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► To cite this version:

Rasool Mehdizadeh, Olivier Deck, Nathalie Pottier, Anne Péné-Annette. Post-Disaster Reconstruction of Residential Buildings: Evolution of Structural Vulnerability on Caribbean Island of Saint Martin after Hurricane Irma. *Sustainability*, 2023, Special Issue Post-disaster Recovery from a Sustainability Perspective, 15 (17), pp.12788. 10.3390/su151712788 . hal-04188484

HAL Id: hal-04188484

<https://hal.science/hal-04188484>

Submitted on 25 Aug 2023

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Article

Post-Disaster Reconstruction of Residential Buildings: Evolution of Structural Vulnerability on Caribbean Island of Saint Martin after Hurricane Irma

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Abstract: This article presents a summary of the results obtained as part of the ANR (French National Research Agency)-RELEV project, which focuses on the long-term recovery and reconstruction of the island of Saint Martin following the passage of Hurricane Irma in 2017. This hurricane was classified as category five on the Saffir-Simpson scale, with an average wind speed of 287 km/h. It caused catastrophic damage along its path and highlighted the significant vulnerability of Caribbean societies to this type of phenomenon. This article focuses on the reconstruction of residential buildings on the French part of the island of Saint Martin. It aims to identify and analyze the factors that have favorably or unfavorably influenced their reconstruction and their structural vulnerability reduction. The research is based mainly on a series of interviews with local actors (construction and insurance companies, architects, territorial services, etc.), an online survey of residents (180 responses), and a field survey involving visits to 104 buildings with interviews of the occupants. The results obtained show that having access to financial resources for the reconstruction of buildings is central. However, different parameters must be considered to understand the disparity of situations and identify the factors that have most favorably contributed to the speed and quality of reconstruction and reduction of vulnerability. Even five years after Irma, a significant number of buildings on the island remain either unrepaired or abandoned. These buildings nevertheless constitute a danger in the case of strong winds (becoming a source of projectiles) and have a negative impact on the reputation and attractiveness of the island. The results reveal that in general, buildings in Saint Martin are slightly more resilient than they were prior to Irma, while presenting a great heterogeneity of situations.

Keywords: reconstruction; tropical cyclone; residential buildings; vulnerability evolution; Saint Martin



Citation: Mehdizadeh, R.; Deck, O.; Pottier, N.; Péné-Annette, A. Post-Disaster Reconstruction of Residential Buildings: Evolution of Structural Vulnerability on Caribbean Island of Saint Martin after Hurricane Irma. *Sustainability* **2023**, *15*, 12788. <https://doi.org/10.3390/su151712788>

Academic Editor: Ali Bahadori-Jahromi

Received: 30 June 2023

Revised: 7 August 2023

Accepted: 10 August 2023

Published: 24 August 2023



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1. Introduction

Over the past five decades, climate-related natural hazards such as hurricanes and floods have become more frequent and more destructive [1], causing significant loss of life and property [2]. They have significant human, economic, social, emotional, environmental, and political consequences [3,4], and disproportionately impact vulnerable people in society [5]. Against this backdrop, the international community is increasingly concerned with the countermeasures needed to reduce these destructive effects [6,7].

Damage and disorganization in the aftermath of a disaster act as a magnification of the vulnerabilities of the affected territory [8]. Nonetheless, a natural disaster can serve as a catalyst and a window of opportunity for anthropic changes with positive effects on the environment [9–11]. It can create an opportunity to take advantage of the post-disaster period to rebuild differently [2,12].

Many working on disaster issues now argue that recovery processes should be more progressive than merely returning communities to a ‘pre-hazard state’ [6]. Moatty et al. (2021) believe that the post-disaster period must meet the injunction of rebuilding resilient territories and societies, based on the postulate that this period is a ‘window of opportunity for change’ [13]. Disasters might provide opportunities for encouraging change, developing structural and institutional transformations of societies to reduce levels of inequality, and increasing the long-term potential for sustained development [14]. Wisner (2017) suggests that to have “recovered”, a household should have not only re-established its livelihood, physical assets, and patterns of access, but also should be more resilient to the next extreme events [15].

Disasters reveal existing vulnerabilities, and the lengthy process of post-disaster housing recovery is seen as a chance to tackle multiple interconnected vulnerabilities while constructing safer homes [16]. Post-disaster reconstruction of buildings can then play a crucial role in restoring communities, ensuring their resilience after a catastrophe [16], and could be an opportune moment to prepare for next disasters [17]. In line with this, the concept of “build back better” has been widely used and discussed by researchers, policymakers, and practitioners when confronted with disasters or crises. It emphasizes the opportunity to rebuild in a more resilient, sustainable, and equitable manner, considering lessons learned from the event [1,18–20].

