert that the decrease in maintenance expenses serves as a crucial financial gauge for the efficacy of the implemented measures.

Liveability and Comfort: Ensuring thermal comfort while simultaneously reducing reliance on electricity is a crucial aspect of effective adaptability (Santamouris, 2020). This actually indicates a reliance on passive systems for cooling and heating, instead of relying on electricity, which has the potential to significantly reduce utility bills. This applies not only to temperature issues, but also to water, sanitation, and drainage issues, all of which have the potential to significantly improve overall housing conditions (Satterthwaite et al. 2020). After implementing the adaptive measures, users' health condition becomes a significant indicator of their overall well-being, particularly when considering climate-sensitive diseases (Kovats and Akhtar, 2008). Replicability and community involvement are also indicators of effectiveness, as it is clear that widespread acceptance of the measures is beneficial (Pelling, 2011).

Collectively, based on these indicators, we can easily create a framework to assess the measures in terms of climate-adaptive housing transformation.

2.5.2 Risk mitigation:

The effectiveness of housing transformation is significantly impacted by the risks associated with the adaptation measures taken. This risk could also be measured and have to be part of overall housing adaptation effectiveness. From the outset, the implementation of measures

shapes residents' perceptions of potential risks, and upon their completion, their comprehension of the underlying issues is the primary method for risk identification (Wamsler and Brink, 2014). By assessing the short-term and long-term impacts of adaptation strategies, it could be easy to identify the adverse effects created by the measurements if they happened and had any impact on their daily lives and well-being (Barnett & O'Neill, 2013). Before initiating any physical transformative changes in housing, a technical assessment can easily identify potential risks. However, residents experiencing extreme financial crises may not fully comprehend the risk level before implementation. But it is definitely possible to raise awareness among them to reduce possible risks, like health risks and environmental risks, by engaging them in a participatory risk mapping approach (Jabeen et al., 2010).

2.6 Conceptual framework:

This research investigates how residents of urban informal settlements utilize local knowledge to contribute to housing transformation and enhance resilience. It is clearly evident in the literature that residents use local knowledge to develop perceptions about climate change threats, comparing frequency and intensity (Adger et al., 2013), and based on that perception, they adopt adaptive strategies related to material and construction methods (Jabeen et al., 2010). This decision depends on the individual capacity of finance and labor management (Adger, 2003). However, due to a variety of resource constraints and, as noted by Wolf et al. (2010), location-based experiential variation, their decisions can vary. Occasionally, they may maladapt due to short-term goals and overlook related risks (Barnett & O'Neill, 2013) which in return help to develop situation-based experience. And if this is overlooked a vicious cycle of maladaptation could be created. But this is also the way residents of urban informal settlements cope with climate change-related threats most effectively. This study will emphasize the interplay between perception and transformation, defining their choices as either effective adaptation or maladaptation, in contrast to improving liveability and functionality (Roy et al., 2018). This research will utilize three primary variables. The first one, LK informed climate change perception, evolved using the traditional knowledge, cultural practices, and everyday experiences of residents, which differ depending on the location (Wolf et al., 2010; Adger et al., 2013) The second one is the LK informed housing transformation, which is driven by local resources such as materials and skills, primarily relying on residents' labor and financial capabilities (Jabeen et al., 2010; Pelling, 2011). The final variable is the effectiveness of housing transformation which is solely resident driven (Satterthwaite and Dodman, 2013; Roy et al., 2018). The effectiveness will be examined by evaluating the climate adaptive capabilities demonstrated by the current state of housing. The relationship among the variables are illustrated in the following conceptual framework (see figure 4).

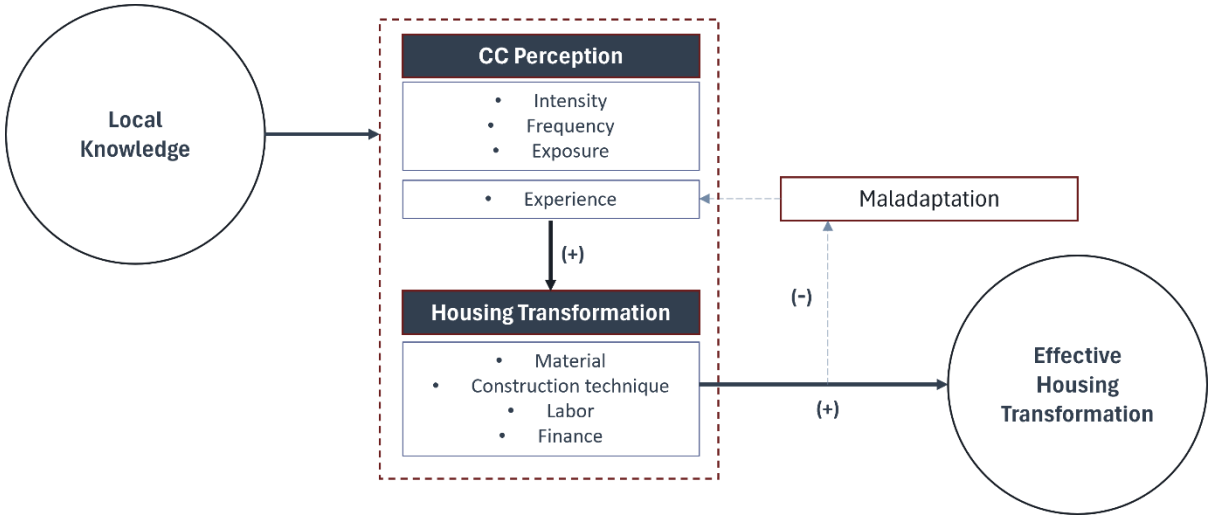


Figure 4: Conceptual framework (Source: Author, 2024)

3. Research design, methodology

3.1 Introduction:

This chapter will elucidate the entire research process, starting from identifying the necessary data and proceeding to its collection and analysis to address the research question. It will be presented through an operationalization table. Beyond that, the rationale behind selecting the case and population will be clarified here, along with the data collection and analysis methods. At the end, the limitations of this research will be addressed.

3.2 Research strategy

Creswell & Poth (2018) assert that a qualitative approach is necessary when conducting research to explore the intentions of a group of people about a social or human problem, particularly when there are limited known facts about the role of context. Subsequently, qualitative research employs the case study method. According to Yin (2017), when we need to conduct exploratory research following a systematic approach in a real-life setting to get a nuanced understanding and holistic insight into a particular phenomenon, the case study method is considered the best. This research examines the role of local knowledge in resident-driven housing transformation in the particular case of the Greenland slum in Khulna, taking into account the specific circumstances of climate change. The main research question is developed based on the specific context of climate vulnerability and informal settlements. Moreover, when a specific research question is present and there is ample opportunity to employ multiple data collection methods and sources of evidence, the case study method offers an in-depth study of a particular phenomenon (Yin, 2017). To explore contextualized understanding, it is indifferent to use this method in qualitative research.

3.3 Operationalization:

3.3.1 Operational definition of variables:

LK informed CC perception: When climatic change perception refers to the understanding and consciousness of local people based on their cultural and traditional context, which is determined by observational knowledge that comparing the frequency and severity of recent climatic risks to their previous experience and knowledge help to develop localized perception of climate change (Adger et al., 2013). Residents are exposed to a range of climate-related hazards, including heat stress, flooding, and tropical storms. The impacts of these threats on the residents vary based on their location preferences and individual interpretations of climate risks (Wolf et al., 2010). It is developed based on traditional knowledge, cultural practices, and everyday experience.

LK informed housing transformation: LK informed housing transformation refers the way individuals residing in Greenland slum face multiple forms of scarcity, including restricted access to resources and services, limited institutional support, inadequate aid, and lack of money and utilize that to alleviate the threats posed by climate change through gradual modification of their dwellings and surroundings, drawing upon their own expertise and knowledge (Jabeen et al., 2010). Emphasizing the importance of using traditional knowledge of skills, construction methods, and locally available materials is particularly crucial in urban informal settings (Pelling, 2011). It also helps to adapt local environmental condition.

Effective climate adaptation: Effective climate adaptation refers to the degree to which residents are decreasing their susceptibility to climate change by utilizing their traditional techniques of upgrading dwellings, therefore minimizing the risks associated with climate change (Satterthwaite and Dodman, 2013). As a result, this improves the quality of life and efficiency of housing (Roy et al., 2018).

3.3.2 Operationalization table:

Table 1: Operationalization table (Source: Author, 2024)

Variable	Sub-variable	Indicator	Sub-indicator	Reference	Data collection method
LK informed CC **perception**	Local knowledge of Hazard (Warning system)	Natural indicator	Cloud, Wind, Temperature, Plantation, Animal behaviour	(Adger et al.,2013; de Graaf-van Dinther & Ovink, 2021)	HH Interview, FGD, Mapping
		Experience of hazard	Frequency & Intensity		
	Exposure	Location	Locational vulnerability	(Wolf et al., 2010)	
		Disaster Awareness	Preparation (Personal & Communal)		
		Disaster preparedness	Asset (Personal & Communal)		
	Impact	Physical impact	Structural	(Wolf et al., 2010; de Graaf-van Dinther & Ovink, 2021)	
		Non-Physical impact	Financial, Social, Environmental, Health		
LK informed Housing **transformation**	LK informed transformation measures	Material	Local & Modern	(Jabeen et al.,2010; Pelling, 2011).	Observation, HH Interview, FGD
		Construction method & technique	Local & Modern		
		Labor	Self, Family, community & hired		
		Finance	Personal saving, Loan, Borrow		
	Asset Constrains	Physical constrains	Structural & Technical	(Wolf et al., 2010; French et al., 2020)	
		Non-Physical constrains	Financial, Legal, Social		
Effective Housing transformation	Climate adaptivity	Functionality (Strength & Weakness)	Incremental, Durable, & Adaptive	(Kovats and Akhtar, 2008; Wolf et al., 2010; Roy et al., 2018; Santamouris, 2020; Escarameia & Tagg, 2021)	HH Interview, FGD, KII
		Liveability (Comfort level)	Light, Ventilation, insulation & Spaciousness		
		Risk (Threats)	Physical & Non-physical		

3.4 Data collection method:

Primary data collection: In this empirical study, necessary social and spatial data will be collected through semi-structured interview (household), focused group discussion (FGD), Key informant interview (KII), and in-depth observation by taking detailed photographs and involving them in participatory mapping. Social data are required here to understand how local knowledge helps the local residents grow their perception of climate change and investigate the effectiveness of their resident-driven housing transformation to address climate adaptivity. Whether spatial data is required to identify the change they made in their dwelling unit and surroundings to address climate-induced threats on their own. A Likert scale is used here to understand the role of local knowledge on their perception of climate change and housing transformation, as well as their satisfaction with the transformation. As the Greenland slum in Khulna serves as the research site for this study. Whether 10 households are selected in two clusters based on having poor locational benefit (beside a water body or not) and poor socio-economic standard purposefully following the purposive sampling method, as they are the worst sufferers of climate change. Two focused group discussions will be conducted based on location, with 6–8 people in each meeting representing climate change sufferers in the community and 2 KII, where one of them is a local researcher from Khulna University and the other one is a built environment specialist of NGO currently involved with local government body. In the interview and FGD, open-ended questions are asked to get proper narratives. Besides that, key informant interview will help to verify the common ground of the data. Spatial data is collected through direct in-depth observation and interpreted through photographs and creating on-site sketches. For mapping purposes, local people will participate in a collaborative drawing development process with their own style of drawing.

Secondary data collection: A comprehensive literature analysis was undertaken to enhance understanding of the circumstances. Furthermore, the study involved an extensive review of statistics information related to the Greenland slum and Khulna in order to conduct a more in-depth investigation and validate the main conclusions. Whether some policies related to the informal settlements in Bangladesh and news related to the site is also checked to figure out biased response in primary data collection.

Table 2: Primary data collection and analysis method (Source: Author, 2024).

Data collection method	Sampling Method	Sample size	Data analysis method
Semi-structure HH Interview	Purposive Sampling	10 (5 & 5 in two different location)	Content Analysis Descriptive Statistical Analysis
Focussed Group Discussion (FGD)	Purposive Sampling	2 (6-8 person in 2 different location)	Content Analysis
Key Informant Interview (KII)	Purposive Sampling	2 (Researcher & NGO worker)	Content Analysis
In-depth Observation & Participatory Mapping	Random Sampling	16 HH	Spatial Analysis

3.5 Sampling:

For qualitative research, the number of cases and sample size are flexible and depend on the study's purpose. Whether it pertains to a solitary case study, it necessitates a comprehensive analysis to delve into the issues, and it's justifiable when the case and research contribute to the exploration of critical and unique knowledge (Yin, 2017). This research typically involves a smaller number of participants, typically between 1 and 25, due to the close relationship of the

collected data to narratives and phenomena (Creswell & Poth, 2018). In this study, Greenland slum was deliberately chosen as the case study due to its inherent locational disadvantage. It would be preferable to compare the study with other cases, but due to time constraints, this is not possible. In this particular area, the general situation of households is relatively similar. Therefore, collecting numerous samples could result in redundancy, which is an important concern for the researcher when determining the final sample size. This is apparent from the pilot study, which has identified two locations: one where 30% of the houses are located near a waterbody, and the other where the remaining houses are not. The proximity to waterbodies plays a crucial role in determining the level of exposure to climate-related events. Furthermore, there is an intriguing chance to gain diverse perspectives in response to this issue. During the selection of a household, the ratio is evenly split at 50% for each option. In terms of HH interview and FGD, purposive sampling is used This method involves purposefully selecting respondents from households that are located in areas with high exposure to climate events and have relatively poor living conditions. The aim is to gain a comprehensive understanding of the actual situation. It is important to maintain this stratification during the FGD. During KII, two specialists, one acting as a researcher and the other as a professional, are chosen to discuss the case from two different perspectives. Through in-depth observation, this study is employing probability sampling to verify and apply findings from other purposive sampling methods. Both individuals who have resided here for 25 years or longer are chosen for both cases. Priority is given to elderly individuals due to the close connection between their responses and their experience. Responses are collected collectively from each household. This guarantees an authentication process when gathering data. In addition, the prioritization of different socio-economic standards leads to varying perspectives on the process of adhered adaptation.

3.6 Data analysis method:

Content analysis: In the data analysis process, content analysis determines the frequency of words and phrases in compiled data in a text format. The selection of words is conditioned upon the operational definitions of variables and research questions of any specific research, as well as its efforts to comprehend their particular meanings and relationships to each other in the specific context of the research (Matthews & Ross, 2010). This research primarily presents the collected data by interview, FGD, and KII in a descriptive text format, incorporating observations from photographs as graphics. Here, the content analysis is applied to figure out respondents' specific responses about utilizing LK to perceive CC threats, housing transformation strategies, and their overall effectiveness in understanding the role of LK in housing transformation in the Greenland slum of Khulna. In order to optimize the efficiency of data analysis Atlas ti is a software program. Van Theil (2014) emphasizes the need of using software to assure the quality of data analysis by providing a systematic method and enhancing its efficacy. The primary data obtained from interviews, FGDs, and KIIs were documented and subsequently transcribed into English for ease of use, as the primary language used was Bangla (local language). During the analysis, the obtained data were encoded using a semi-inductive method that was essentially created from the conceptual framework. Additionally, new in-vivo codes were developed during the coding assignment. The codes were organized according to significant themes and subsequently linked to relevant content by creating quotations. In order to ensure the clarity of the data, codes were organized into themes. These themes were generated based on the variables and indicators set for this research. This approach helps to build clear relationships among the data and ensures the validity of the research (Yin, 2017). The coded texts were studied using frequency count and by checking the co-occurrence of codes. This analysis helps build clear relationships among the codes, which are then displayed through tables and Sankey diagrams. By analyzing the data provided, it is possible to identify major themes and patterns in the text. This may be done by examining the frequency, density,

and co-occurrence coefficient (ranging from 0 to 1), where higher values indicate a stronger association which is represented as broader strap in diagram. Through this representation, relevant quotations can be readily identified and utilized as evidence. The process guarantees the authenticity of the study result (Hwang, 2008).

Descriptive statistical analysis: To clarify some data, it is required to run descriptive statistical analysis based on data collected by Likert scale multiple-choice questions to verify the data provided in descriptive format during the interview. It's considered an essential data analysis method for qualitative research (Matthews & Ross, 2010). This analysis employs validation and cross-referencing techniques to verify and corroborate the results of textual data analysis and develop the trend based on using Microsoft excel application.

Spatial data analysis: In order to comprehend the evolution of any settlement with regards to its social consequences Although gathering earlier data may be challenging, spatial analysis can be utilized to comprehend the autocorrelation tendency (Darmofal, 2015). Maps have the ability to simultaneously identify spatial dynamics and social phenomena. The process of validating textual data is enhanced by including real-life validation and engaging local individuals, as suggested by Fagerholm et al. (2021). By analyzing the initial data and actively engaging the local community, we aim to gather their input through self-drawn illustrations, which will be used to collaboratively develop a prediction model. The drawings will be analyzed within the conceptual framework to identify themes and ascertain their significance.

3.7 Limitations:

Due to the remote nature of this research, certain constraints have inevitably arisen. The data is collected by local surveyors who are university students in their last year, supervised by an architect. Nevertheless, the lack of active participation from researchers results in a limited level of comprehension due to a communication gap, which sometimes obstructs the progress of data analysis. The majority of respondents mistakenly believed that this research was connected to financial resources, resulting in biased data regarding their economic hardships. While that is true, the lack of trust has hindered its development. This is apparent in their contradictory replies. Through the process of cross-referencing data from many sources, researchers are able to verify the accuracy of the data and mitigate any potential bias. Although there are ongoing concerns around privacy and confidentiality, one notable aspect is the distinct cultural sensitivity in terms of safety and privacy compared to other areas in the region. In addition, gender dynamics are crucial as women have a substantial influence on decision-making in both the family and community spheres in Greenland Slum and interviews are faced by them because due to the timing of data collection, most of the males were not available due to livelihood purposes those who are main actor in construction and reconstruction process. In order to address this problem, it is necessary to increase male participation in the data collection process during FGD and if possible, during observation. In addition, respondents are encouraged to provide both positive and negative feedback regarding the responses help to overcome the limitations. Furthermore, weather conditions play another key role, as during data collection a severe heat wave is active. That's why most of the problem-related questions are related to heat issues which is further checked by secondary data source.

3.8 Validity

To enhance validity of this research, multiple data collection method is employed here. Yin (2017) asserts that highlighting repeated operations and responses in any data pool is necessary to reduce the magnitude of errors in a study, a concept known as reliability. In this study, all the questions are set based on indicators that are cross-connected and wherever they are used to ask. We followed the same process for different types of respondents, including semi-

structured HH interviews, FGDs, and KIIs. Moreover, data extracted from in-depth observation through photographs and drawings is also used as source data. That increases the likelihood of repeated responses, ensuring reliability. Whether triangulation is considered an important method to cross-check the reliability of the collected data (Cohen et al., 2007). For this research, triangulation has been done with the data collected through conducting semi-structured interviews on different days, multiple focused group discussions, and in-depth observation that enriches the validity of the study.

4. Results, analysis and discussion

4.1 Introduction:

This chapter examined the data gathered from the study area and provide interpretation and in-depth analysis. The main goal is to demonstrate how LK fostering climate adaptive housing transformation in Greenland slum, Khulna. The study pertains to explore how local people use LK to transform their housing living in the Greenland slum, Khulna. Firstly, it symbolizes the use of LK to identify threats and vulnerabilities is determined by presence of different phenomena. Additionally, it examines the influence of LK to determine the pathway of housing-transformation efforts driven by themselves. Furthermore, it demonstrates the extent of effectiveness of adaptation at household level that is influenced by LK. Ultimately, the study concludes by examining the various findings that impact the transformation of housing influenced by LK. The chapter ends with a concise overview that offers a series of suggestions.

4.2 Case description:

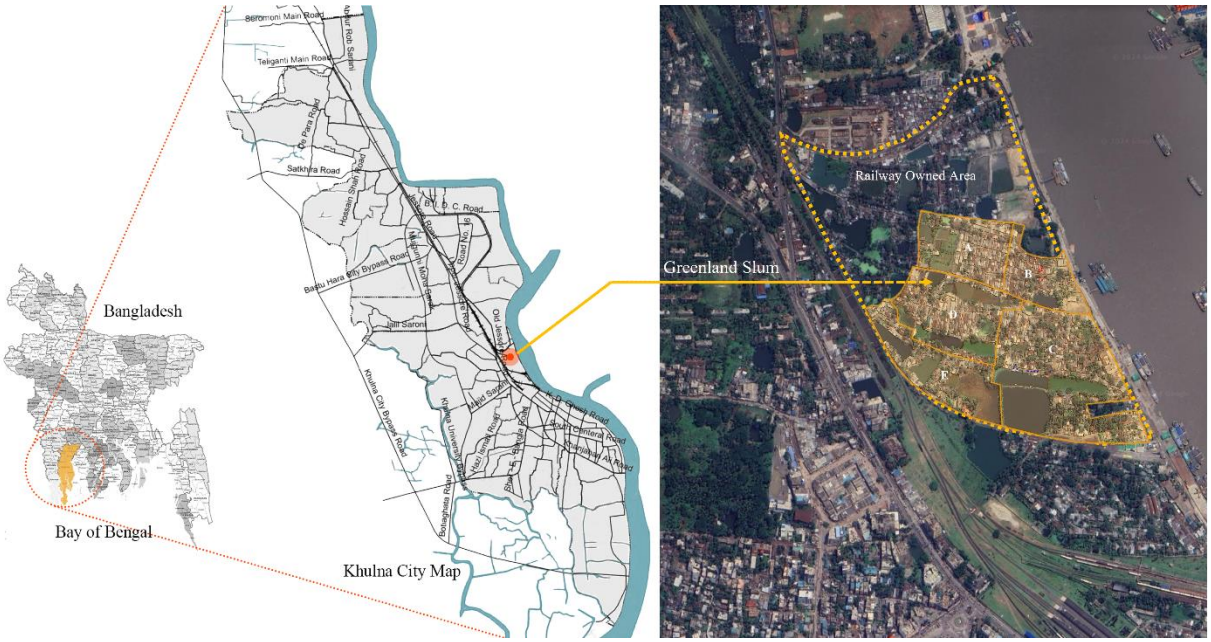


Figure 5: Location map of Greenland slum (Source: Author, 2024)

Khulna is widely recognized as the most susceptible region to climatic impacts in Bangladesh, and the informal settlements within this area bear the brunt of these effects (Jabeen, 2019). The Railway Slum, located on the land of the Bangladesh Railway Authority (BR), is one of the most significant and second-largest informal settlements in Khulna located by the mighty Bhairab river (Roy et al., 2018; Alam & Mondal, 2019) (see figure 5). It has been growing since 1970. The railway slum consists of three slums, with Greenland slum being the largest. The total population of this settlement is 5806, with 1523 households. Among them, 6% are aged over 60 (Akter et al., 2021). The area is particularly renowned for its population of climate refugees who have relocated from the Khulna coastal region. On average, there are 54 households per acre in this area (Jabeen, 2019). This slum is recognized for its inadequate housing, which exhibits a high susceptibility to climate-related hazards (Mondal et al., 2013). The primary climate issues in this region include river flooding, intense storms and surges, heat stress throughout the summer, and salinity intrusion (Jabeen, 2019). Whether the local residents perceive these threats and hazards intuitively and take further decisions about housing and surrounding environmental development, such as the dig and mound process to create water bodies that help to develop land and raise plinths, the use of portable materials for tenure

Figure 6: Greenland slum in 2012 (Source: Sowgat, 2012)

insecurity, the shift to materials like corrugated iron sheets for stability in rain and storms (see figure 6), and even the use of green roofing to reduce heat stresses, are their coping strategies to challenges (Afroza et al., 2016). They developed these responses based on their extensive experience and understanding of combating climate-induced vulnerabilities (Rahaman et al., 2018; Alam et al., 2019). Climate change exacerbates these issues by causing an increase in temperatures, resulting in heat stress along with humidity rise. This has lately been amplified numerous times, accompanied by a significant increase in the frequency of seasonal storms (Hossain & Rahman, 2021). While climate change is constant, their responses are to some extent helping them to withstand climate threats, but tenure security remains a vital barrier to more extensive climate adaptive transformation efforts. Despite demonstrating strong community resilience, their fear of eviction prevents them from investing in more resilient and permanent structures (Jabeen, 2019). This case has demonstrated the intricate interplay of several socio-economic factors that compel local residents to utilize LK in enhancing the awareness of climate change and modifying their housing, regardless of environmental degradation.

4.3 Perception of climate threat from LK perspective:

Local residents of the Greenland slum have developed a nuanced understanding of climate change-related threats, driven by their long-standing experience-based knowledge. In the next sub-sections, how local inhabitants utilize their traditional knowledge to perceive and recognize these changes will be explored. The data was mostly collected through semi-structured HH interviews and FGD and was further validated by in-depth observations. The data will be cross checked with a community map (see appendix 5). Based on natural indicators,

comparative analysis of climate-induced events, and socio-economic impacts, the key threats will be identified, which is crucial for developing resident driven housing transformation.

4.3.1 Natural indicators & contradictions

The local inhabitants of a specific region depend on many indicators along with natural cues to recognize climate hazards (see table 3). They pass on this knowledge from one generation to the next and refine it based on their current experiences. This ability to effectively guide the process of adapting to climate change is regarded as the primary advantage of traditional knowledge in addressing such issues. Residents usually depend on environmental cues like wind and cloud patterns, changes in animal behavior, and atmospheric conditions to predict any upcoming weather events, but in this case, only those who are older are mostly capable of this. According to the HH interview, only individuals over the age of 45 (40%) responded that they still rely on natural cues to recognize weather patterns, while the remaining individuals (60%) are not significantly reliant on such cues. Respondents think in an informal settlement like the Greenland slum within dense urban area, biodiversity is scarce, and the dense settlement creates a barrier between nature and life could be the reason behind that. In addition, there have been changes in the usual weather pattern, which is another important element that hinders the use of natural indicators as an early warning system, as observed by the elders and mentioned in the FGD. It is clear from the response that the HH situated near the waterbody are more capable of identifying changes and predicting weather based on nature than the HH located by the road (see figure 7). The significance of this is also evident in the table, where the code "Traditional weather pattern" has a coefficient of 0.19 (See table 1). As one of the respondents (70 years, HI-4) say, *"...The environment is not remaining the same as before, I could tell when the storm or rain will arrive and possibly how long it will sustain, I could tell before, but now it is become difficult to predict... It becomes so unpredictable..."*

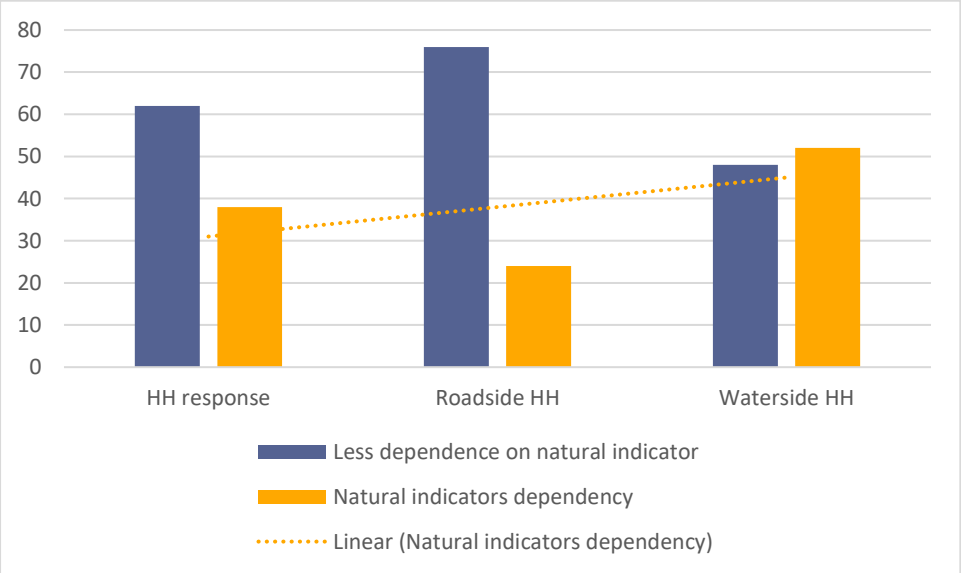


Figure 7: Location wise nature as a medium of weather pattern indication (Source: survey, 2024).

According to the respondents that rely on natural cues (40%), they believe that the presence of remaining trees is currently the most important indicator. The code co-occurrence table (See table 1) clearly indicates that the codes "Loss of natural indicators" and "Natural indicators observation" have the greatest coefficients of 0.25 and 0.19 respectively, occurring concurrently. Most of the residents recall that when there were so many trees, the area did not feel as heated as it does right now because it provided shade and natural cooling. They still recognize this loss of trees as a key indicator of temperature rise, and they identified it as the change in color of the leaves as they faded, the comfort of being outdoors under these trees,

the sound of the leaves moving, and the movement of trees during the storm. That helps them identify when it is the right time to take shelter or leave the house during a storm. In the FGD participants mentioned how these loss makes them understand how environmental change impacts their lives, especially by increasing heat stress and wind shear during storms. The table reflects the "intergenerational knowledge transfer" coefficient of 0.17, which indicates that individuals can understand and predict current weather conditions based on their daily activities and surroundings, such as being near a waterbody, outdoors, indoors, or under a tree.

As one of the respondents (42 years, HI-14) say, *"...Now I have to sit near the water or under the tree all the day. Otherwise, what could we do, this is unbearable hot..."*. Even during a storm, what are they going to do, like seek refuge under the bed, tie up the loose bonds, measure the intensity of the shaking of the house, pump out the amount of water from the house, and repairing cost, this will also help them understand the intensity of the storm and they learned it over the years, a knowledge passed down through generations. Moreover, they use the costs of rebuilding and maintaining their houses as a benchmark for disasters, regardless of the cause. They typically apply this learning when anticipating weather events, which, as they noted, are becoming increasingly frequent. Besides that, the rising number of illnesses and diseases, such as seasonal fever and flu attacks, among children and the elderly, the rise of heatstroke, and vector-borne disease, are other indicators of a shift in temperature, rapid weather, and environmental change. They continue to view this as a cue for seasonal transition, noting its frequent and unpredictable occurrence. However, their growing reliance on media, news, and TV indicates a reduced ability to independently anticipate the weather, as evidenced by a coefficient of 0.22 in the code "Reliance of media for information." (See table)

Table 3: Code Co-occurrence within subcodes for weather pattern indicator (Source: survey, 2024).

	● CC-1: Weather pattern indicators Gr=32	
	count	coefficient
Loss of natural indicators Gr=8	8	0,25
Loss of traditional prediction skills Gr=1	1	0,03
Reliance on media for information Gr=7	7	0,22
Community-based preparedness Gr=3	3	0,09
Intergenerational knowledge transfer Gr=3	5	0,17
Natural indicators observation Gr=5	6	0,19
Traditional weather prediction Gr=5	6	0,19

The decreased reliance on natural indicators is evident from the response of local residents, although they are aware of its significance, and it is not lost. The current situation may not be sufficient to alert them in advance. They can only be informed about upcoming or ongoing events mostly based on experience they gathered by intergenerational skill. Being prepared for a disaster early is very important for them because stocking up food and money and reinforcing the weakest part of the house is very important to reduce different kinds of resource losses

repeatedly mentioned in the FGD. Whether the codes related to dependency on natural indicator is comparatively more grounded against the loss of natural indicator in FGD rather than HH interviews signifies its importance. This is because, this traditional weather reading skill helps them fight back damage and increase safety, especially for those who are most vulnerable. As one of the respondents (34 years, HI-9) say, *"...If we understand a little in advance that the storm will come, it is easier for us to be prepared. And if not, then the problem, how the storm reverses we don't know..."*

4.3.2 Climate induced hazards and their evolution

Over time, there has been a substantial alteration in the global weather pattern, and the inhabitants of the Greenland slum acknowledge the intricate and dynamic nature of these severe weather occurrences. The identified risks from the literature review are of special concern due to their multidimensional nature, presenting various challenges at different periods, and their ongoing evolution. They interpret the current weather phenomena as a typical event, drawing from their personal experiences and comparing it to prior climate occurrences both in interview and FGD (see table 4). During the interview, respondents were asked about their personal experiences with incidents that occurred at various times during the past 25 years. They were asked to determine the magnitudes of these events based on their intensity and frequency and then it is visualized in the figure 8. Based on that experience, it is clear that heat stress and storms currently pose the most significant climatic threat to them. In contrast, during the start of the 2000s, rainfall and flooding were the primary threats. Analysis of the FGD reveals that there is a pressing need for rainfall to alleviate heat stress. However, there is currently a shortage of rainfall, which exacerbates the problem and leads to the occurrence of intense storms after periods of heat stress. Whether based on location, waterside HH face soil erosion related problems severely. The subsequent sections will elucidate the increasing unpredictability, intensity, and frequency of various climate hazards within the evolving urban informal setting of Greenland slum, as well as how these hazards are experienced by the local residents.

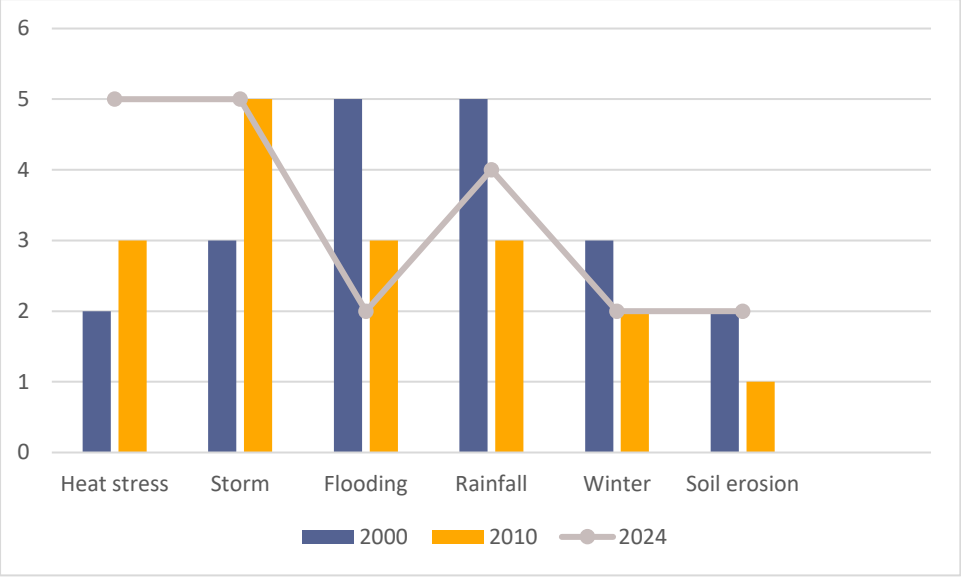


Figure 8: Frequency of extreme weather event over time (Source: survey, 2024).

Heatwaves: Among all the climate-related threats, heatwaves and extreme temperatures are considered the most critical issues for the dwellers of the Greenland slum nowadays (see table 5). During the HH interview, around 47.54% of the discussion focused on heat realted issues, including the significant increase in extended heat stress and high temperature spikes in recent

years. In the FGD, covers 20.83% of the content, making it the second most important climate concern in the conversation (See table). People frequently use the terms 'unbearable' and 'intolerable' to describe their experiences with heat-related issues, and they have never experienced such extreme temperatures in their lives. During the peak hours of the day, most people couldn't stay in the house; even they couldn't get comfortable by using a fan, and they also became sick due to this extreme heat. And even changing the pattern of living with heat can't save them anymore. As one of the respondents (38 years, HI-7) states, *"...Previously, I used to cook during the day, but now I cook at night due to the heat, but I don't receive any relief from the heat. Even at night, the inside of the house remains as hot as during the day, and during the day, we find no comfort anywhere in this settlement..."* When there were trees, providing shade and cooler air helped reduce the heat effect. However, due to the need for housing and infrastructure expansion, extensively cutting down trees significantly damages the natural cooling effect and exacerbates heat-related problems. As one of the respondents (48 years old, HI-3) states, "*...The temperature rises significantly. The rising temperature is causing numerous issues. It was not like this before. The clearing of all the trees must have caused this. We can't tolerate it anymore..."* As with him, so many of them reported that the recent summer was exceptionally difficult to endure. Not only that, but most of them also become dehydrated, and the elderly face heatstroke-related health issues. This increase in heat-related illnesses, along with the need to use additional fans and seek shade, provides further evidence of the severity of heatwaves and extreme temperatures. It is evident from this discussion that heat waves have a substantial influence on the indoor living environment, perhaps resulting in unpredictable health problems.

Table 4:Climate threat perception in FGD & HH Interview (Source: survey, 2024).

	FGD Gr=126; GS=2	**Household Interview** Gr=750; GS=10
• **Flooding events** Gr=10	4,17%	5,74%
• **Heat stress recognition** Gr=68	20,83%	47,54%
• **Rainfall pattern shifts** Gr=17	16,67%	9,84%
• **Soil erosion** Gr=6	0,00%	4,92%
• **Storm intensity changes** Gr=50	58,33%	27,87%
• **Winter duration reduction** Gr=6	0,00%	4,10%

Storms: Residents of the Greenland slum observed a significant increase in frequency and intensity of storms, characterized by a stronger gust of wind than rainfall (see table 5). During the HH interview, around 27.87% of the content was dedicated to discussing matters pertaining to storms and winds. In the FGD, this percentage increased to 58.33%, indicating that it was the most prominent topic of discussion (See table). Storms were always present, but their nature and impact grew increasingly devastating. Due to the strong wind gusts and the use of lightweight and less durable housing materials, the risk has increased multiple times. As one of the respondents (42 years old, HI-11) states, "*...I have seen storms before, but they were not as strong as now. It was raining before, but not so windy. Now, the wind is strong, and if it persists for a bit longer, the house will undoubtedly collapse..."* Strong gusts from the storm

often cause a house to collapse or the roof to blow away. This motivates them to find more safety and stability in housing solutions than anything else. Furthermore, the provision of a smaller number of openings increases the impact of wind on surfaces, highlighting the shortcomings of residents' adaptive measures even with this knowledge. The physical damage to the houses that requires repair and the increase in this kind of activity make it evident that the storms have become more powerful. It is also evident from this discussion that storms are the primary cause of damage to the dwelling units.

Rainfall patterns: Residents of the Greenland slum observed a significant change in rainfall patterns, characterized by shorter rainfall sessions, unpredictable rainfall timing, and a mismatch between actual and expected raining periods (see table 5). Approximately 9.84% of the HH interview content focused on the topic of rainfall. Within the FGD, the figure rose to 16.67%, suggesting that it was a more prevalent subject of conversation at the general level compared to the household level. The pattern has undergone a complete transformation, becoming less predictable. Since it no longer follows the traditional pattern, the shorter periods of rain lead to droughts, and subsequent rains result in flooding. As one of the respondents (44 years old, HI-12) states, "*...It doesn't rain when it needs to, and when it does, it pours...*" According to the respondents, flooding is no longer a problem due to infrastructural development, such as the construction of permanent pedestrian roads and drainage systems connected to waterbodies and raised plinths. However, the unpredictable nature of rainfall still poses problems, such as shorter periods of water logging in certain areas and damage to households. This creates a significant amount of unpredictability, which in turn affects the preparation of households to deal with water-related challenges. Based on the discussion, it is evident that rainfall significantly influences the decision-making process regarding the re/construction of housing units due to its unpredictable nature and the resulting problems such as water logging, soil erosion, and structural damage.

Table 5:Code Co-occurrence within subcodes for identifying climate induced hazards (Source: survey, 2024).

	• CC-2: Climate threat perception Gr=164	
	count	coefficient
• Heat stress recognition Gr=68	80	0,53
• Rainfall pattern shifts Gr=17	25	0,16
• Seasonal unpredictability Gr=9	21	0,14
• Soil erosion Gr=6	7	0,04
• Storm intensity changes Gr=50	58	0,37
• Winter duration reduction Gr=6	8	0,05

Other climatic challenges:

In addition to these issues, residents have also identified shorter winters and soil erosion issues. The shorter and less intense winter presents fewer challenges than the increasing summer heat. Conversely, dwellings positioned adjacent to the waterbody have seen disparate effects of soil erosion, posing difficulties in maintaining a satisfactory standard of living within the same

community. Both of these shifts are not that big departures from the past, but their current impact is somewhat less noticeable. Based on this comprehensive discussion, it is clear that the residents are conscious of the rapidly changing climate, and they have recognized heatwaves as the foremost issue for residing here, with a coefficient of 0.53 among the subcodes. Following that, there is a rise in storm intensity with a coefficient of 0.37 have the considerable impact. These two poses substantial threat to their life in Greenland slum compared to other events. Furthermore, they acknowledge that the lack of a seamless seasonal transition leads to an abrupt change from one climatic state to another, thus entirely interrupting their typical preparations that are dependent on the subcode co-efficient of 0.14. These changes significantly affect the daily life, health, and physical infrastructure of the Greenland slum. They typically implement specific adaption measures based on this perspective of intensification of weather events and increased unpredictability.

4.3.3 Identified impact of changing weather pattern

The altered weather pattern has a significant impact on the daily lives of residents of the Greenland slum because it increases the frequency and changes the regular pattern of climate hazards. It has an impact on physical, social, economic, and environmental aspects. However, the impacts have distinct meanings in FGD and HH interviews. In the context of FGD, the focus is primarily on assessing the physical and economic impact (See table 6). In the responses obtained from household interviews, both aspects are given equal priority. However, the environmental issue is given greater priority. In the following sub-sections, it will be identified which impacts drive residents to take adaptation measures as they are related to their living conditions and well-being.

Table 6: Content density of Climate threat impacts in FGD & HH Interview (Source: survey, 2024).

	FGD Gr=137; GS=2	**Household Interview** Gr=776; GS=10
• **Daily life activities disruptions** Gr=3	2,13%	1,52%
• **Economic consequences** Gr=44	27,66%	23,49%
• **Environmental degradation** Gr=43	12,77%	25,00%
• **Health issues** Gr=32	6,38%	21,97%
• **Physical damage** Gr=52	42,55%	23,49%
• **Social segregation** Gr=11	8,51%	4,54%

Physical impacts: In order to maintain habitable conditions in the Greenland slum, residents have to face severe challenges such as extreme heat, storms, and occasional unanticipated rainfall leading to flooding. The FGD covers 42.55% of its content on the topic of physical damage resulting from climate events, which is the most prominent consequence. In contrast, the HH interview focuses on physical damage as the second most significant impact of climatic conditions, accounting for 23.49% of the discussion. Residents of the Greenland slum, particularly those with tin roofs that potentially trap heat inside the house, report experiencing unbearable temperatures inside their homes during the summer, a situation further exacerbated

by their living conditions. This makes it difficult for them to stay inside the house during peak hours of the day and even after sunset, increasing their dependency on using fans, raising their electricity costs, and modifying their daily activities to avoid heat stress. As one of the respondents (48 years old, HI-3) states, *"...It is difficult to stay indoors during the day, even at night, because it seems to be made of tin. That's why the interior appears to retain more heat..."* Apart from that, the flooding issue is now resolved to some extent, but it had a severe impact on their memory during the waterlogged time, and they still remain prepared. But the stronger wind gusts of the storm are now the real challenge. They report substantial damage to the structure, roof, and veranda, necessitating constant inspection and reinforcement of various parts of the houses during and after the storm. Additionally, some residents carry traumatic memories from previous storms, which continue to influence them during subsequent climate hazards. Occasionally, the house collapses or the roofs blow away, forcing the residents to seek shelter under their beds. As one of the respondents (70 years old, HI-4) states, *"...during the storm called 'Mohasen', part of our house was blown away; we were lucky that we found some part of it later, but we were under the open sky for 2-3 days..."* In addition, sporadic downpours occasionally inundated their homes, causing structural damage, despite not taking adequate precautions when building with tin. This is essential since the main cause of housing transformation depends on the tangible damage caused by storms and flooding, which have the most noticeable influence on the house.

Non-physical impacts: Residents in Greenland Slum are currently experiencing a higher occurrence of health issues, which is not typically normal stated by the respondents. During HH interviews, 21.97% of the content focuses on health-related problems, which clearly demonstrates a substantial and thought-provoking impact. However, this issue was not emphasized significantly throughout the FGD, as it only accounted for 6.38% of the material. The rise in heat-related illnesses such as fever and heatstroke, along with a potentially higher mortality rate, particularly in children and the elderly, has led to a common occurrence of year-round flu and fever. Some of the respondents mention their poor housing conditions, which could exacerbate this climate-related illness. One of the respondents (48 years old, HI-3) states, *"...Look at the inside of our house; how can we stay healthy in this type of house? It's hot inside and outside, there's no airflow, and illness is present throughout the year among us..."* Along with health issues, they also suffer psychological strains, like their house could be damaged, and how could they handle this or the next storm, which would be similar or heavier compared to their previous trauma. All of these factors indicate that climate change contributes to health-related problems. However, inhabitants tend to attribute their health issues solely to housing conditions, rather than recognizing the broader impact of climate change on their well-being.

Social impact: The residents of the Greenland slum face difficulties in individually addressing the complex challenges presented by the shifting weather patterns. They are also apprehensive about the escalating social problems associated with these changes. Both the FGD and HH interviews contain somewhat lower amounts of content that indicate a socially separated scenario. The content coverage in FGD is 8.51% and in the household interview it is 4.54% only. They believe they need to form strong community bonds and pool their knowledge to tackle problems together, as they did during the flooding crisis and road construction, which they found to be somewhat successful is also evidential by this lower level of content's presence. But ongoing resource scarcity and stress lead to conflict and social tension. One of the respondents (39 years old, HI-16) states, *"...We understand that this problem must be solved together. However, we cannot reach a consensus when it comes to making decisions collectively, as we all lack the necessary skills..."* The respondents clearly identified this as

representing unstable social dynamics in informal settlements because they have to prioritize personal survival and repair efforts over social activities.

Economic impact: The primary consequence of climate change on the residents of Greenland Slum is the significant economic burden resulting from increased housing expenses and energy use. The predominant focus of both the FGD and HH interviews is on economic difficulties caused by climate change. The percentage of concern in FGD is 27.66%, whereas in the HH interview it is 23.49%, making it the second largest concern. Due to frequent weather-induced events like storms with strong gusts, wind necessitates frequent repairs and reinforcements of houses, increasing housing maintenance costs. Moreover, the heat stress pushes residents to increase their use of electricity to take cooling measures, resulting in higher utility bills. This has placed a significant strain on their household budget. Because most of their housing transformation-related decisions revolve around this economic issue, the respondents identify it as vital. One of the respondents (41 years old, HI-5) states, *"...All our decisions depend on money; there is no money to manage food, and meanwhile we can't stand up for frequent disasters..."* From those statements, the link between climatic change and the prolongation of suffering is evident, as it leads to financial instability and exacerbates the influence on decision-making on housing transformation.

Environmental impact: The exponential expansion of Greenland slum has resulted in a precarious living situation for its inhabitants considering climate change. During the interviews, respondents repeatedly discussed nostalgic scenarios and around 25% of the content focused on environmental issues, which is highest. Conversely, in FGD, it encompasses 12.77% of the content, as the general environment is much enhanced through the construction of roads throughout the settlement. Over the years, the settlement's growth has led to the removal of numerous trees, exacerbating heat-related problems and altering the local microclimate. Previously, these trees offered shade and aided in natural cooling. So, the loss of green made the environment hot and less resilient to climate-induced hazards like heat stress and gust wind. Furthermore, those who live near waterbodies may get some relief from the heat, but it makes them vulnerable to wind gusts, storms, and soil erosion. Changing rainfall patterns also cause them to suffer from drought and sudden floods. The deforestation process and increasing hard surfaces have worsened all these difficulties, making the population more vulnerable to extreme weather events.

Summary of impact: The residents of the Greenland slum find all this challenging because the weather patterns change substantially and do not remain reliable. The inherent unpredictability, coupled with the occurrence of severe weather events, profoundly affects all facets of their existence, whether it the formulation of pivotal choices or the management of consequential aftermaths (see table 7). Based on the sub code co-occurrence analysis, it is evident that the primary issue provided by climatic risks is physical damage. This concern is highlighted in the table with the highest coefficient of 0.36. In addition, extreme weather events result in economic effects and environmental deterioration, with both exhibiting a coefficient of 0.30. The coefficient of 0.21 for health issues indicates its significant importance. Based on the impacts, it is evident that intensified storms create these impacts mostly in Greenland slum and compelling residents to implement adaptive measures for their living spaces and adjust their daily routines. In addition, the problem of severe heat is disregarded, despite being identified by the health concern indicator. However, by direct response, it has been determined that health issues are well recognized in houses located along roadsides. Whether households located near waterbodies are more concerned about the economic consequences (see figure 9). However, Physical damage is the predominant factor in both cases which highlight the urgent

issues need to re-assess their housing solutions to be climate resilient and reduce damage along with maintenance cost.

Table 7:Code Co-occurrence within subcodes for climate threat impacts (Source: survey, 2024).

	• CC-3: Climate hazard impacts Gr=183	
	count	coefficient
• Economic consequences Gr=44	53	0,30
• Environmental degradation Gr=43	52	0,30
• Health issues Gr=32	38	0,21
• Physical damage Gr=52	62	0,36
• Social segregation Gr=11	11	0,06

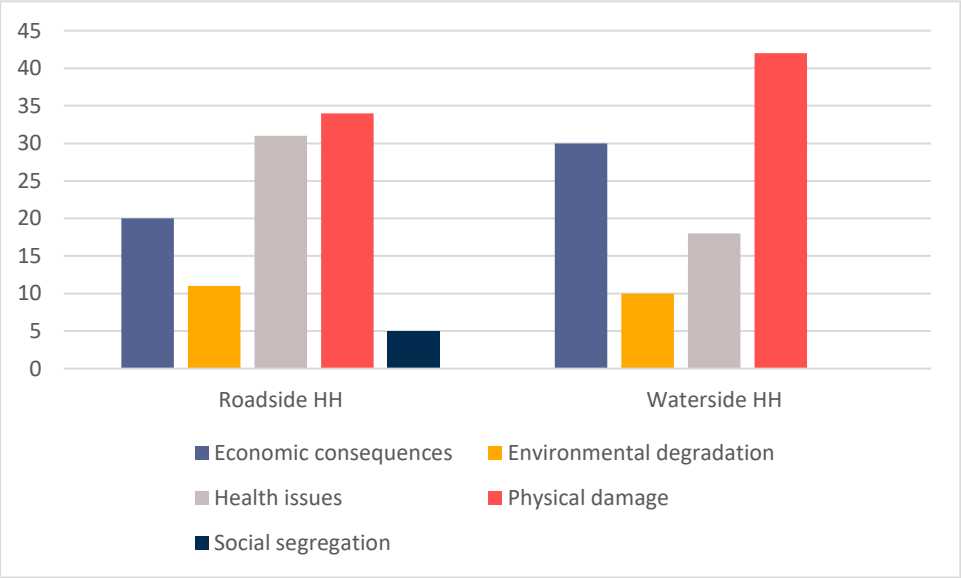


Figure 9: Location wise variation of climate change impact (Source: Survey, 2024)

4.3.4 Implications of the climate change perception:

The analysis indicates that the people of Greenland slum are aware of the climate threat. They judge the impact of the threat based on its frequency and intensity, rather than predicting events in advance. This is clearly shown in the Sankey diagram (see figure 10). It is clear that the storm is the most important climate event for them, regardless of whether they consider heat stress or rainfall problems. Despite the fact that natural indicators still exhibit a significant link with the indication of storms (0.05) and particularly rainfall (0.10). The association between heat stress and natural indicators is low, with a value of 0.04. The low correlation coefficient of 0.02 between storm strength and less reliance on natural indications suggests a significant degree of unpredictability in storms. The diagram shows a significant association between storm severity and physical damage, with a value of 0.29. The correlation coefficient between health issues and heat stress is 0.12, which ranks as the second highest. In contrast, the correlation coefficient between heat stress and environmental degradation is 0.09, whether they

identified environment play vital role in heat mitigation during summer. Rainfall also has the co-relation with physical damage (0.10). The connection coefficient between storm intensity and financial consequences is 0.08, whereas the correlation coefficient between storm intensity and health issues is 0.05. The residents of informal settlements are profoundly concerned about the physical and economic consequences of incidents, and they possess a keen understanding of the enduring consequences of these events on surrounding environment. Nevertheless, in recent years, health and environmental problems have become as significant in addition to physical and economic challenges. Physical harm and health difficulties are crucial factors in this case. The correlation presented here illustrates the complex and diverse issues that helps to develop perception based on the weather events experienced by the residents in Greenland slum.

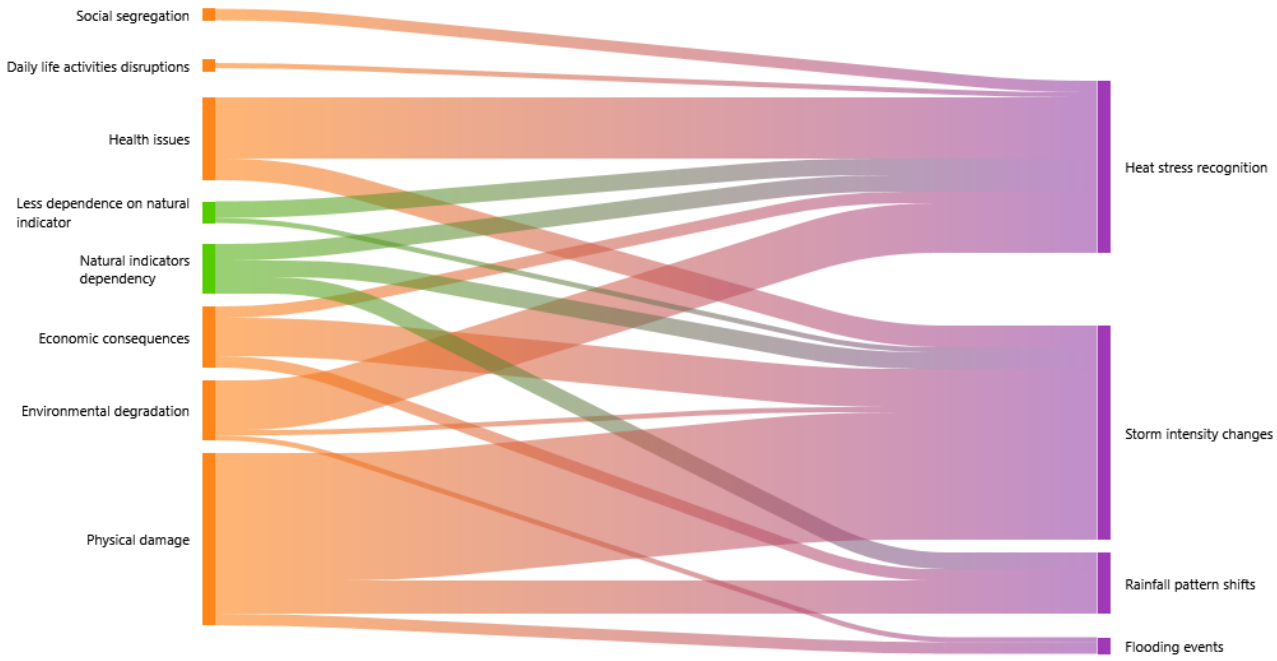


Figure 10: Sankey diagram of climate change perception (Source: survey, 2024: See appendix 4 for values).

Based on this perception, in the next section, the adaptive measures that have been taken by the residents are going to be assessed to what extent they are taken based on this perception and how much they are aligned with their LK. And it is evident that heat stress and storms with gusts of wind are the most pressing concerns right now, which is also evident in their LK-based perception having numerous types of impact that requires immediate action.

4.4 Resident-driven housing adaptation from LK perspective

In the Greenland slum, residents frequently transform their housing based on numerous understandings and needs. As a part of informal settlements, these solutions are most of the time driven by scarcity. In informal settlements, residents typically use their local knowledge of materials and construction methods, as well as their unique context-specific experiences, to adapt their dwelling to improve its liveability and functionality (Chaudhari et al, 2012; Roy et al., 2018). The adaptation approach also follows a similar pattern in Greenland Slum. The following sub-sections will discuss the changes made to the dwellings, the challenges faced during implementation, and the role of local knowledge behind all this. The data is mostly gathered through in-depth observation and semi-structured HH interviews and is further

confirmed by FGD. Based on this discussion, we can gain valuable insight into how traditional knowledge guides housing transformation with extreme resource constraints, especially in the Greenland slum. Obstacles and innovation will both be highlighted.

4.4.1 Changes towards adaptation

In response to the increasing climate threats posed by climate change, residents of the Greenland slum have taken multiple measures to adapt their dwellings. Residents' perception and application of LK heavily influence these adaptations. We observe significant alterations to the structure, plinth, opening, and roof, primarily aimed at enhancing flood resilience and fortifying the structure as proactive measures to lower the overall expenses associated with housing maintenance. Some kind of innovation is also observed here.

Figure 11: Plinth modification mapping (Source: survey, 2024).

4.4.1.1 Physical adaption

Plinth modification: This is one of the most critical adaptation strategies because it is the lowest and most structural part of the house, making it difficult to improve with the addition of new structures above it. Nevertheless, in-depth observation reveals that every household consistently raise their plinths numerous times to safeguard against water infiltration during floods and intense rainfall with taking multiple actions (see figure 11). Approximately 75% of households have replaced their mud plinths with cement concrete to improve their resistance to flooding and erosion, so ensuring long-lasting durability. One of the respondents (39 years old, HI-16) states, *"...If there is flooding, we have to remain safe; we don't want our mud*

(plinth) to float away, and we also don't want to drown under the water. If something happens like that, everything will be spoiled..." As they have limited capacity, they made the concrete from different kinds of waste brick chips and loose cement that they bought from second-hand markets. If the plinth is still constructed with mud, then during the rainy season, it is necessary to apply a layer of mud and loose cement mixture over mud. This is apparent in 25% of the dwellings. Alternatively, the plinth can be covered with polythene, which has been observed in 31% of the houses' bases whether 6% are made of cement concrete. For further development, they now secure the structural part of the house with a clamp. This allows them to easily adjust the height in the future, ensuring the safety of that part of the house. They also have to put multiple barriers in between the layers with the same or different heights of plinth to remain safe from being flooded which is evident in 38% houses. Even those houses that are located next to the waterbody have plantations to save the edge and plinth from being erased by running water. When the condition gets worse, they have to apply a retention wall with bamboo, timber, or brick. All the methods prioritize their objective to guarantee resilience in the event of a flood, ultimately leading to improved living conditions.

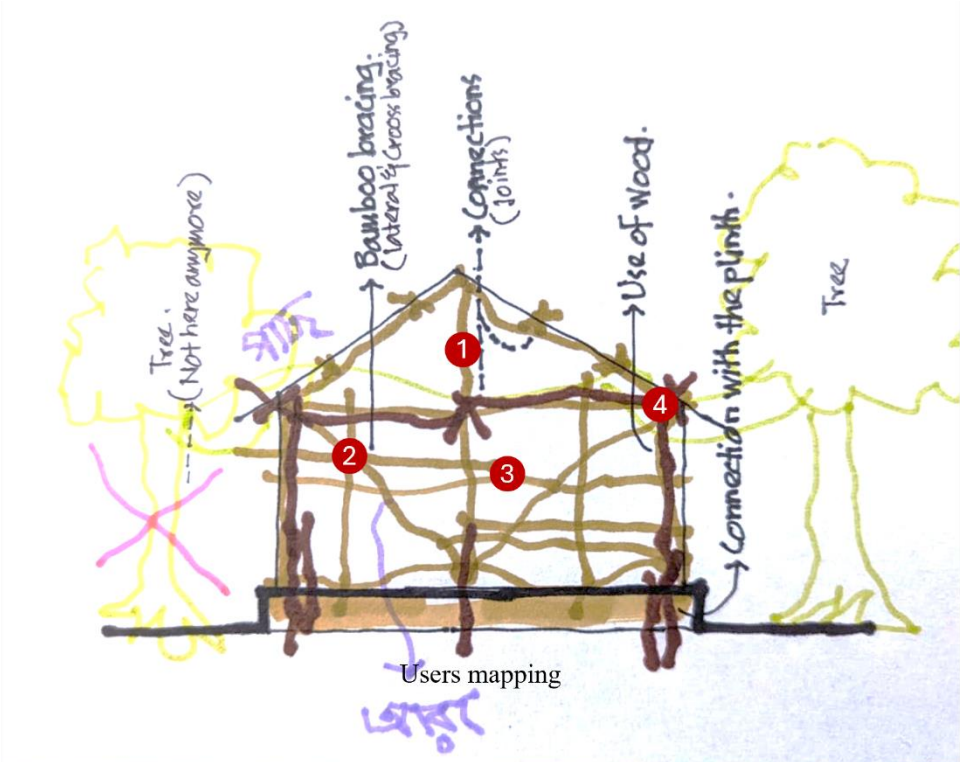


Figure 12: Structure modification mapping (Source: survey, 2024).

Structural modification: The most evident shift is observed in material choice in terms of structural stability in Greenland slum. In recent years, most of the residents have converted their houses from ‘Golpata’ and ‘Bamboo’ to more durable options like corrugated iron sheet

(CI), mainly for roofing and peripheral walls with wooden post on permanent plinth (see figure 12). The roof of the houses is composed of 94% with CI sheet and 6% cement sheet, which are combined in composite structures along with CI sheet. Regarding the exterior, 75% of houses exclusively utilize CI sheet, while 19% are constructed with bamboo and wooden plank, and the remaining 6% incorporate a little quantity of brick. The primary reason for this change is their preference for long-term durability over initial cost, although initial capacity is still a factor. One of the respondents (38 years old, HI-7) states, *"...Tin is very durable, has a long life, has a low maintenance cost, and we get a high level of benefits. So why not use it...?"* For structural support, they prefer timber posts over traditional bamboo posts due to their better durability, longevity, and resistance against insects like beetles. Based on the observation, wood is present as a fundamental structural element in 88% of houses. Additionally, in 81% of houses, bamboo is also observed, which partially supports the timber posts. Currently, 70% of houses have composite structures, which incorporate materials such as wood and bamboo, as well as metal bars and brick, as structural components. This is a significant change, though it is more expensive. One of the respondents (41 years old, HI-5) states, *"...If it is made with bamboo, then it will last for 5–6 years at best; it is easily damaged by bite beetles, but now we hope it will last for at least 12–13 years as it is made of wood..."* This sturdy wooden structure securely fastens the roof to withstand storms. The transformation of dwellings in the Greenland slum has involved a shift from using traditional and less permanent building materials to more resilient ones, which offer a combination of permanence and portability to some level.

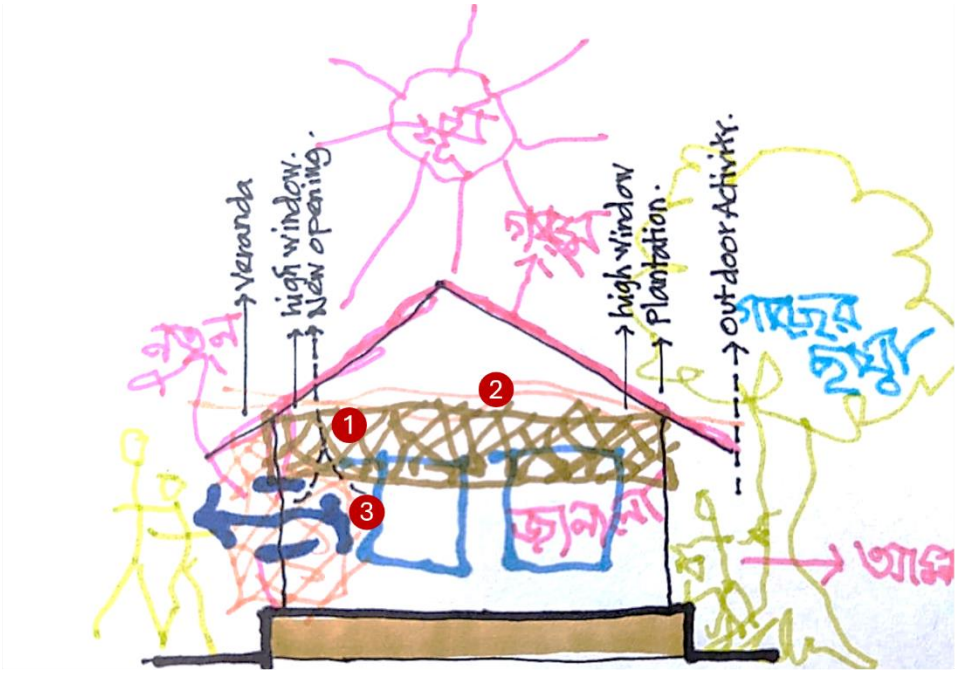
Users mapping

Figure 13: Roof modification mapping (Source: survey, 2024).

Roof modification: The roof plays a crucial role in the adaptation process here, as most houses prioritize durability over thermal comfort by taking numerous initiatives (see figure 13).

Nowadays, most houses (94%) have tin-made roofs due to their durability and low maintenance, while reports suggest that organic roofing materials such as golpata-made roofs offer greater thermal comfort but necessitate extensive upkeep. This requires expensive initial investments but provides greater resistance to storms and heavy rain. Following the installation of tin-made roofs, approximately 50% of households choose to apply a false ceiling. This serves as a barrier between the roof and the residents, achieved by adding an extra layer made of plastic sheeting, polythene, and often old cloths known as 'Chandina'. Additionally, 31% of residents utilize this space for storage purposes due to the excessive indoor heat caused by the CI sheets. One of the respondents (38 years old, HI-7) states, *"...If we don't apply the 'Chandina' beneath the roof, then we couldn't sustain this hot summer here in this house..."* In addition, 36% of the respondents indicate that they periodically utilize climbing plants on their roofs to provide shade, thereby helping to maintain a cool temperature. Leafy vegetables are preferred as they grow quickly and also serve as food**.** This helps them create a more stable indoor temperature. According to 12% of the respondents, in order to maintain the temperature, they occasionally need to keep the 'Çhandina' moist. Occasionally, it becomes necessary to modify the location and alignment of the roof in order to prevent rainwater from seeping into neighboring houses. To address this issue, a gutter is installed to collect the water, a practice observed in 38% of households. They sometimes added an overhead transparent sheet (6%) to reduce the darkness of the house, which also helped reduce the utility bill. Based on the findings, it is clear that residents prioritize durability over thermal comfort when choosing roof materials. This factor influences to rethink their decision-making process on addressing heat-related problems.

Ventilation strategies: To battle extreme heat, residents have taken some innovative solutions sporadically (see figure 14). These solutions are not generally found. Strategically positioning windows in informal settlements is a vital adjustment to optimize airflow and reduce the effects of severe winds. This is particularly important because there is limited space for making such alterations, as noted by 40% of the respondents. One of the respondents (42 years old, HI-14) states, *"...We know the wind comes from the east, but we could not make it large enough because during the storm it will blow all the things we have here; even the whole house could be blown away..."* it is observed in 25% households, an aperture at the upper section of the wall, akin to a tall window, to prevent rainwater from penetrating and maintain their privacy in a tin-built house, while simultaneously aiding in the escape of hot air and the intake of fresh air. In 25% dwellings, residents convert their front wall into a perforated bamboo slit-made wall, especially for the veranda portion, ensuring improved ventilation and light without compromising structural integrity. This kind of space offers multipurpose use and better social integrity, leading to functional transformation. In 6% of households, an extra layer of bamboo 'Chatai' (mat) is used on the interior side of the wall for insulation purposes. In 19% of cases, a composite wall is constructed using tin, bamboo slits, and wood planks. The wooden parts are strategically placed at the base of the wall to prevent scratches or at the top to facilitate ventilation. Residents, despite limited space, demonstrate ingenuity in addressing heat-related issues.



Users mapping

Figure 14: Facade modification for ventilation (Source: survey, 2024).

Disaster preparedness: Residents of Greenland Slum consistently prioritize avoiding unnecessary expenses related to house maintenance. Additionally, they proactively take precautionary actions in response to potential weather occurrences, a practice that applies to all residents according to their individual capabilities (see figure 15). Their past experience and collective knowledge, primarily acquired through trial-and-error, fully inform this approach. 94% of the participants surveyed inspect the joints and vulnerable parts of the building, assuring structural integrity by coupling them together or reinforcing the weaker segment with a stronger component. A quarter of the participants secure their roofs with putting extra weights on them to prevent from being blown away. Even after the storm, they repaired it quickly to prevent further deterioration. For long-term preparation, raise the plinth with permanent material and use durable materials like timber and CI sheet. They implemented preventive measures by consulting with community elders about the possible outcomes. The responders

demonstrate a proactive and cost-effective strategy through their resourcefulness, coordination, and implementation of preventive steps to adapt to extreme weather events.

Figure 15: Local way of disaster preparedness (Source: survey, 2024).

4.4.1.2 Non-physical adaption:

Financial strategies: Financial strategies have a crucial role in transforming households in various dimensions which is directly connected with HH income and expenditure. There are 4 types of financial composition found which are use personal savings (PS), PS with loan, Ps with debt and composite (utilize all methods) (see figure 16). About the adaptation, 63% respondent usually doesn't have any emergency funds, but they deposit money for a long time if they have any plans about changing the dwelling and most of the repair works depend on this emergency fund. This constraint significantly influences their adaptation strategies, leading them to adopt coping mechanisms that take into account local circumstances. This gradual savings allows them to upgrade their house incrementally. 75% of the residents, over long periods of time, save money little by little to construct a new house, but most of the time they have to spend that money on repeated repairs due to unexpected weather events. Those who have no savings have to rely on a community cooperative loan to repair their house, what is mostly adopted by waterside HH as well they show less debt dependency could indicate lower social cohesion among them. Which has a long-term impact on their financial condition. Whether roadside HH mostly dependent on their savings. However, despite amassing a substantial sum of money, 44% of respondents opt to take out a loan in order to expedite the building or repair process and mitigate any further uncertainties. One of the respondents (52 years old, HI-13) states, *"...We would not have taken the loan if we could; now what if we eat and drink or not? We have to repay the installments..."* This repayment creates absurd pressure on their usual daily lives. Despite the potential burden, they choose to handle the repair tasks themselves. One of the respondents (48 years old, HI-3) states, *"...Using labor for any repair task is costly; why should I pay them when I can do the task? I am not that old that I can't do that..."* But after all, any kind of housing cost puts significant stress and pressure on their economic condition. Overall, residents demonstrate remarkable resilience in managing challenges despite low financial resources, while this hampers their potential to establish a more secure and improved living environment in the long term.

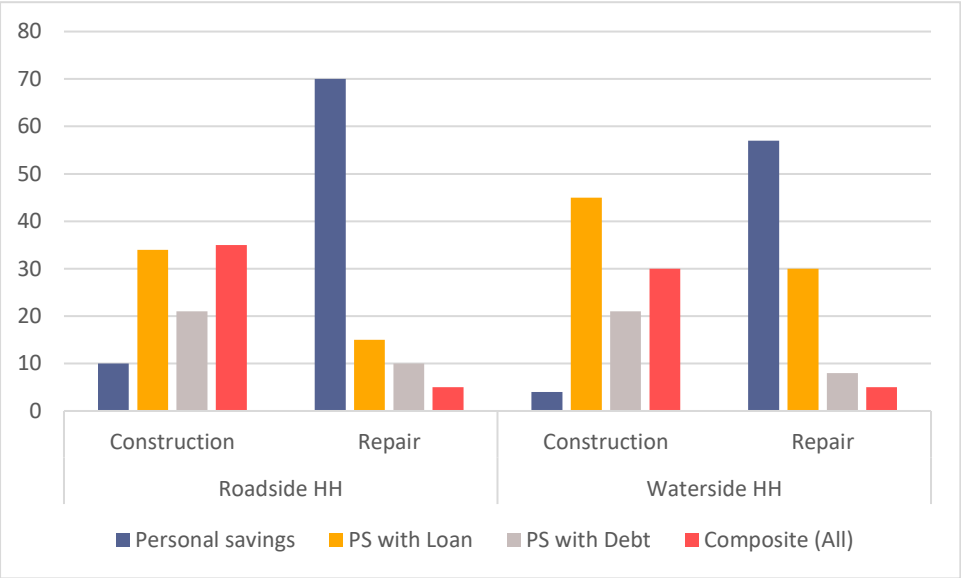


Figure 16: Local financial management composition (Source: survey, 2024).

Labor consideration: Labor plays a crucial role during housing adaptation because, in informal settlements, necessity, skill, and financial capacity primarily determine the use of labor. Whether through self-help or by hiring labor and seeking assistance from the community, they always collaborate and work together (see figure 17). In the Greenland slum, people are compelled by financial limitations to undertake the majority of the tasks they have on their own resulting in around 25% of dwellings being entirely self-built. When it comes to repairing or maintaining something, 48% of respondents indicated that they do it themselves. One of the respondents (48 years old, HI-3) states, *"...We don't have money to eat; how could we spend money behind masons? If we save that money, then we could invest it somewhere else. As much as possible, we do it ourselves..."* Necessity drives them to be skilled in most of the construction tasks, as they have to do them themselves. Despite the utilization of labor in the rest of 60% households, it is necessary for them to be on the premises to oversee and maintain control over the work's quality. According to the response obtained, it is mandatory for at least one of them to be present during the labor's operation. Furthermore, by providing assistance, they aim to expedite task completion and reduce costs which is reported by 94% respondents. One of the respondents (34 years old, HI-9) states, *"...If we don't present there, then they unnecessarily elongate the task and demand more money..."* Most of the time, when they construct the whole house, labor is required, but for repairs, they usually don't use labor. In the waterside HH, labor dependency is seen more, whether in roadside HH community help dependency is found. For more complex tasks, typically, the use of new materials necessitates the use of labor. Once that part is completed, they gradually complete the remaining work. This gradual development also benefits them financially. One of the respondents (70 years old, HI-4) states, *"...We have to stop at some point because we don't have the money to complete all the things necessary at a time..."* From this discussion, it is clear that their self-reliance is apparent in their utilization of labor, which is driven by financial constraints underscores the significant barriers to improving housing condition.

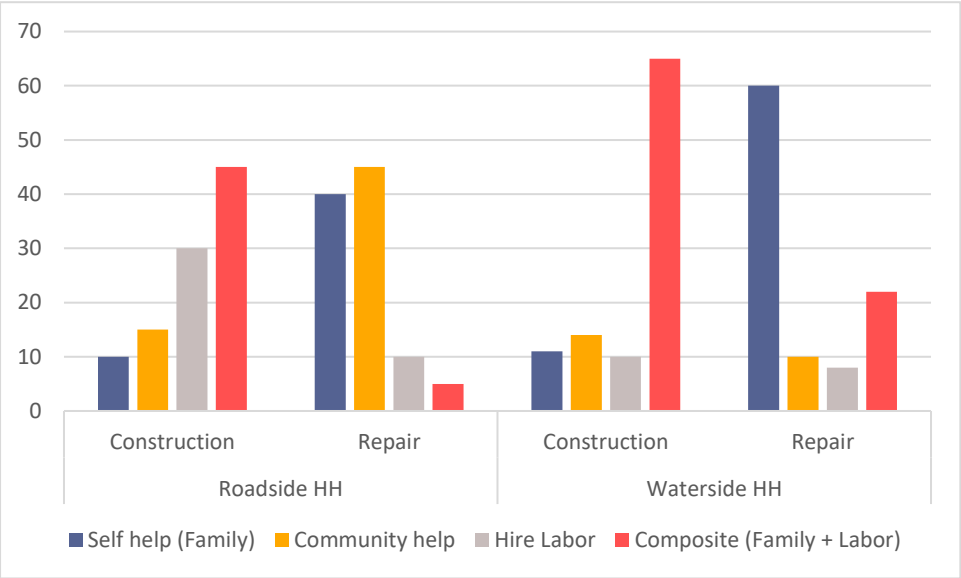


Figure 17: Local labor management composition (Source: survey, 2024).

Innovative measures: Residents are usually involved in continuous innovative adaptation due to facing numerous types of scarcity, using their living experience and shared knowledge to make their house more functional. Particularly, they demonstrate their resourcefulness for instance, by using cement bags or polythene covers for waterproofing and old cloths as insulating layers. By using ancestral knowledge and contemporary innovation in dwelling adaptation, the residents effectively face the challenges posed by climate change by continuously developing local knowledge. Furthermore, they possess expertise in resource mobilization and have collaborated with non-governmental organizations on community-focused projects. They also possess communal funds, which typically assist them in mobilizing resources following any disaster to minimize additional maintenance costs. The development of the adaptation process here relies heavily on experiential learning and their knowledge, as they frequently acquire these skills through necessity and self-education. One of the respondents (52 years old, HI-13) states, *"...No one actually teaches us how to do it, but we learn by watching our seniors do that and by helping them. And now we know if there is any new problem that arises, then we could anyhow handle it..."* So, the knowledge is passed down from generation to generation and sometimes shared within the community, but not always. The next section will discuss the challenges that guide all these adaptation measures.

4.4.2 Scarcity of resource

Residents of the Greenland slum face several limitations during the housing reconstruction and adaptation process that force them to take decisions to overcome climate threats. These limitations can be categorized based on the residents understanding and perceptions of what they experienced during the process. The most crucial issue in FGD and HH interviews is the financial constraint. In addition, the presence of legal barriers and a lack of technical expertise are regarded crucial factors in FGD. Similarly, along with them, the issue of material scarcity in HH interviews is seen as significant in household-level decision making (See table 8). In the following section, it is discussed how these limitations drive them to make decisions.

Table 8: Content density of resource scarcity in FGD & HH Interview (Source: survey, 2024).

	FGD Gr=137; GS=2	Household Interview Gr=776; GS=10
• **Climate change unpredictability** Gr=3	0,00%	2,56%
• **Financial constrains** Gr=55	43,75%	39,32%
• **Labor intensive** Gr=6	0,00%	5,13%
• **Material scarcity & non-durability issues** Gr=22	6,25%	17,09%
• **Regulatory barriers** Gr=41	37,50%	21,37%
• **Social constraints** Gr=14	0,00%	10,26%
• **Technical knowledge gaps** Gr=8	12,50%	4,27%

Financial limitations: Financial limitations play the most crucial role in the decision-making process of residents, as they often struggle with everyday necessities. The HH interview and FGD both focused on the topic of the financial crisis, with percentages of 39.32% and 43.75% content related to the overall resource scarcity respectively, which is the highest in both cases (See table). As a result of their scarce finances, they give priority to fulfilling their fundamental needs initially, frequently disregarding housing enhancements until the situation deteriorates. Due to their limited savings during emergencies, they are forced to borrow money repeatedly, which adds to their burden. One of the respondents (48 years old, HI-3) states, *"...We know how to tackle the problem; that is not the issue, but we have no money to do it; it is the real problem..."* This often forces them to make compromises in their adaptation process, leading them to choose less durable and more affordable materials. This necessitates further repairs and ongoing maintenance, which further exacerbates financial strain. Sometimes it also prolongs recovery time, but it often leads to incremental development and cost-effective choices. This discussion highlights the intricate relationship between financial incapacity, housing conditions, and the process of adaptation that initiates targeted improvements.

Material crisis: Material-related issues play also vital role in adaptation decisions along with the affordability issue. The HH interview encompasses 17.09% of the total content related to resource scarcity, while the FGD only covers 6.25% of the content in comparison (See table). This is evident because, finding a particular durable material with suitable thermal performance is still the greatest challenge there. Whether the most used traditional material, 'Golpata', becomes scarce in the urban context and less reliable in this changing weather pattern pushes them to use corrugated iron sheet (Tin) as the key material. Which is comparatively expensive. One of the respondents (42 years old, HI-14) states, *"...Maybe in the village now it could still be abundant, but still they only use it in the kitchen..."* The issue of sourcing and the relatively higher cost of durable materials encourage them to reuse materials, which may be sustainable. However, the changing weather patterns can negatively impact the quality and longevity of the house repaired with these kinds of materials. From this discussion, it is clear that there is a recurring pattern of decision-making regarding materials, where there is a compromise between cost-effectiveness and durability.

Labor intensity: The reconstruction process is always labour-intensive, and it requires not only significant physical effort but also specific skills. Although the HH interview only includes 5.13% of the content, it is not present in the FGD (See table). It is also closely connected to financial condition, whether it's not always possible to hire labor due to financial crisis always elongates the recovery time. Most residents, regardless of gender, prefer to perform tasks themselves with their family members to reduce labor costs. One of the respondents (48 years old, HI-3) states, *"...We try to save money from all the way, especially doing the things ourselves, but sometimes it really becomes burdensome, and when it is about Tin, it's heavy..."* However, when dealing with new materials and techniques, they find it difficult to consistently manage the issues and the construction related tasks. This benefits residents in overcoming specific challenges, but it also presents a threat to durable and resilient transformation.

Technical gap: The shift towards more durable materials like tin and timber sometimes required advanced technical knowledge initiates skill gap. This issue is more mentioned in FGD (12.50%) compared to HH interview (4.27%) (See table). During emergencies, individuals sometimes lack the necessary technical expertise to effectively install and maintain unfamiliar materials at the household level. The emergence of this topic occurred during the collective discussion in the FGD. While some of the residents learn it by trial and error, they don't make any lasting improvements with these materials. One of the respondents (44 years old, HI-12) states, *"...We had no idea how to repair if this tin-made house was going to be damaged; it is not easy to handle like Golpata, but we learned a lot by making mistakes..."*. Sometimes it requires technical and physical support to handle an emergency because of the shift from traditional to modern materials. This underscores the necessity for capacity building requirements that involve the introduction of new materials to address and adapt to climate challenges.

Legal crisis: The legal issue significantly impacts the adaptation process in this area, as the residents lack tenure security and imposes restrictions on the construction of permanent structures, thereby limiting the residents' ability to make their own decisions. In FGD and HH interviews, they account for 37.50% and 21.37% of the material, respectively, compared to other content linked to resource constraints and this play most vital role in decision-making after financial issues (See table). This legal barrier prevents them from making any permanent and effective improvements. Residents become frustrated about this issue because a good number of residents have the capacity to improve their condition significantly. One of the respondents (48 years old, HI-3) states, *"...We could make our condition a lot better, but why do we invest in others land? What if they evict us tomorrow?..."* These restrictions, in fact, significantly limit the scope of further housing improvement as they found this as a major barrier towards achieving effective housing adaptation.

Social concerns: The need for privacy and the risk of theft both play a vital role in making a balanced decision about the structure's design and improvement. However, the problem is entirely non-existent in FGD. In the HH interview, it is present in 10.26% of the content. At the household level, it is considered significantly relevant, but in a community situation, it is not (See table). They use small openings and limited windows in their houses to shield their belongings from prying eyes. From observation it has been determined that 44% of the dwellings lack any windows facing roads, exacerbating heat-related problems. One of the respondents (38 years old, HI-7) states, *"...We know if the window will be larger, then we could get more air, but then all we have exposed to others..."* Even during the storm, they stayed inside the structure for fear of collapse and couldn't leave their belongings behind, fearing theft. Addressing social concerns is of equal importance to addressing physical and financial difficulties in order to ensure long-term growth in informal settlements.

Summary of resource scarcity: These multifaceted challenges actually drive the adaptation process in the Greenland slum in a unique way, demonstrating resourcefulness and resilience (see table 9). Based on the code co-occurrence analysis, it is evident that financial constraints have the greatest impact on decision-making, with a coefficient of 0.41. The next biggest impact is regulatory barriers, with a coefficient of 0.30. Whether, from the direct response it becomes evident that regulatory obstacles have a greater impact on decision-making in waterside HH than economic constraints alone (see figure 18). In addition to the challenges of material scarcity and non-durability, social constraints also have a substantial impact on household transformation in the Greenland slum. In the literature, tenure security is often blamed for the barrier against the effective growth of informal settlements. However, this research shows that economic constraints also play a crucial role, and there may be a connection between economic factors and tenure security. Despite these obstacles, they demonstrate their dedication to gradually improving their living conditions. In the following section, how they overcome these shortcomings by following local knowledge will be discussed.

Table 9: Code Co-occurrence within subcodes for challenges and limitations (scarcity) for HT (Source: survey, 2024).

	• HT-2: Challenges and limitations of HT Gr=148	
	count	coefficient
• Climate change unpredictability Gr=3	4	0,03
• Financial constrains Gr=55	59	0,41
• Labor intensive Gr=6	7	0,05
• Material scarcity & non-durability issues Gr=22	23	0,16
• Regulatory barriers Gr=41	44	0,30
• Social constraints Gr=14	15	0,10
• Technical knowledge gaps Gr=8	8	0,05

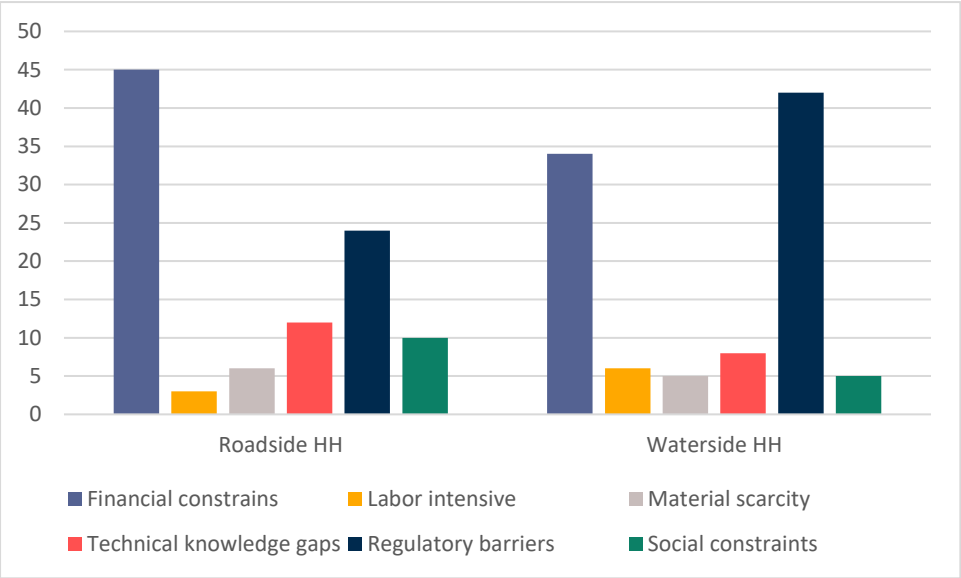


Figure 18: Location wise adaptation limitation (Source: survey, 2024)

4.4.3 LK informed adaptation measures

Local knowledge is great relief for residents towards managing finance, Labor and material during adaptation process to overcome climate threat. From various perspective they are important especially for the context of informal settlement enabling residents to adapt these multifaceted threats (see table 10 & 11). Based on code co-occurrence co-efficient the significance of indigenous techniques (0.47), materials (0.35), labor (0.26), and financing (0.18) differs in different data collection methods, according on participants' perceptions of LK-informed housing transformation. This is briefly discussed in relation to the Greenland slum below.

Table 10: Code Co-occurrence within subcodes for LK informed HT techniques (Source: survey, 2024).

	• Indigenous construction techniques Gr=111		• Indigenous financial strategies Gr=39		• Indigenous Labor management Gr=55		• Material choice and adaptation Gr=90	
	count	coefficient	count	coefficient	count	coefficient	count	coefficient
• HT-1: Local knowledge utilization for HT Gr=331	142	0,47	56	0,18	80	0,26	110	0,35

Table 11: Content density of LK informed HT in FGD, HH Interview & KII (Source: survey, 2024).

	FGD Gr=137; GS=2	Household Interview Gr=776; GS=10	KII Gr=54; GS=2
• Indigenous construction techniques Gr=111	25,64%	39,24%	42,11%
• Indigenous financial strategies Gr=39	10,26%	13,92%	10,53%
• Indigenous Labor management Gr=55	30,77%	17,30%	10,53%
• Material choice and adaptation Gr=90	33,33%	29,54%	36,84%

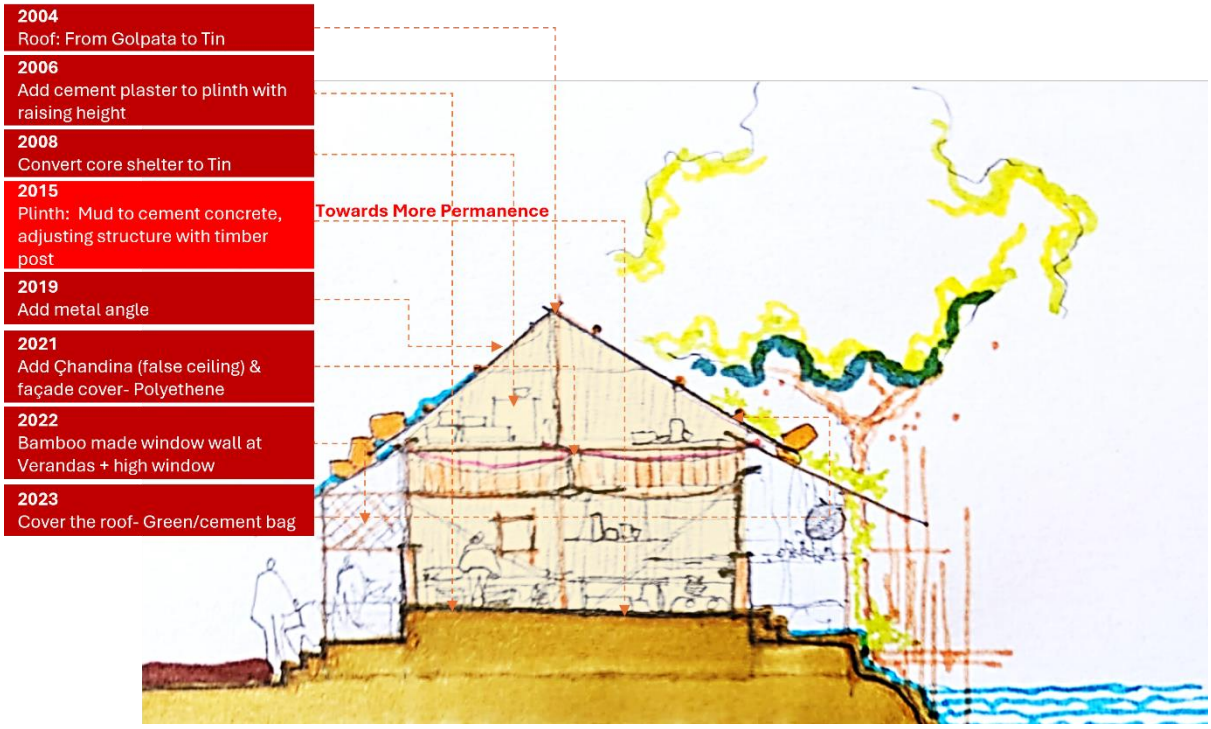


Figure 19: Evolution of material in a typical dwelling (Source: survey, 2024).

Material selection: Local knowledge has a significant impact on material usage and choice during the adaptation process which is developed over time (see figure 19). The data reveals that KII has the largest percentage of occurrences at 36.84%, followed by FGD at 33.33%, which is also the highest percentage for FGD. The fact that it is noted at 29.54% in the HH interview, making it the second highest content holder, highlights its significance. When it comes to durability due to climate change, traditional materials like 'Golpata', 'Mud' and 'Bamboo' have become obsolete make this issue so important. However, local people understand this due to the presence of insects such as 'Bash beetles' among them. Even they follow traditional techniques for processing materials like wooden posts and planks, like soaking them in water for a certain period before use. Traditionally, they also utilize the materials for potential reuse. One of the respondents (52 years old, HI-13) states, *"...Actually, the wooden plank and bamboo you see here are part of my previous house, and I know it will last more..."* Furthermore, they make logical choices by selecting the most suitable material within their capabilities, rather than relying on their personal preferences. They understand that traditional materials become scarce in urban contexts when they require frequent changes.

According to their knowledge, the right material always requires less maintenance and becomes more readily available. One of the respondents (70 years old, HI-4) states, *"...When the material that is suitable for the weather is always available nearby, or people use it frequently..."* This topic focuses on the issue of limited resources and how it affects the process of adapting to changing circumstances. This involves making a choice between cost and durability.

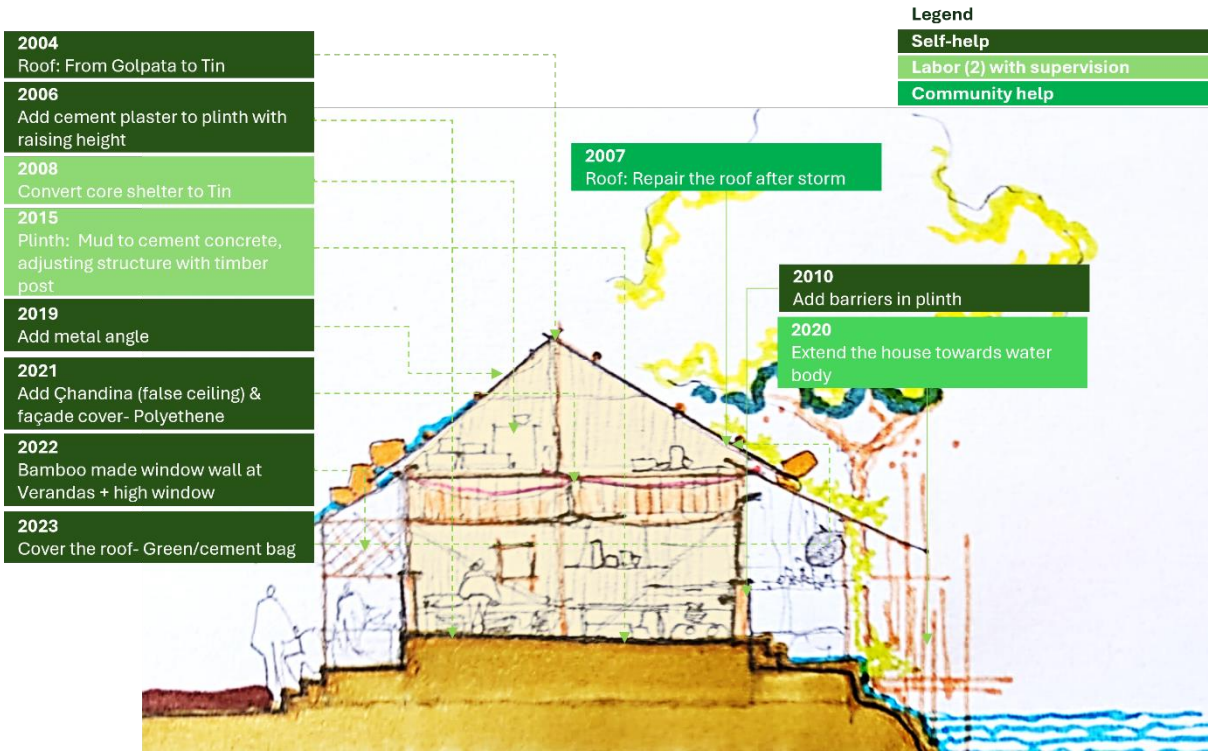


Figure 20: Typical labor management of a dwelling (Source: survey, 2024).

Labor management: The residents themselves handle most of the case adaptation process, demonstrating their unique capacity by utilizing skills passed down through generations (see figure 20). The topic is extensively addressed in the FGD, accounting for 30.77% of the content, making it the second most prominent theme. In the HH interview, it constitutes 17.30% of the discussion. The experts largely disregard the mention of the least developed change in KII, which is primarily driven by local labor because they focus on discussing the background of informality makes it so common. Due to residents' distinct definitions of quality construction, which encourage them to avoid labor and foster self-reliance. When they do use labor, they closely supervise their workers, especially the seniors in the family, to prevent any form of manipulation. They are also concerned about time because they have a clear idea of the required time for any recovery process. They usually rely on their traditional knowledge to monitor and guide, ensuring they meet the standard. The majority of individuals possess a traditional understanding of construction. One of the respondents (34 years old, HI-9) states, *"...Actually, no one taught us these; since we were young, we were involved in this kind of work; we learned by watching and doing..."* To complete any burdensome task, usually family members, relatives, and others with whom they have good relations within the community involved together and share the skills help pass down the knowledge. One of the key learnings is that this shared effort reduces the cost of adaptation and enhances community bonding. This underscores how they address the limitations of local labor concerns and promote the

transformation of self-help housing through involving community, particularly in situations where access to skilled labor is limited.

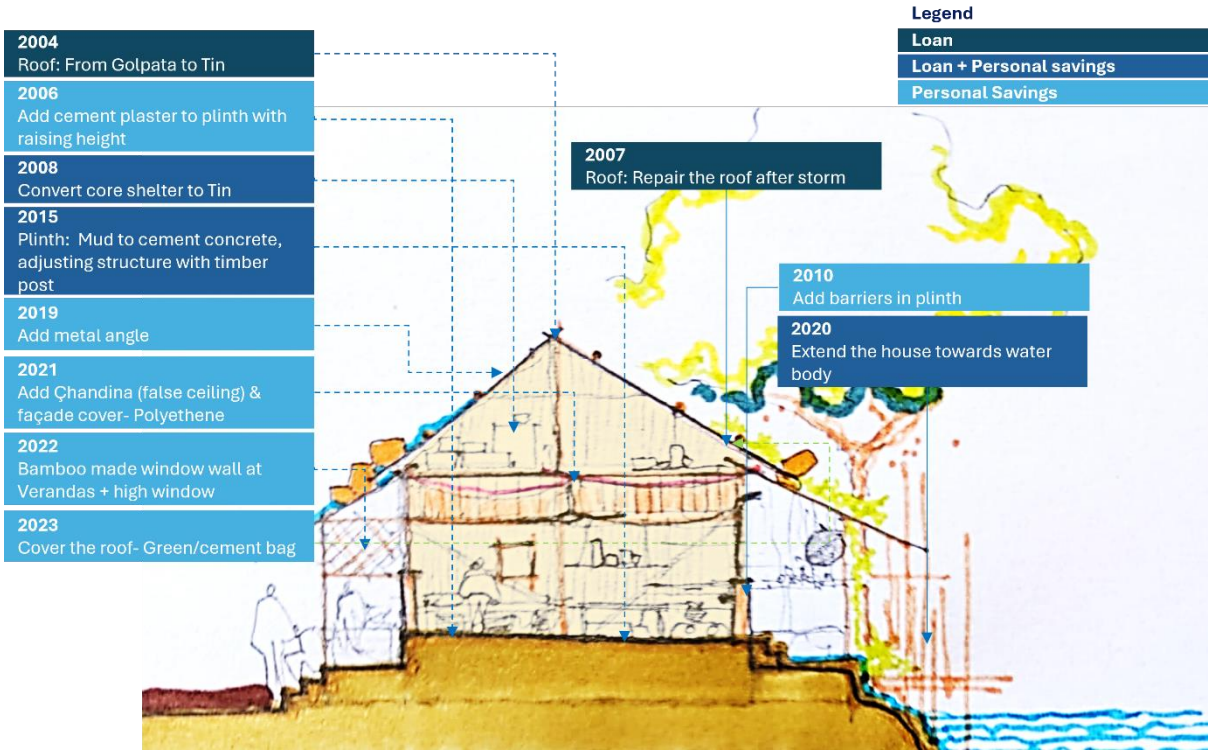


Figure 21: Typical financial management of a dwelling (Source: survey, 2024).

Financial management: Traditionally, informal settlements developed incrementally, and this practice is still ongoing at the Greenland slum mainly due to different kinds of financial constraints (see figure 21). The content with the least prominence is found in all three categories, specifically 10.26% in FGD, 13.52% in HH interview, and 10.53% in KII. This situation may have occurred due to the financial constraints that influenced the adaptation process in informal settlements but, the residents of these communities somehow find ways to manage and cope. One of the respondents (70 years old, HI-4) states, *"...We save money over the years, and at a certain point in time, when it is required to upgrade any part of the house, we take decisions based on how much we saved and how much we can spend then..."* This process allows them to avoid large loans and manage their finances sustainably. Moreover, their financial constraints drive them to make efficient decisions by choosing cheap and long-lasting materials, helping to manage costs effectively. This search process also makes them experts in materials. It also enhances their ability to recycle and reuse materials. In any kind of emergency, they use a community-based fund. Though it has aftereffects, it surely eases them during a post-disaster situation. They also acknowledge that senior guidance plays a crucial role in managing finances to repair, reconstruct, or construct a new house, and assists in managing financial challenges throughout the process. One of the respondents (34 years old, HI-9) states, *"...When we don't find a way to solve the issue, we go to our parents or grandparents; they show us how they reduce and manage the cost..."* This section emphasizes the gradual growth of housing in Greenland Slum as a result of financial limitations. It highlights the use of savings-based improvements and cost-effective solutions for development.

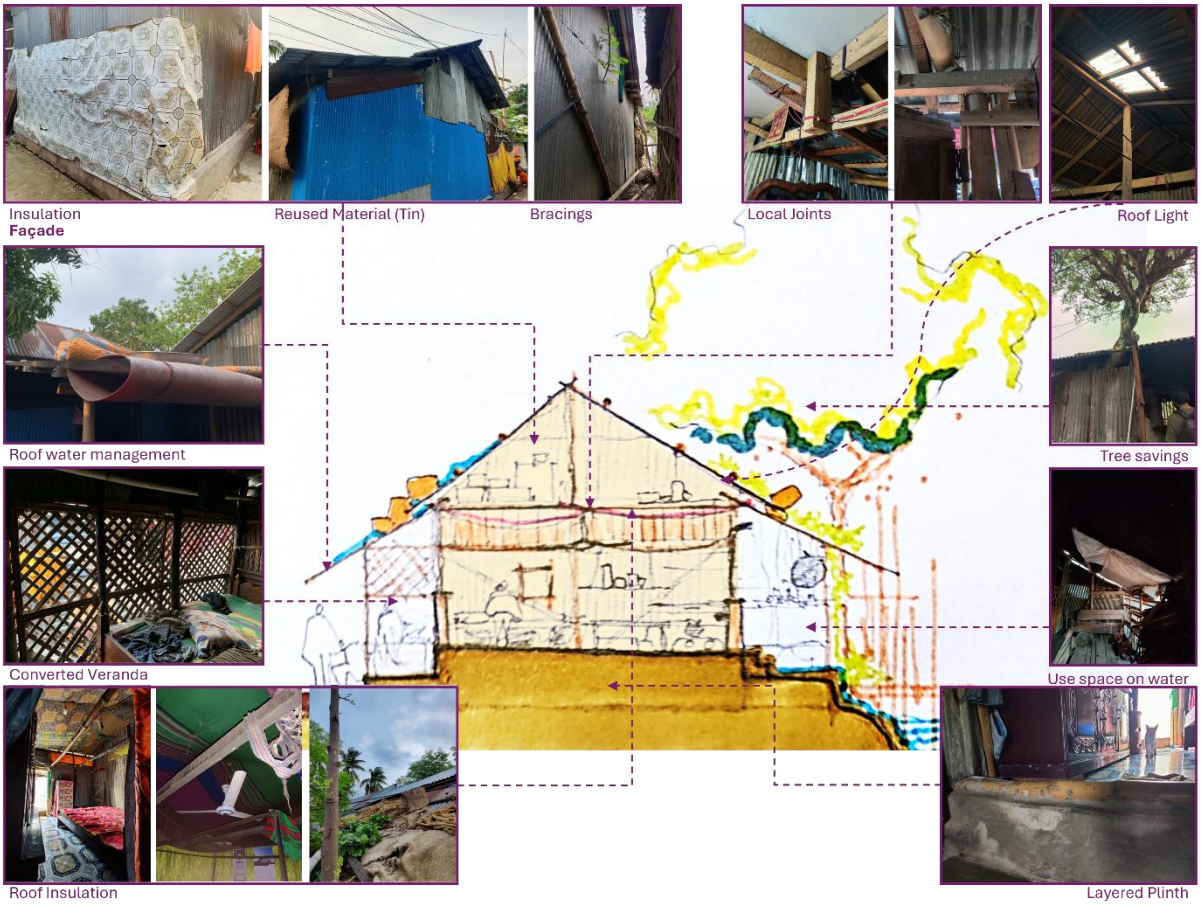


Figure 22: Local adaptation techniques (Source: survey, 2024)

Adaptation techniques and innovation: The selection of techniques is typically influenced by the interplay of labor, finance, and material resources. Residents of the Greenland slum employ traditional techniques and strategies in an innovative way to improve household resilience (See figure 22). The topic of this subject is most extensively discussed in the KII and HH interviews, with a content density of 42.11% and 39.24% respectively. In the FGD, the content density is 25.64%. Most of them rely on experience-based solutions, a practice they inherited from their village ancestors. Residents usually innovate solutions to tackle specific challenges based on their rich experience. In response to heavy rainfall and storms, residents have already converted their house, which was made of comparatively durable and permanent materials such as 'Tin' and 'Timber', into a permanent 'Concrete' made plinth, based on their knowledge and experience. However, they have experienced some aftereffects in the settlement. Due to severe heat stress issues, residents have taken site-specific passive measures rather than depending on mechanical solutions. Considering safety and security concerns, they have strategically placed new windows at strategic locations and directions such as the upper part of the wall or towards the waterbody. Additionally, they have converted the entire wall into a perforated area to accommodate activities (such as the veranda). They also take into account the potential wind impact on the house during storms and adjust the opening size to minimize the risk of structural damage. One of the respondents (44 years old, HI-12) states, *"...We have to put an opening towards the waterbody to get a cool year, but we can't make it big because during the storm it also intakes heavy loads..."* Besides that, they plant trees and climbing plants around the house to provide shade on the roof and, at the same time, add insulating layers beneath the roof and inside the wall made of local materials. These site-specific initiatives leverage local knowledge to adjust to climate-related uncertainty, thereby enhancing resilience.

4.4.4 Implications of the adaptive measures:

It is evident from the above discussion that residents' knowledge, perception, and experience about managing material, labor, and finance significantly determine the technique and method of construction, which varies from house to house to overcome climate threats (see table 12). This knowledge was derived from their scarcity-based self-reliance and possible collaborations, which enabled them to become more resilient despite many challenges through enhancing structural integrity, improve thermal comfort, flood resilience, economic efficiency, and social cohesion. In the following table presents climatic threats, and the conclusions made by LK are verified through content analysis and observation. Only the most important findings are displayed. Through continuous learning and sharing, residents utilize their wisdom through these decisions to adapt to changing weather patterns because most of the decisions developed were to solve experienced problems in Greenland Slum.

Table 12: Code co-occurrence & observation frequency for climate threat and LK informed decisions (Source: survey, 2024).

Climate threat	Part of the structure	LK informed Adaptation measures	Frequency of Code	Frequency in Observation
Heat stress Gr-68	Plinth	Cover the plinth with mats & keep them wet	*6*	*25%*
	Structure	Adjust height of the structure	*5*	*6%*
	Facade	Add opening at strategic position	*16*	*56%*
		Convert Veranda	*5*	*38%*
		Add insulating layer	*9*	*56%*
	Roof	Green roof	*7*	*36%*
		Use 'Çhandina' beneath the roof made of used clothings	*20*	*50%*
Seasonal storm with wind gust Gr-50	Plinth	Make it permanent with 'Concrete'	*7*	*75%*
		Use 'metal/bamboo' clamps to connect structure	*6*	*13%*
	Structure	Use durable material like 'Timber post'	*13*	*88%*
		Use adhesive and nails along with the knots	*3*	*38%*
	Facade	Adjust size of the opening	*3*	*31%*
		Use 'bracing and ties' with strong elements	*9*	*25%*
	Roof	Tie it with main stricture strongly	*5*	*88%*
		Put additional load on it	*4*	*25%*
Heavy rain and flooding Gr-27	Plinth	Raise the height with 'Concrete'	*8*	*75%*
		Apply mud and cement mixed plaster	*3*	*25%*
	Structure	Keep the structural element away from rainwater	*2*	*75%*
	Facade	Use durable (Water resistant) material like 'Tin'	*5*	*75%*
		Cover the facade during heavy rain with 'Polythene'	*2*	*56%*
	Roof	Use durable (Water resistant) material like 'Tin'	*4*	*100%*
		Cover the roof during heavy rain with 'Polythene'	*3*	*25%*

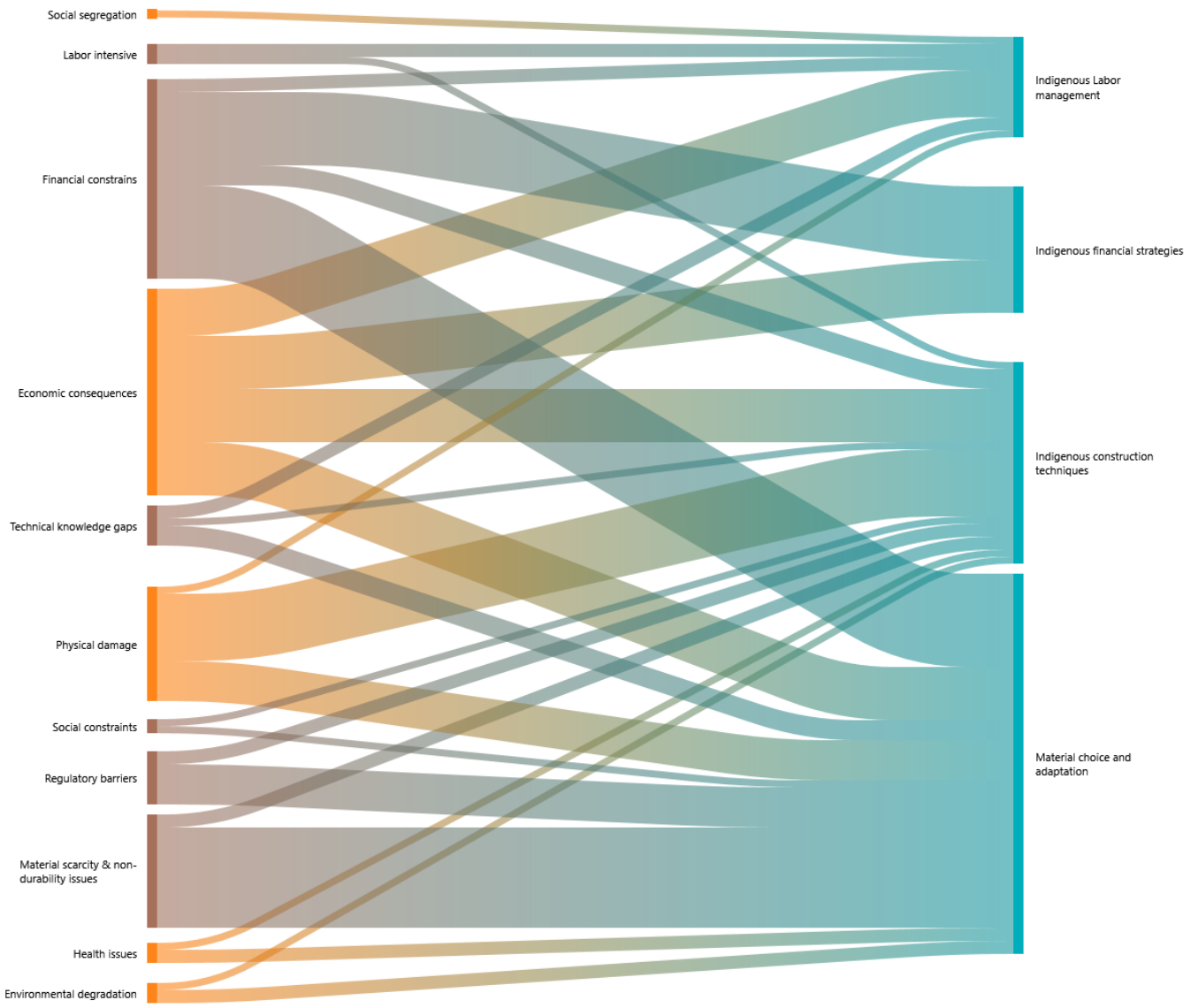


Figure 23: Sankey diagram of correlation of LK informed HT with resource scarcity and perceived consequence of CC (Source: survey, 2024: see appendix 4 for values).

After identifying LK, decisions that have been made based on threats. If the codes are then evaluated in conjunction with CC impacts and limited resources, it becomes clear that material choice is a crucial concern in this evolving situation (see figure 23). Firstly, the LK provides information on procedures, followed by finance, and finally labor issues. That means, with the right materials, anyone can implement adaptive strategies using the correct methods specific to the material, ensuring financial stability. The figure clearly shows that the selection of materials is strongly influenced by the scarcity of materials and the issue of non-durability (0.15), as well as financial limitations (0.11). Whether economic consequence of climate threats influenced the material choice also with a co-efficient of 0.06. The economic consequences of climate threats have the most significant effect on all matters related to LK informed HT. However, indigenous techniques are primarily shaped by the impact of physical damage (0.07), while their connection to economic consequences is weak (0.05). Financial strategies are closely linked to both individual financial constraints (0.13) and economic implications (0.11). The labor issue is mostly influenced by the economic consequences of climatic occurrences (0.08). So, economic factors play a crucial role in driving the adaptation process in the HT

in Greenland slum, influencing decisions related to material selection and labor participation. Nevertheless, the scarcity of traditional material and changing weather patterns also have a substantial impact on all the challenges identified. In the following section it will be discussed how these measures have impact on their liveability and functionality.

4.5 Effectiveness of housing transformation from users' perspective

During this period of rapid and unpredictable climate change, residents of the Greenland slum have to go through housing transformation to ensure their safety and comfort. To address environmental challenges, they use a perfect blend of traditional knowledge and innovation in materials and techniques based on their unique perception of climate change. Individuals' post-residual assessment, risk perception, and the potential for further improvements greatly influence the effectiveness of these measures within the settlement. This data is gathered from the response of HH interview, FGD, and KII (see figure 24). In the following figure, from the content related to effectiveness, it is found that most of the responses are negative. In HH interview it is 59.86% and in FGD it is also 58.33%. Whether, from empirical evidence it is found the overall satisfaction about decision-making is neutral but in waterside HH the level of satisfaction is comparatively higher (see figure 25). In the following sub-sections, these are going to be discussed briefly.

Figure 24: Overall response ratio of LK informed HT (Source: survey, 2024).

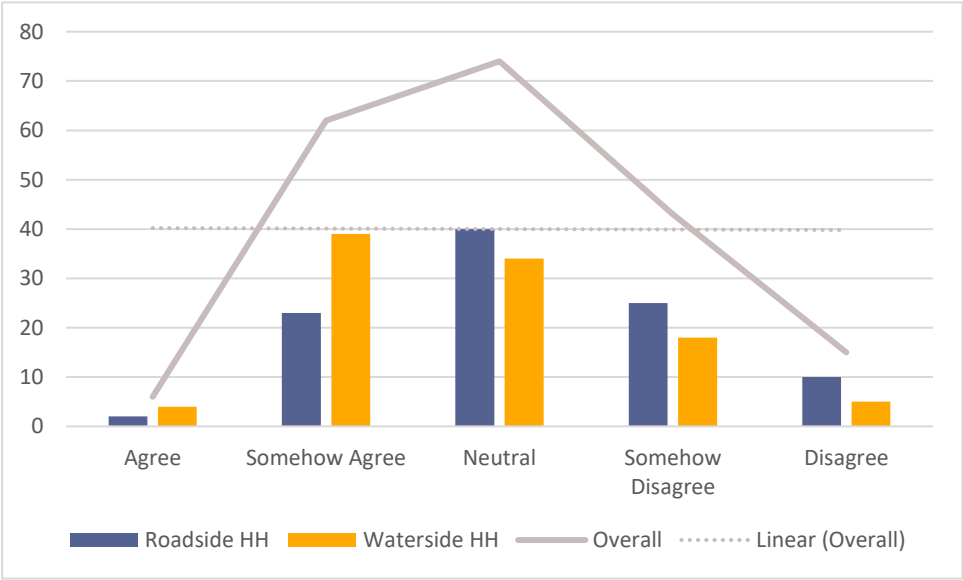


Figure 25: Empirical evidence of location-based satisfaction (Source: survey,2024)

4.5.1 Relation among satisfaction indicators

After taking the necessary measures to stay safe from climate change issues, the residents developed a mixed perception, as they found this process to be never-ending (See table 14 & 15). If the positive sides are enlightened, then the modification of the plinth, making it pucca (permanent), will provide them with significant benefit. They could use the floor for various purposes with a little cleaning, especially during the summer. Most importantly, they no longer have to deal with mud during rain and flooding events, even if the water manages to seep in. Moreover, the house became more spacious and enlightened compared to their earlier dwellings after shifting to 'Tin'-made houses, which primarily require a four-sided roof, and raising the height of the structure inherited the feeling of spaciousness even within the same area. All of these decisions indicate a substantial enhancement in livability, with a coefficient of 0.62, the highest recorded. This indicates that the residents are perceiving the improvements in a positive way, with a focus on the durability improvement measures (0.28), which are considered the second most significant factor by the respondents. Moreover, it decreases the frequency of maintenance duties, resulting in cost and time savings, hence improving cost-effectiveness with a coefficient of 0.17 for positive response. Not only in the dwelling units, but also throughout the settlements, the improved infrastructure such as walkways, drainage, electricity, and potable water sources has led to a slight increase in resident satisfaction compared to earlier times.

Table 14: Code co-occurrence for positive HT outcome (Source: survey, 2024).

	● Cost-effectiveness of adaptations Gr=11		● Durability improvements Gr=15		● Improved liveability Gr=34		● Risk identified Gr=4	
	count	coefficient	count	coefficient	count	coefficient	count	coefficient
● HTE-1: Housing transformation positive outcome Gr=63	11	0,17	17	0,28	37	0,62	5	0,08

However, many people voice expressed frustration with the excessive heat they experience, which suggests a low quality of livability in their homes after moving. This raises concerns about the effectiveness of their efforts to adjust to the heat. This issue surpasses all the good aspects with a coefficient of 0.96. It makes them heavily dependent on fans, especially those who don't have any free space around their houses, and they find it unbearable during power outages. There have been reports of people leaving their homes during hot periods in search of cool outdoor spaces. The settlement's unprecedented growth has resulted in a scarcity of open spaces for windows, limiting the natural ventilation options, with the exception of waterbodies. It also raises their electricity expenditure, particularly in the summer months, prolonging their financial load due to durability concerns shown by a coefficient of 0.27, which is rather considerable. And after all, they found that this unbearable heat within the houses made them sick, which is the key reason for their dissatisfaction with dwelling improvements.

Table 13: Code co-occurrence for negative HT outcome (Source: survey, 2024).

	● Cost-ineffectiveness of adaptations Gr=2		● Durability concerns remain Gr=20		● Poor standard of liveability Gr=70		● Risk unidentified Gr=3	
	count	coefficient	count	coefficient	count	coefficient	count	coefficient
● HTE-2: Housing transformation Negative outcome Gr=93	2	0,02	24	0,27	80	0,96	3	0,03

There is actually mixed perception developed. Most of the residents say their current dwellings provide better protection against at least rain and cold compared to their previous conditions indicates the increased durability. But they are struggling with intense heat and heat waves indicates low liveability. Along with the overall improvement of the settlement, the use of certain materials, particularly 'Tin' for the roofing and facade, presents a significant challenge to the residents. Following the sequence of material changes, extreme heat has emerged as the primary climate threat, with the use of 'Tin' potentially exacerbating the overall suffering. Due to its location within a dense urban area, it easily traps heat in living spaces. However, they couldn't avoid it because, according to their knowledge and experience, employing 'Tin' enhances resistance to rain and offers a sturdy structure against storms. Which has a direct impact on dwellings, or whether the temperature rise doesn't have a visible impact on dwellings. Currently, their primary focus is on mitigating and adapting to the issue of rising temperatures, while simultaneously exploring alternative solutions.

4.5.2 Risk perceptions

The residents demonstrate some sort of awareness based on perceived risk about their decision-making and use these as natural directives towards further decisions evident in interview response and FGD. They clearly identify extreme heat as a potential health-related risk that increases sickness among vulnerable members of the community. They cited the use of 'Tin' as a contributing factor, but they had to change their dwellings from 'Golpata' due to fire hazards, durability risks, maintenance issues, and potential pest infections. Although the permanent materials they use are relatively less risky, they are still susceptible to these risks. As they mentioned, they used 'tin' to get rid of rainwater, but it still penetrates in and, in terms of durability, they blow away. Furthermore, if these materials sustain damage, the cost will surpass that of locally sourced materials. They require a more comprehensive understanding of the potential risk of health and safety issues, as the current weather-changing phenomena often leave them puzzled and unable to make prompt decisions. This is important because risk identification is a key indicator of positive effectiveness of HT in terms of adapting changing weather pattern.

4.5.3 Necessity of LK for enhancing effectiveness

Based on the data collected from HT effectiveness in FGD, HH interview, and KII, it is clear that the overall response is predominantly negative. However, when examining the code co-occurrence with LK informed housing transformation, it is clear that LK informed responses are primarily associated with positive reactions (See figure 26). The indigenous building

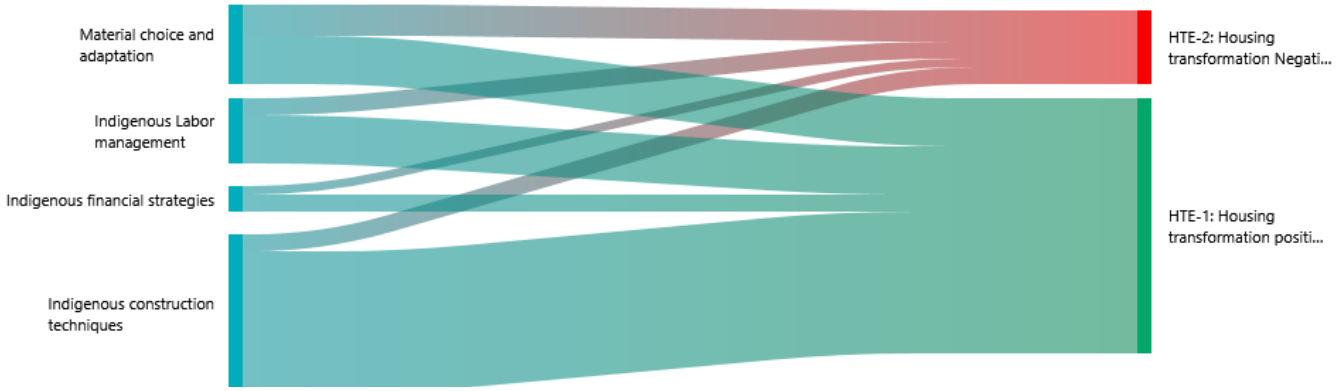


Figure 26: Sankey diagram of correlation of LK informed HT technique with HT effectiveness (Source: survey, 2024: See appendix 4 for values).

technique, labor management, and material choice have a substantial relationship with favorable response, with respective coefficients of 0.23, 0.10, and 0.08. The choice of materials has a considerable impact on unfavorable responses, with a coefficient of 0.04. In contrast, for labor management, the coefficient is 0.03. Moreover, residents of the Greenland slum report they face major barriers to adapting to climate change-related challenges due to a lack of tenure security and financial instability. Most of them expressed their inability to spend on more resilient solutions. Moreover, even those with the ability are reluctant to invest their money in unsecured land. The constant threat of eviction by the railway authority (BRA) keeps them away from long-term planning. Both of these securities severely hamper the adaptation process and push them to use materials offering limited protection against climate change-related threats.

Despite facing these challenges, they consistently strive to adapt by implementing effective strategies using their available resources and knowledge. Their development shows a strong willingness to improve their situation. However, if they had tenure security or understood the government's long-term plan for them or the land, it would be more comprehensive and easier for them to determine the level of intervention. They urgently need to overcome their fear of eviction. Their land rights could be secured through legal recognition or a formal agreement with the appropriate authority. If they secure the tenure agreement, they anticipate the abolition of the current building regulations at the site, paving the way for a truly permanent transition. Providing financial aid or the necessary materials would ease their financial burden during any post-disaster emergency situation. Some of the respondents prefer direct material over money because they cannot ensure the proper use of financial aid due to many kinds of personal problems. Moreover, they require permanent livelihood solutions to ensure a stable income and save money for any kind of emergency. In addition, they need external assistance such as controlling the density of the area, planting according to a plan, and maintaining open spaces and waterbodies within the community to mitigate the heat island effect.

Addressing these issues, risks, and limitations could really push forward the adaptation measures that are being taken by the residents of the Greenland slum, Khulna.

4.6 Discussion

The empirical data clearly demonstrate that the decision-making process of local residents about housing transformation is complicated. Due to differences in location, their level of exposure to vulnerabilities and risks varies. Their decision-making process is primarily influenced by the challenge they have experienced most frequently and the significant impact it has had on their lives. Their decision on the construction approach is determined by an intricate interaction between their perception and their capacity to effectively employ their knowledge of materials, labor, and finance. This decision-making process occurs after they have identified the most urgent climatic issue they are confronted with.

LK informed CC perception: In Greenland slum, users construct their perspective of climate change mostly through comparing incidents based on their own experiences which is unique for informal context. Due to environmental deterioration and the increasing concerns of climate change, as well as the congested urban environment, there is a clear lack of progress in enhancing nature-based weather forecast methods further. The dependency of media especially in the urban area and in the younger generation may further diminish these intergenerational skills. Moreover, when it comes to dwelling transformation, they prioritize minimizing maintenance expenses due to their consistent experience of socio-economic difficulties help them prioritizing threats. Heat stress has become a prominent climate concern in the region,

surpassing other issues. It is marked by illness resulting from high temperatures and a strong dependence on electricity. This has led to the implementation of passive cooling solutions. However, managing these solutions in a densely developed urban area is challenging due to safety and privacy concerns, which dictate the number and placement of windows. This is a unique phenomenon for them, since they often assess the climate-related effects on their dwellings based on evident damages caused by storms, rainfall, and flooding. However, heat stress does not have as noticeable an influence on their housing units. They have readily acknowledged the danger posed by other climate hazards, which directly affect dwellings, and are actively working to tackle it by adopting sustainable and resilient solutions that are affordable for each individual. However, due to variations in impact based on location, it is necessary to tailor these solutions to the specific perceptions of climate change in each individual of the urban informal context. It might be argued that in Greenland slum, the impression of LK informed CC perception has become less reliant on natural cues and more influenced by everyday experiences, especially among young people. Furthermore, in addition to economic impact, non-physical repercussions, as well as physical damage, are equally useful in identifying climate threats.

LK informed housing transformation: This is a complex process demonstrated in the figure 27. The results unequivocally demonstrate that inhabitants utilize their expertise to select materials that are easily accessible and long-lasting, rather than depending on purportedly natural indigenous resources such as 'Golapata' or 'Bamboo'. For major changes, they depend on outside support for labor, but they manage minor modifications themselves during after any disaster or at any time required, frequently with the involvement of family members and relatives. From observation, it becomes apparent that they primarily make decisions through relative observation of applied solutions to similar kind of problems, as they prefer to rely on their own judgment. This approach often leads to additional innovation. This may arise from a lack of trust, since they are reluctant to share their concerns with others until they are confident that those individuals are not their competitors within the community. Their financial instability frequently leads to insufficient savings, which subsequently contributes to incremental housing

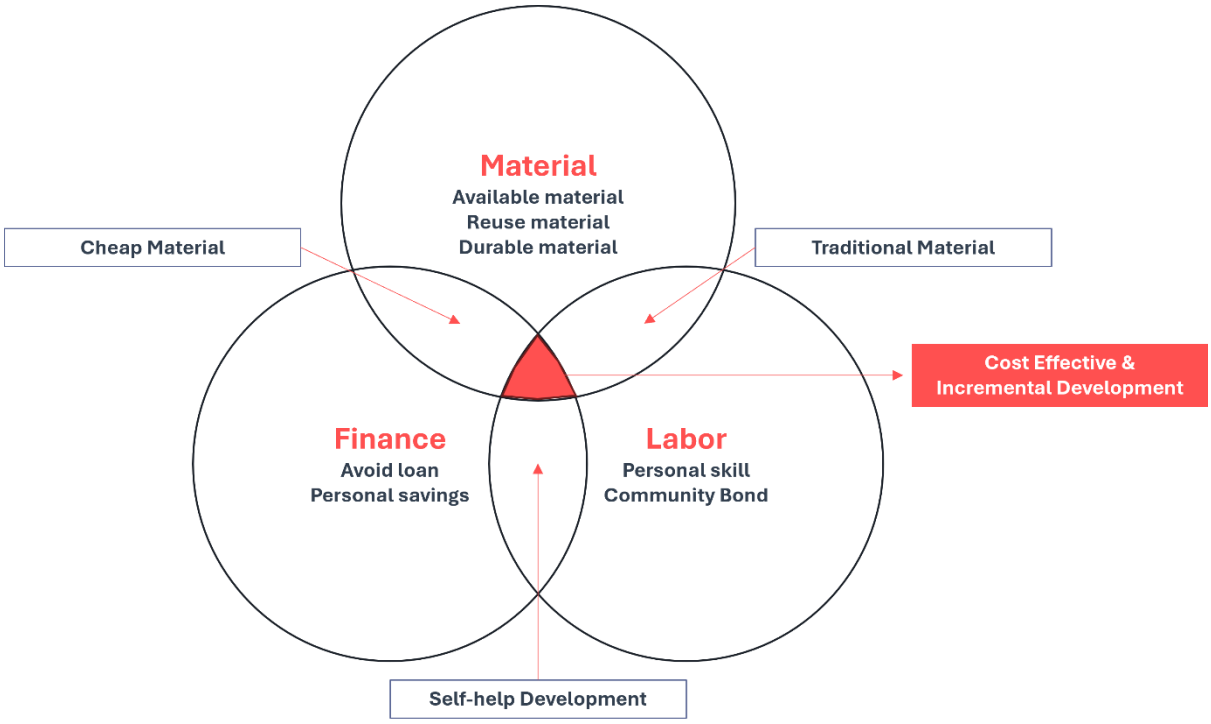


Figure 27: HT related decision-making process in informal context (Source: Author, 2024).

development. Following any climatic incident, they are compelled to rely on loans, yet they retain a dislike for these liabilities due to their tendency to become burdensome. When it comes to considering materials and labor together, people consistently choose their familiar traditional materials. This is due to their comprehension that the utilization of novel materials necessitates supplementary expertise and technical assistance, leading to extra expenses and time consumption. When it comes to labor and finance, they consistently prioritize self-help development to reduce cost. If external labor is required, the number of individuals involved often ranges from 1 to 2. Additionally, it is often necessary to provide supervision for the laborers. In addition, in matters of financial and material concerns, they have a tendency to give priority to the cheapest resources that are accessible, which sometimes results in the reuse and recycling of materials that may not be suited for climate adaptation enhance maintenance cost. Overall, the development suggests a focus on cost-effectiveness and incremental development. Furthermore, after they reach a particular level of assets, they frequently upgrade their home to one built of tin, without considering any other factors, as it is largely seen as a symbol of status.

Effective housing transformation: The findings indicate that there is no direct correlation between the efficiency of HT and climate adaption in informal contexts. Nevertheless, when a residence becomes climate adaptive, it necessitates reduced maintenance and relies less on electricity, which is seen as a definitive sign of an efficient housing solution in the Greenland slum. Consequently, despite taking so many LK informed decisions, the level of satisfaction with the living conditions is not very high. Currently, the evaluation of effectiveness is limited to durability and spaciousness, which are directly linked to storm-related concerns. A significant number of households overlook to assess whether the housing maintenance expense is a negative indicator directly linked to heat stress. Recently, the heat stress has increased as a result of certain actions that were previously seen as climate adaptation measures. For example, using Tin to divert rainwater and the widespread development of hard surface roads for easy movement during rain and flooding, along with a decrease in the number of trees, have led to the emergence of new heat-related climate challenges. All the decisions made at that location are temporary in nature due to the lack of tenure security. These decisions have led to the implementation of a unique, impermanent solution specific to this urban informal settlement could end up with similar result in similar informal condition.

When it comes to making decisions about housing transformation, these indicated conditions based on variables collaboratively play a crucial role (See figure), demonstrating a high level of knowledge and understanding in their decision-making process. Nevertheless, considering the insights gained from interviews and observations, it is evident that the individuals' full capabilities have not been realized due to the absence of secure tenure and the looming possibility of eviction. Furthermore, the general deterioration of the environment in the settlement leads them to ponder if it would be prudent to stay here in the future if they acquire the ability to reside elsewhere. The table 15 below lists the important empirical findings that drive decision-making related to HT in the Greenland Slum, organized by variable.

Table 15: Empirical findings based on variables (Source: survey, 2024).

Variable	Sub-variable	Empirical findings
LK informed CC **perception**	Local knowledge of Hazard	• Young residents are less reliant on natural cues compared to the elders. • Dependence on media reflects less dependency on nature to predict weather. • Presence of trees plays vital role to identify and assess threat whether loss of trees is also an indicator of weather pattern change.

		• Dense urban settlement with scarce biodiversity hinders climate prediction and understanding existing condition. • Residents use experience of previous weather events more and take practical actions based on that. • Health condition play vital role to identify change in weather.
	Exposure	• From rainfall and flooding to Heat stress and storm become the key climate threat now. • Heat stress increase health related issues. • Extensive cutting down of trees and increasing hard surface have severe impact on residents. • During storm wind creates more problem to lightweight and less durable materials. • Soil erosion create problem only to the households next to waterbody. • Housing maintenance cost is increased due to hazards. • Inconsistent seasonal transition hampers preparedness.
	Impact	• Extreme heat and storm have severe impact on dwelling unit whether storm impacts the form and heat stress impact the living condition. • Poor housing condition exacerbate health and psychological issues. • Storm induces frequent dwelling repair and reinforcement whether heat increase electricity dependency strain HH expenditure. • Collective decision making is absent hampers social cohesion. • Based on location impact significantly varies.
LK informed Housing **transformation**	LK informed transformation measures	• Passive measures are preferred to adapt climate issues. • Construction method is continuously evolving unconventional methods. • Material reuse is a common practice to reduce cost. • Durability is primary concern based on capacity for low maintenance to ensure cost-effectiveness. • Traditional techniques are used to challenge climate change induced problems. • Regular inspection and reinforcement to dwelling is common. • Financial constrains lead to self reliance with innovation whether loans induce economic stress. • Incremental development is a common practice due to several constrains.
	Asset Constrains	• Financial constrains play most crucial role in HT related decision-making. • The choice of less durable but more affordable materials are frequently used and increase cost. • Traditional materials become obsolete and expensive. • Financial constrain leading self-help housing. • Using new material creates technical gap enhance sufferings during emergency. • Legal barrier impedes significant adaptation process. • Social concerns influence decision making and could hamper adaptation process.

Effective Housing transformation	Climate adaptivity	• Response about the overall satisfaction is mixed because achieving overall adaptation satisfaction is difficult to meet. • Sense of spaciousness and durability are the key factor for residents' positive response. • Limited natural ventilation scope with poor choice of material exacerbates heat issue. • Due to poor indoor living state, housing maintenance cost rise. • Eviction threat hinders possible long-term adaptation strategy.

5. Conclusions

5.1 Introduction

This chapter synthesize the research's key findings by addressing the sub questions. Based on these key insights, it offers recommendations to residents, policymakers, and built environment professionals on how to further enhance the use of local knowledge in resident-driven housing transformation based on empirical findings. This will be conducted based on the insights gained from analyzing the findings on the pivotal role played by local knowledge in climate adaptive housing transformation by the residents of Greenland slum Khulna, which was elaborately discussed in the previous chapter. The central question that guides this research is how local knowledge contributes to the transformation of climate adaptive housing, taking into account the residents' perceptions of climate threats, the materials and techniques they use, and the effectiveness of these methods from their perspective. Here it will be reflected that the further scope of potential utilization of local knowledge to enhance the adaptive capacity in vulnerable informal settlements.

5.2 Contribution of LK to climate adaptive housing

Local knowledge is crucial for the development of climate-adaptive housing, particularly in urban informal settlements. The process commences by identifying potential threats and directing the formulation of strategies for adaptation. The residents of the Greenland slum in Khulna, Bangladesh, are well aware of the dangers posed by heat stress and destructive windstorms, from their everyday experience and comparative situation similarly the way mentioned by Adgar et al., (2013). These hazards significantly impact their housing preferences, as noted by Jabeen et al. (2010). Satterthwaite et al. (2020) argue that physical damage is crucial in influencing decision-making for a significant fraction of climate adaptation efforts, as it happens in this case and some nonphysical impacts remain untouched particularly in relation to heat stress. The primary effect of heat stress creates on health and efficiency especially in urban informal settlements is discussed by Nightingale et al. (2020). However, the majority of their actions are influenced by economic constraints (Adgar et al., 2013). As a result, in order to make the adaption process cost-effective, they use sub-standard materials and techniques, which are led by LK, leading to additional housing-related problems. This occurred not solely as a result of financial limitations, but also due to the absence of tenure security, which is a crucial factor in the setting of informality (Archer, 2012). Due to the constant threat of eviction before climate adaption, individuals are forced to make decisions regarding short-term solutions that do not guarantee long-term sustainability. As a result, they often resort to maladaptive tactics. Subsequently, they make another attempt to address the issue by implementing temporary solutions. This potentially result in additional deficiencies and perpetuate a harmful cycle of ongoing adjustment as predicted by Barnett & O'Neill (2013). As a result, this process has developed into a sort of experience that enhances the understanding of local knowledge for residents to a higher degree. The whole decision-making process emphasizes a short-sighted approach that prioritizes cost-effectiveness and physical interventions in housing transformation. While this approach helps to some extent in responding to climatic challenges, it also worsens new issues. This is the process by which local knowledge evolves in urban informal context especially without tenure throughout time, as represented in the updated conceptual framework that follows in figure 28.

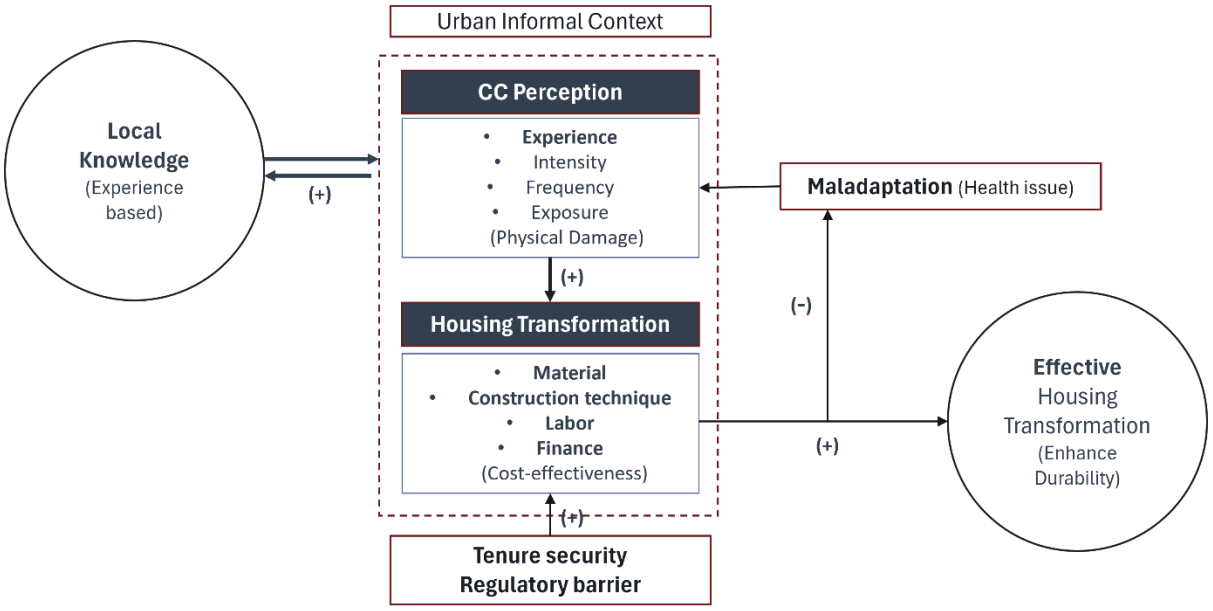


Figure 28: Adapted conceptual framework (Source: Author, 2024)

The subsequent sub-sections provide explicit responses to the sub-questions and offer additional elucidation on how local residents employ LK to adjust to these alterations, emphasizing their efficacy. It is quite difficult to establish a definitive answer in a dynamic setting, especially in urban informal settlements where residents do not have legal protection for their land ownership.

5.2.1 LK informed climate threat perception

Local residents of Greenland Slum recognize climate threats through their everyday life experiences, unique insights, and traditional knowledge, which have been greatly influenced by environmental degradation, such as the reduction in biodiversity and flora, which is very much aligned with the claim of Satterthwaite et al. (2018) on less predictability following natural cues in an informal context. The reliability and trustworthiness of using natural indicators such as wind patterns, tree growth, temperature, color, and bug presence to anticipate weather incidents may become less reliable. Currently, the local community acknowledges heat stress as the primary climate hazard due to its increasing influence on daily circumstances, including illness, discomfort, reliance on electricity, and inadequate indoor living conditions, which are identified by Revi et al. (2014) to question the adaptation effectiveness. However, according to Nightingale et al. (2020), this heat related issue is common in most of the urban informal settlements located in the global south. Furthermore, the increased frequency of storms accompanied by strong gusty winds presents an additional significant hazard. The least perceived challenges are distinguished by periods of intense rain that are both less predictable and shorter in duration. Heat stress may be less acknowledged in comparison to storms and rains due to its lack of direct physical impact on dwellings, and this is concerning since they implement adaptive procedures in response to the immediate effects of weather emergencies (Nightingale et al., 2020). Nevertheless, the substantial reduction of trees and vegetation in the region, coupled with a notable increase in various illnesses, has led them to believe in the presence of climate change. The major findings highlight the unpredictable and extreme nature of the weather change pattern, as informed by LK.

5.2.2 LK driven adaptation strategy

Local residents apply their acquired understanding of material and construction skills in a creative manner, while also drawing upon traditional wisdom in an ordinary manner. Satterthwaite et al. (2020) argue that local perception is crucial for effectively responding to climate change. However, in this specific context, durability and cost-effectiveness take precedence over climate adaptivity. They transition from constructions made of 'Golpata' and 'Bamboo' to structures made of 'Tin' and 'Timber' in terms of durability. In order to achieve cost-effectiveness, it is common practice to recycle and reuse materials, as well as acquire materials from more affordable sources. However, this approach can occasionally result in more maintenance requirements, as anticipated by Santamouris (2020). They employ their existing expertise to address various challenges. For instance, they elevate the plinth above the highest anticipated flood level to prevent flooding. They strategically position windows to optimize ventilation and manage indoor temperature. Additionally, they install a false ceiling to mitigate indoor heat issues, based on their understanding of climate change. According to the definitions provided by Jabeen et al. (2010) and Ahmed (2018), these coping strategies are all grassroots in nature and are highly effective in terms of adaptability. Their approach is distinctive as it relies solely on their expertise and is predominantly carried out autonomously. However, due to the utilization of resilient materials like "tin" and "timber," which are relatively recent in this context, they may sometimes necessitate expert assistance. Due to financial constraints, individuals often construct their housing incrementally to avoid excessive financial burdens. However, their adaptation with relatively newer materials can sometimes result in shortcomings, which contradicts Pelling's (2011) claim that adaptation with locally available materials is more effective. Extreme weather occurrences prolong the financial burden of house adaption, which has recently increased dramatically, aggravating the issue as predicted by Moser and Satterthwaite (2008). In order to alleviate these burdens, individuals instinctively adhere to their indigenous understanding of materials and techniques, as discussed by Alam et al. (2018) in relation to the decline in overall quality of adaptation. Typically, they achieve a harmonious combination of conventional knowledge and modern methods in a rapidly changing and delicate environment setting as researchers expected.

5.2.3 Effectiveness of LK driven approach

The efficacy of local resident-led efforts in adapting to climate change has yielded varied outcomes. They have effectively addressed the issues of heavy rains and flooding by using durable materials such as 'tin' and elevating platforms using 'concrete'. The use of "timber post" as a structural element has furthermore played a role in alleviating storm damage. According to Jabeen et al. (2010), this might be referred to as a success that is specific to any particular circumstance. Moreover, when compared to their prior dwellings, these approaches also lead to a decrease in maintenance cost and an augmentation in the amount of space inside, which is typically observed in housing adaption situations (Roy et al., 2018). Nevertheless, inhabitants have claimed that their efforts are mainly ineffective in attaining a desirable interior temperature, which has been identified as a prevalent climate risk noted by Nightingale et al. (2020) in the context of urban informality. Although 'Tin' offers better protection against storms and rain, it intensifies heat issues and leads to reliance on excessive electricity consumption, resulting in substantial energy expenses. This not only worsens their financial burden, but also intensifies their physical health risks due to the uncomfortable indoor heat. In regions with high population density and limited ventilation options like urban informal context, the issue becomes significantly more intricate (Revi et al., 2014). According to Barnett & O'Neill (2013), this adaptation outcome exhibits resemblances to maladaptation, which subsequently exacerbates the burden. Moreover, they face financial limitations and uncertainty about their tenure, which hinder their ability to make significant investments in order to attain longevity, a necessary condition for successful adaptation (Archer, 2012). Despite these

challenges, individuals continue to demonstrate a strong desire to enhance their quality of life. Therefore, it might be contended that the effectiveness is only partially achieved, as it may not consistently meet individuals' needs, especially in regard to thermal comfort.

5.3 Recommendation

Local residents in the Greenland slum of Khulna demonstrate a significant use of their local knowledge, blending it with modern practices to forge a unique new path and actively transform their housing. From the evidence, it is clear that the practice shows some success along with a few shortcomings, especially managing heat-related issues and financial constraints. Based on this result, to convert this LK-informed housing transformation effort into a more effective one, it is crucial to provide some targeted recommendations in terms of material choice, financial management, labor management, and construction technique for residents, policymakers, and built environment specialists. Regardless of the specific context, we can learn a lot and make recommendations for a broader urban informal context, but we can't apply them universally without ensuring context similarity.

Table 16: Table of immediate recommendation based on findings (Source: Author, 2024)

	Local residents	**Policy makers**	**Built environment professionals**
Material Choice - Searching heat resistant material (Current need)	1. Explore among available materials that offer both durability and heat resistance to combat the effects of both storms and heat stress simultaneously. 2. Incorporate locally sourced organic materials such as 'Golpata' or 'Bamboo' in conjunction with modern materials like 'Tin' and 'Timber', specifically for the exterior surface of the structure itself. And protect it from rain using a 'Polythene' cover. [An existing model in the given environment.] 3. Apply and recycle existing insulating materials that are already being utilized.	1. Financial support could be provided that actively encourage the use of climate adaptive material especially heat-resistant materials in slum areas. 2. A survey could be conducted encompassing economical and long-lasting materials suitable for communities at risk and inform peoples about the outcome.	1. Research could be conducted on cost-effective heat-resistant materials and the durability of organic materials. 2. Incorporating recycled and locally sourced materials into potential future solutions could be suggested.

Financial Management - searching emergency fund (Current need)	1. Maintain a consistent practice of incremental development and prioritize investment in crucial matters, such as enhancing the ventilation system. 2. Endeavor to establish a personal housing emergency fund that can provide residents with financial security, eliminating the need to take out loans or borrow money. 3. Enhance the current community savings fund to promote incremental development, while also providing a flexible repayment option as needed.	1. Vulnerable communities could be offered low-interest loans for improving post-disaster homes. 2. Easy access to credit could be enabled to secure the stability of one's livelihood, which might in turn motivate individuals to establish personal savings for the purpose of emergency housing.	1. A cost-effective housing module could be developed by adapting traditional mechanism and construction methods that allow for easy incremental building. One possible solution to address budgetary limitations is to implement cost-effective construction methods.
Labor Management -improving self reliance (Current need)	1. Foster self-sufficiency and transmit knowledge by exchanging talents within the family and community. 2. Pursue training opportunities to acquire proficiency in contemporary methodologies for enhancing capability. 3. Engage the younger generation in the construction and repair processes.	1.Training program could be established focused on sustainable construction methods for communities that are at risk or susceptible to climate induced damage. 2.The labor force engaged in post-disaster emergency/voluntary work could be managed, as maladaptation is particularly prevalent during this period.	1. In-situ Collaborative building construction workshop could be arranged to enhance resident-driven adaptation. 2. A documentation of local techniques could be conducted with their positive outcomes for future use.
Construction Technique -Achieving heat resiliency (Current need)	1. Instigate all available insulating measures. 2. Identifying a more appropriate choice for placing new windows opportunity based on dimensions and placement. 3. Maximize the use of the area below the roof by adding false ceiling.	1. Communal climate adaptive infrastructure development project could be offered, such as introducing cooling methods through a large-scale plantation project or developing a drainage system by	1. Housing module with overhead storage, upper deck or mezzanine could be explored as this kind of practice already started there with residents' self initiative. 2. Traditional construction

	4. Utilize the most effective traditional knots to ensure the durability of the connections between the plinth, skeleton, and roof. 5. Retain the option to elevate the plinth if necessary.	implementing bio-swells.	techniques related to passive cooling and ventilation approaches could be explored.

Based on these site-specific measures, residents, policymakers, and built environment specialists chould collaboratively solve any issue related to resident driven housing transformation in urban informal settlements.

5.4 Potential for further study

The housing reform effort currently taking place in the Greenland slum in Khulna is being led by the people, and mostly LK informed. In order to push further this research, it would be beneficial to undertake a longitudinal study over an extended duration to determine the efficacy of different climate adapting strategies using a more extensive dataset. Subsequently, researchers would systematically emphasize and quantify the effects of their incremental adaptation strategy on their lives through empirical study. Particularly, it has been seen that local adaptation measures can significantly affect health issues. Further investigation is needed to identify the most suitable adaption method that is tailored to the specific climate hazards in a given setting that could mitigate health risk by addressing it properly. Furthermore, this research reveals that economic constraints play a crucial influence in decision making. The impact of economic constraints on different settlements can be examined through looking at how it restricts investment in the adaptation process. Additionally, economic constraints can aid in the development of sustainable finance mechanisms. In addition, financial mechanisms play a crucial role in determining the choice of materials and techniques for a given context. This decision-making process also takes into account the location and the need to create a composite structure. Furthermore, it involves considering whether it is required to further explore and rely on traditional materials and techniques based on their effectiveness. Nevertheless, further investigation can provide suggestions regarding the effectiveness of LK-informed and resident-driven housing reform. The study's limitations stem from its high contextual specificity, restricted dataset, and disregard for the majority of scientific and statistical information. However, it is important to note that this settlement does not have a legal tenure security, which is a critical aspect in housing transformation. This lack of security could have a big impact on the overall dynamics of the study and provide insights on how to implement long-term housing adaptation strategies based on local knowledge.

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Appendix 2: HH Interview, FGD- Guide & Guidelines for Observation

Household Interview Guide (Semi-structured)

I am Nur Mohammad Khan, a graduate student at UMD-20, IHS, and EUR.

I am conducting this interview as part of my UMD thesis, "Local Knowledge for Resilient Communities: Resident-Driven Climate Adaptive Housing Transformation in Greenland Slum, Khulna." The data collected here will be analyzed to investigate the role of local knowledge possessed by the residents of Greenland Slum from their experience and ancestors in climate-adaptive housing transformation in response to climate threats. This report would aim to promote the overall well-being of local residents and gain insight from them, especially those facing extreme climate change-related challenges in their daily lives. This interview's goal is to determine how to better utilize local knowledge to tackle climate change-related problems through housing transformation at both household and community levels.

We expect the interview to last approximately 30 minutes, following the rules and regulations established by the IHS and EUR, including adherence to ethical standards. We will maintain the confidentiality of the respondents' identities and record this session for proper transcription of your responses later. You have complete discretion in deciding how much of their personal experience they will disclose during the interview. You also have the right to end the interview at any time.

If the respondent agrees to these conditions, the interview can proceed to the subsequent stages.

Research Question:

How local knowledge (LK) contribute climate-adaptive housing transformations in Railway Slum, Khulna, Bangladesh?

Demographic information:

Household ID:	
Type of tenure:	
No. of household member (How many generations belongs):	
Highest education level of Household members:	
Source of livelihood (how many of them involved?), annual income & emergency fund (specially for HH reconstruction purpose):	
Assumption of utility cost (water, waste, electricity):	
Connection to local community network/institution:	
The length of stay at this location and settlement:	
History of migration (Reason):	

The reason of choosing this location (Pros & cons):	

Sub Question 01:

How do residents in Railway Slum perceive climate threats based on their local knowledge?

Variable- Local Knowledge informed Climate Change perception

Q.1. In recent years (3-5), how do you feel about the changing weather pattern? (Dimension-1: Heatwave/flooding/tropical storm/prolonged monsoon/cold wave) *-Identify most critical events that you face.* *-Measurement method of extremity/severity.*	
*Please mention based on three time period- Now/10 years ago/about to your childhood)	
Heat stress- Ventilation issue	**1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
Tropical storm- Wind issue	**1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
Prolonged monsoon- Rain related issue	**1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
Cold wave	**1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
Others: Drought, Potable water crisis, sanitation problem etc.	
Q.2. How do changed weather patterns (climate hazards) impact your day-to-day life compared to past? (Dimension-1: Physical- Housing, service /Non-physical- Financial, Health & well being Dimension 2: Social/Economical/Environmental) *-Focus on recent years/events.* *-Focus on their prioritized climate change related problem.* *-Focus on living condition at current dwelling.*	
*To what extent do you think each of the impacts influence your life? - **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)	

Q.3. During this critical time, how do you try to tackle the problems with your long experience? *-Knowledge (traditional) based preparation before the climate hazard, such as identifying the presence of natural indicators before any hazard occurs.* *-How do you usually learn about upcoming climate threat?* *-How seniors of the family and community provide information and advice related to climate threat?*
*****To what extent do you think natural indicators help you to identify upcoming climate threats? Can you mention the time period also. - **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
*****To what extent are you worried about climate change related threats? Mention highest problem making incidents. **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
*****To what extent do you think your personal experience help you to be aware of climate threats? - **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest) *****To what extent do you think your societal experience help you to be aware of climate threats? - **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)

Sub Question 02:

How do residents utilize local knowledge of materials and construction methods to adapt their dwellings for improved functionality and liveability?

Variable- Local Knowledge informed Housing Transformation & Climate Adaptive Housing Transformation

Q.4. To address the climate threat raised recently, what changes have you made to your dwelling in recent years (3-5 years)? (Dimension-1: Plinth/Partition/Roof/Locational change. Dimension-2: Ventilation/Insulation/ Flood resilience. Dimension 3: Strengthening structure/ Strengthening roof/ insulation-roof cover/ Functional transformation/ Plantation. Dimension-4: Long term/ Short term/Preventive precautions) *-Focus on recent changes within the household territory.* *-Focus on their innovation and preference in terms of material & construction method (could be something using within the community).* *-Try to figure out how they learned what to do.*

-What is their believe about specific method that make the dwelling resilient. Search example they have done something to withstand climate threat. *-What helps you to take that particular decision?*
Heat stress- Ventilation issue
Tropical storm- Wind issue
Prolonged monsoon- Rain related issue
Cold wave
Others: Drought, Potable water crisis, etc.
Q.5. What type of difficulties do you face during the dwelling reconstruction/adaptation process to overcome climate threats? (1. Financial crisis, 2. Labor intensive, 3. Material shortage, 4. technical gap, 5. Lack of legal permission or, others any) *-Try to reform the options in a logical order based on their answer.* *-Availability or shortage of external supports from NGO/Govt.* *-Usual time span to recover*
*****To what extent do you think each of the limitations influence your adaptation process? - **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
Q.6. How do you manage technique, finances, labor, and materials to conduct dwelling reconstruction/adaptation process to overcome climate threats? (Dimension-1: Finance/Material/Labor/Technique. Dimension 2: Self knowledge/Community shared.) *-How do they learn it?* *-Do they innovate anything?* *-Do they share it with others? Is any of their solution use other people of the community?* *-Connect their improvements with their ancestral knowledge? Based on their believe over effectiveness of their decision.*
Q.7. How do you tackle emergency situation raised due to climate change? Can you provide any example.
*****To what extent do you think your knowledge of construction method help you to change dwellings to adapt climate threats efficiently? **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)

*To what extent do you think your knowledge of building material help you to change dwellings to adapt climate threats efficiently? **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
*To what extent do you think your knowledge of dwelling construction help you to change dwellings to adapt climate threats efficiently? - Personal (Family), Hire labor, Community help **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
*To what extent do you think your knowledge of financial management help you to change dwellings to adapt climate threats efficiently? – Personal savings, Loan, Debt **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)
*To what extent do you think you are capable to change dwellings to adapt climate threats efficiently? **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)

Sub Question 03:

How effective are resident-driven housing transformations, informed by local knowledge, in adapting climate change threats in informal settlements?

Variable- Climate Adaptive Housing Transformation & Effective Housing Transformation

Q.8. How do you feel now about the specific climate threats based on the changes you have made to your dwellings in terms of comfort and safety? (Dimension-1: Comfortable & Safe/To some extent satisfied/Need change. Dimension 2: Lighting/ Ventilation (cooling/heating)/ Spaciousness/ Hygiene) *-Assess based on specific climate threat & improvements of living condition.* *-What is their standard of measurement?*
* To what extent are you satisfied with your current dwellings in terms of efficiently adapting to climate threats? **1/ 2/ 3/ 4/ 5** (1=Lowest, 5= Highest)

Q.9. What do you think about the risks associated with employing experience based solutions in dwelling transformation? (Dimension-1: Structural risk/Fire hazard/Health hazard/Accidents during construction.) *-Is there any notable occurrence of accident happened?*
Q.10. What would make your local knowledge-informed dwelling transformation more effective in terms of comfortability and adaptability to local climate threats? (Dimension 1: Financial/institutional/ legal/ Technical) *-Highlight the lack of support.* *-Focus on resident-driven transformation.* *-Lack of what you can't make your planned change.*
Q.11. Would you like to add anything more about the urgent and long-term need to adapt to climate threats at the dwelling level?

Focussed Group Discussion Guide (Semi-structured)

Topic 1: Address Climate Threat
Q.1. What is the worst climate related hazard people face here? Is there any notable change you can address in changing weather pattern? *- Try to define the unpredictability of the weather* *- Frequency & intensity of the weather events* *- Can you be alert earlier than the event anymore?*
Q.2. How would your experience help you to address these climate threat? Compare to past how severe the impact? *- The change in Frequency & intensity of the weather events* *- Do you get any help from the seniors of the community?* *-How have you learned about these climate threats?*
Topic 2: Extreme weather event related Problem & Solution
Q.3. What kind of problem and challenge do you face (most of the residents) here most due to these extreme weather event? *(Physical/ Non-physical; Financial/Social/ Environmental/ Political)*
Q.4. How do you tackle these challenges with your knowledge and experience? Do you have any common plans? *- maybe the answer is 'NO' but recall their strength and they still survive. What is the secret?* *-The process of self-help reconstruction.*
Q.5. What do you think is essential for dwellings to adapt to these challenges using your knowledge and experience? *-Focus on the type of support. May be the answer you get following the previous answer.* *-You know what to do but how?* *-The pros and cons of using traditional technique and material (focus on time consuming issue)*
Topic 3: Adaptation measures
Q.6. How do you prioritized which adaptation measure should be taken immediately? *- Immediate & Long-term need. How have you learned about these climate adaptation priorities? From experience/seniors?* *- For dwelling & community level*

Q.7. How do you measure the effectiveness of the adaptation process? *- For dwelling & community level* *-Based on comfortability, safety, risk*
Topic 4: Community Measures
Q.8. Do you collaborate on any projects related to community infrastructure to address climate threat? *-Do you take precautions for disasters, develop warning systems, or collaborate to overcome post-disaster situations?* *-Willingness of people.*
Q.9. Is there any way for residents to share their knowledge and innovation associated to building construction method to face climate threats together? *-Community networks.*
Q.10. During common decision-making, how can the local people hold the stake to express their opinion related to a particular climate problem-related solution? *-Do you find any relation of knowledge sharing here?* *- What is the role leaders/politicians play there?* *-Community networks.*
Topic 5: Others
Q.10. Would you like to add anything more about the urgent and long-term need to adapt to climate threats whether community can work together?
Q.11. What additional measures can be taken to enhance community resilience? *-Are their anything present right now.*

In-depth Observation Check list

(Household- Photographs and Mapping: Spatial Data)

Household ID:	
1. Site periphery and connection to access road - *Is there any? If yes, then how it is made of?*	
2. The purpose of outdoor area - *Any considerable plantation.* - *Toilet/wash area*	
3. Is there any water body or drainage nearby, then how its edge is constructed? - *How the rainwater discharged?*	
4. Observe the dwelling unit - *Address most vulnerable portion* - *Address where the most effort have been put*	
5. Observe all the materials and techniques (especially local and reused materials and techniques) - *Plinth, Wall, and Roof* - *Focus multiple material at single surface* - *Address most common and also considered most efficient building material usually residents used (particularly good for local weather). consider reuse and readily available (could be organic) issue.* - *Use of any damp-proofing, insulating technique and material.*	
6. The position of Opening & their cover - *Privacy and Ventilation*	
7. How the indoor space distributed (knowledge of Summer & Winter) - *Do you find any climatic consideration in space distribution?* - *Is there any multipurpose use based on climatic consideration?*	
8. Do you find any insulating layer? - *Roof cover or layer under roof.* - *Any color or other material coat (Tar) on the outer wall.*	
9. Construction details (finding local techniques) - *Structural joints* - *Is there anything used for strengthening (structure/roof/wall) purpose?*	
10. Rainwater collection.	

**Let them draw their dwelling unit/mapping with the surrounding climate threats and adaptation measures they have taken within 3-5 years.*

Appendix 3: Code book used in Atlas ti.

RQ: How local knowledge (LK) contribute climate-adaptive housing transformations in Greenland Slum, Khulna, Bangladesh?
Boolean operator: CC3 + HT2 > HT1 = HTE 1/2

RQ.1. How do residents in Greenland Slum perceive climate threats based on their local knowledge?
Boolean operator: CC1 (Indicator) +CC3 (Experience & Impact) = CC2 (Threat identification)

CC-1: Weather pattern indicators

- Natural indicators
    - Traditional weather prediction
    - Natural indicators observation
    - Intergenerational knowledge transfer
    - Community-based preparedness
- Less dependence on natural indicator
    - Loss of traditional prediction skills
    - Loss of natural indicators
    - Reliance on media for information

CC-2: Climate threat perception

- **Flood awareness**
- **Rainfall pattern shifts**
    - Shorter and less predictable monsoon season
    - Untimely rain and flooding
    - Insufficient rain for cooling
- **Storm intensity changes**
    - Stronger and more frequent storms
    - Heavy winds
    - Decrease in rainfall during storms
- **Heat stress recognition**
    - Increased temperature over recent years
    - Intolerable heat during summer
    - Dependence on rain for relief
    - Dependence on electric fan for relief
- Winter duration reduction
    - Less severe winters
    - Shorter winter season
    - Reduced intensity of cold and fog
- Salinity level rise
- Seasonal unpredictability

CC-3: Climate hazard impacts

- **Housing damage**
    - House collapse

    - Roof blown
    - Water penetrates
    - Undaunted plinth
- Health issues
    - Heat-related illnesses
    - Seasonal diseases
    - Mental health impacts
    - Vector borne dieses
- Daily life activities disruptions
- Economic consequences
- Social segregation
- Environmental degradation
    - Urban densification
    - Loss of green spaces
    - Increase hard surface

RQ.2. How do residents utilize local knowledge of materials and construction methods to adapt their dwellings for improved functionality and livability?
Boolean operator: CC3 (Threat Vulnerability) + HT2 (Scarcity) = HT1(Decisions)

HT-1: Local knowledge utilization for HT: LK informed HT

- **Material choice and adaptation**
    - Availability of traditional building materials
    - Traditional to modern material shifts
    - Available building materials nearby
    - Material durability considerations
    - Material recycling & reuse
- **Indigenous construction techniques**
    - Adjust plinth height
    - Plaster the plinth
    - Develop segregated plinth section with barrier
    - Protect the roof
    - Add insulation and buffering layer
    - Create new opening for ventilation
    - Considering size & direction of new opening for ventilation
    - Local ties, bracings, & knots for strengthening
- Local knowledge transfer methods
- **Indigenous labor management**
    - Self-help development
    - Hire minimum external labor
    - Skill development within family
    - Community labor cooperation
- **Indigenous financial strategies**
    - Incremental development with self deposit
    - Community-based financing & loan management
    - Personal savings development
    - Cost-saving construction methods
- Activity & behavioural adjustments
- Limited resource management

- Temporary solution mindset

HT-2: Challenges and limitations of HT: Perceived vulnerabilities

- Financial constrains
- Regulatory barriers
    - Tenure insecurity
    - Regulation of impermanence
- Technical knowledge gaps
- Material scarcity & non-durability issues
- Climate change unpredictability
- Social constraints
    - Theft prevention measures
    - Privacy concerns in design

RQ.3. How effective are resident-driven housing transformations, informed by local knowledge, in adapting climate change threats in Greenland Slum?
Boolean operator: HT1 = HTE 1 / HTE 2 whether HT1 have impact on CC3

HTE-1: Housing transformation positive outcome

- Improved liveability
    - Flood resistance measures
    - Heat mitigation strategies
    - Increased light and space
- Durability improvements
    - Storm/wind protection features
    - Enhanced structural integrity
    - Reduce maintenance cost
- Cost-effectiveness of adaptations
- Risk identified
    - Fire hazards
    - Structural instability

HTE-2: Housing transformation Negative outcome

- Poor standard of liveability
    - Scarcity of light & ventilation
    - High indoor temperature
    - High electricity dependency
- Non-durable improvements
    - Durability concerns remain
    - Increased maintenance cost
- Cost-ineffectiveness of adaptations
- Risk unidentified
    - Fire hazards
    - Health risks

Appendix 4: Code co-occurrence value to answer research questions

	Economic consequences Gr=44		Environmental degradation Gr=43		Health issues Gr=32		Less dependence on natural indicator Gr=16		Natural indicators dependency Gr=16		Physical damage Gr=52		Social segregation Gr=11	
	count	coefficient	count	coefficient	count	coefficient	count	coefficient	count	coefficient	count	coefficient	count	coefficient
Flooding events Gr=10	0	0,00	1	0,02	0	0,00	0	0,00	0	0,00	2	0,03	0	0,00
Heat stress recognition Gr=68	2	0,02	9	0,09	11	0,12	3	0,04	3	0,04	0	0,00	2	0,03
Rainfall pattern shifts Gr=17	2	0,03	0	0,00	0	0,00	0	0,00	3	0,10	6	0,10	0	0,00
Seasonal unpredictability Gr=9	1	0,02	1	0,02	0	0,00	0	0,00	5	0,25	0	0,00	0	0,00
Storm intensity changes Gr=50	7	0,08	1	0,01	4	0,05	1	0,02	3	0,05	23	0,29	0	0,00

Code co-occurrence value for figure 10.

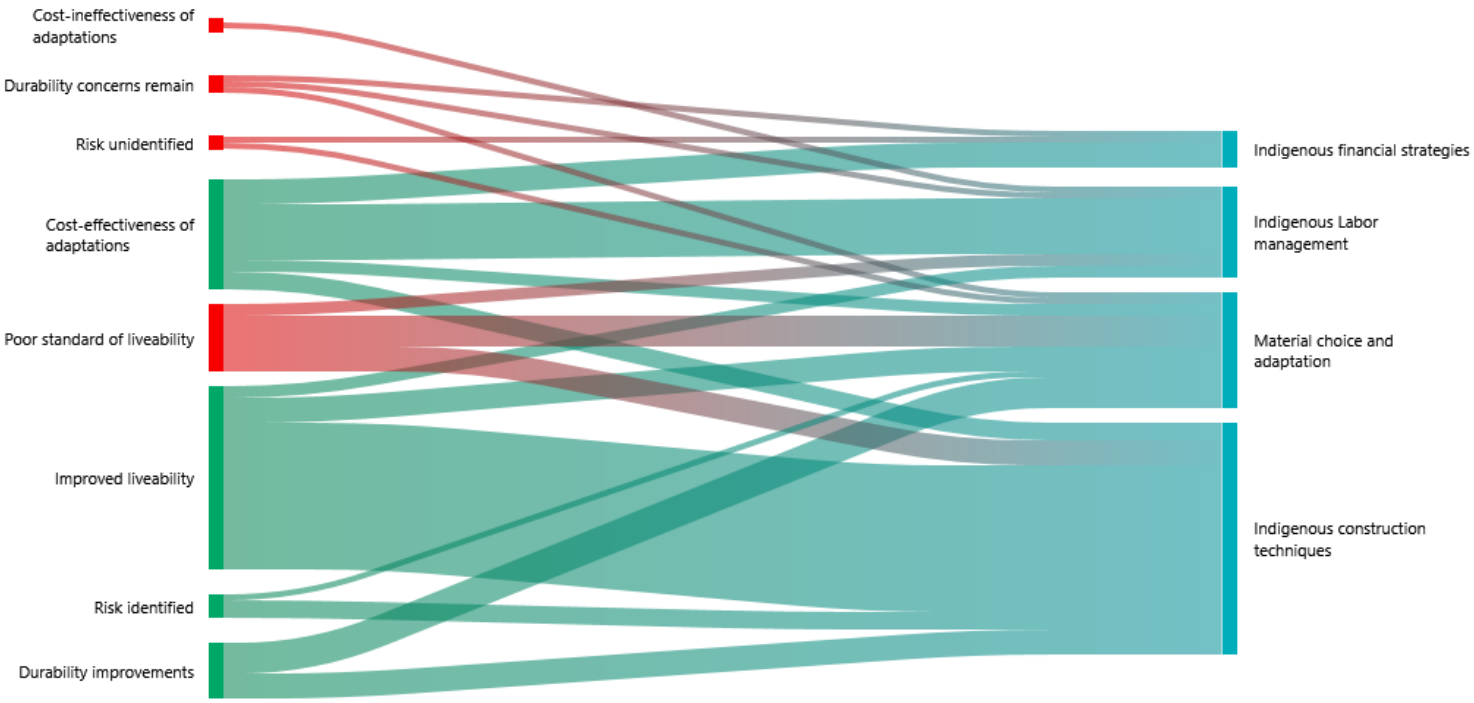
	Indigenous construction techniques Gr=111		Indigenous financial strategies Gr=39		Indigenous Labor management Gr=55		Material choice and adaptation Gr=90	
	count	coefficient	count	coefficient	count	coefficient	count	coefficient
Economic consequences Gr=44	8	0,05	8	0,11	7	0,08	8	0,06
Environmental degradation Gr=43	1	0,01	0	0,00	0	0,00	2	0,02
Financial constrains Gr=55	3	0,02	11	0,13	2	0,02	14	0,11
Health issues Gr=32	1	0,01	0	0,00	0	0,00	2	0,02
Labor intensive Gr=6	1	0,01	0	0,00	2	0,03	0	0,00
Material scarcity & non-durability issues Gr=22	2	0,02	0	0,00	0	0,00	15	0,15
Physical damage Gr=52	10	0,07	0	0,00	1	0,01	6	0,04
Regulatory barriers Gr=41	2	0,01	0	0,00	0	0,00	6	0,05
Social constraints Gr=14	1	0,01	0	0,00	0	0,00	1	0,01
Social segregation Gr=11	0	0,00	0	0,00	1	0,02	0	0,00
Technical knowledge gaps Gr=8	1	0,01	0	0,00	2	0,03	3	0,03

Code co-occurrence value for figure 23.

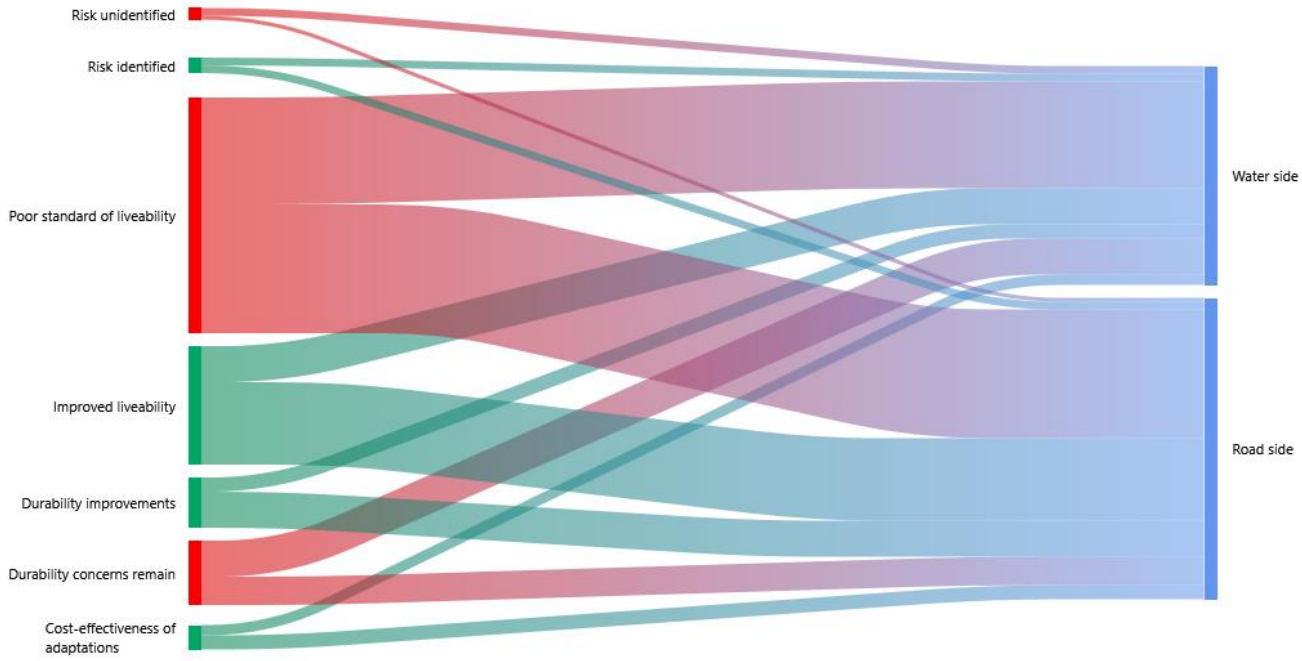
	Indigenous construction techniques Gr=111		Indigenous financial strategies Gr=39		Indigenous Labor management Gr=55		Material choice and adaptation Gr=90	
	count	coefficient	count	coefficient	count	coefficient	count	coefficient
HTE-1: Housing transformation positive outcome Gr=63	32	0,23	4	0,04	11	0,10	11	0,08
HTE-2: Housing transformation Negative outcome Gr=93	4	0,02	2	0,02	4	0,03	7	0,04

Code co-occurrence value for figure 26.

Complex relation among indigenous techniques to measure effectiveness.



Location wise distribution of indigenous techniques to measure effectiveness.



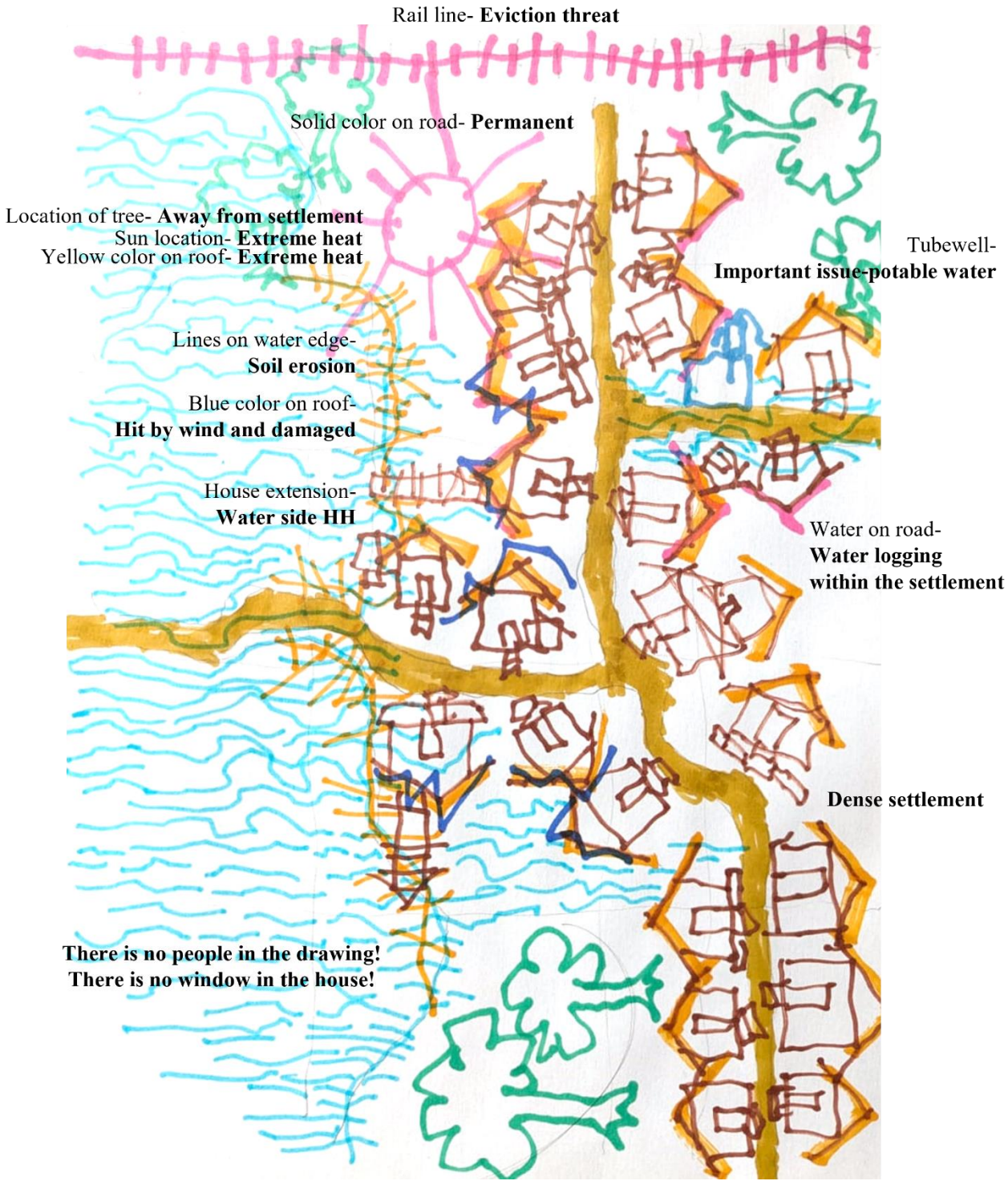
The following table presents the relationship among weather indicators, hazard, & decision user have already made.

Residents' perceptions and experiences, in conjunction with traditional knowledge and lived experiences, can facilitate the development of effective context-specific adaptation measures. With an understanding of the local climate challenges and limitations developed due to it, in the next section, how it drives resident-driven housing transformation will be explored.

Indicator	**Frequency of code**	**Climate threat**	**Impacts**	**Resident driven decisions**	**Frequency of code**
Increase seasonal sickness	23	Heat stress (Seasonal)	Non-physical impact (Health)	Being safe from heat: Reducing heat impacts at indoor and outdoor by increasing ventilation and shaded area.	22
Persistence of heat related problems	68		Social impact	Having interactive space within house: Introducing shared space where people can pass time together	10
1. Increased utility bill 2. Reduction of household income	14 X		Economic impact	Reducing heat inducive utility bill by proposing passive cooling system	31
Reduction of shaded area provided by trees and their appearance	30		Environmental impact	Reintroduce plantation & create more shaded area	X
No wind before the storm & high temperature	22	Storm with gust wind (Extreme weather event)	Physical impact (Structural)	Increase structural stability by taking proper measurements like using durable materials and taking pre-disaster measurements for high wind speed and heavy rainfall	89
Similar weather pattern related to traumatic experience of previous storm	15		Non-physical impact (Psychological)		
Reduction in local help & connection during storm weather	11		Social impact	Increase interaction among community: Use local labor and technique before and after any disaster	55
Increased housing maintenance cost	55		Economic impact	1. Using affordable & local materials 2. Incremental design possibilities	68

Appendix 5: Community Map

The map is drawn by a 13-year-old child with the instruction of local residents where the data collectors help to develop this drawing. This drawing represents an imagination of a real scenario.



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