Nonetheless, post-disaster reconstruction programs have been considered more complex than regular reconstruction and development programs, given that a successful post-disaster reconstruction process needs to account for the history and psychological, physical, and economical sustainability of the community [21]. The issues and challenges of post-disaster reconstruction process and the identification of factors influencing the success or failure of the projects have been studied by many scholars in different cases.

Kaklauskas et al. (2009) believe that the identification and analysis of these barriers to post-disaster recovery are the key to effective and sustainable recovery [22]. According to Ismail et al. (2014), the most important factors are related to: problems in integration, finances, inappropriate assessment, communication and coordination, inadequacies of resource procurement, ineffective design, transportation, corruption, and delay [2]. Ahmed (2011) also presents a list of success factors for post-disaster reconstruction in developing countries and presents some examples of good practices and the reasons for their effectiveness [23]. Barakat (2003) stated that disasters have a greater impact on the built environment of developing countries than industrialized ones [24]. According to Zhou et al. (2022), the main barriers to an effective and sustainable recovery can be classified into the following topics: the involvement of local communities, social capital, financial and economic issues, leadership, and physical reconstruction [1]. Other research works show that social capital [25], income, and substantial financial resources [26] are also important factors that affect the post-disaster recovery efficiency at the household level.

In a post-disaster context, social capital is seen as an essential resource that enables individuals, families, and possibly communities to access and mobilize additional sources of support through existing and emerging social networks [27]. Zhang (2016) found that low-income working families tend to be more vulnerable and suffer worse economic conditions for a longer time after disaster events, while high-income families can recover more quickly after the reconstruction period [28]. Strong leadership from responsible institutions and organizations is also highlighted as one of the impacting factors on reconstruction efficiency [1]. Dube (2020) points out that some reconstruction processes have failed to effectively benefit disaster-impacted populations because the concept of building-back-better was lacking [20].

This study specifically addresses the post-disaster reconstruction challenges faced by residential buildings on Saint Martin Island following Hurricane Irma. It focuses on identification and analyses of factors that have favorably or unfavorably influenced the reconstruction process and the reduction of cyclone vulnerability of buildings. The existing literature frequently overlooks the significance of communities’ and local people’s

perceptions in the recovery process [4], despite their crucial role in improving the quality of post-disaster recovery [29–31]. Therefore, this article aims to investigate, through questionnaires and direct interviews, the viewpoints of local actors and affected residents of Saint Martin regarding the evolution of buildings' vulnerability to cyclones. Their perceptions are then compared with the real evolution of the vulnerability, evaluated objectively through field surveys. The assumption is that any gap between the perceived vulnerability and real one could have negative impacts due to overconfidence or excessive fear.

This article seeks to contribute to a better understanding of the post-disaster reconstruction process and provides valuable insights for future risk mitigation and recovery efforts. The remainder of the paper is as follows: After presenting the context of Saint Martin and its pre-Irma urban development strategies, Section 2 describes briefly the employed study methods, focusing on their modality and objectives. Sections 3 and 4 then present and discuss the obtained results, highlighting the favorable and unfavorable factors affecting the reconstruction of buildings. Section 5 concludes and presents some recommendations.

1.1. Irma Hurricane and Saint Martin Island

The island of Saint Martin is situated at the northern end of the Lesser Antilles Arc [32], located in the Caribbean Sea (Figure 1). It is divided between two countries: the southern part, Sint Maarten, is a constituent country of the Kingdom of the Netherlands, while the northern part, Saint Martin, is an overseas collectivity of France, having Marigot as its capital. Whereas Sint Maarten is outside the territory of the European Union, Saint Martin is inside [33].



Figure 1. Map of Saint Martin Island (adapted from Eric Gaba [34]).

Hurricanes are relatively common in the Caribbean and have regularly caused deaths and major damage on the islands of the northern Antilles [35]. Since the beginning of the 20th century, 17 hurricanes and at least 9 tropical storms have been recorded on Saint Martin, the most significant of which were Luis in 1995, Lenny in 1999, and Irma in 2017 [36].

In their respective studies, Jouannic et al. (2020) and Pasquon et al. (2022) provide an extensive analysis of the urbanization history of Saint Martin [33,37]. Between 1954 and 2017, an increasing number of buildings were constructed in areas exposed to marine flooding risk on Saint Martin Island (more than 3000), facilitated by successive tax exemption laws since the late 1980s that promoted economic investment in the French overseas territories. There is no clear evidence that historical hurricanes Luis and Lenny directly caused a reduction of new construction in marine inundation zones. However, a reduction of new construction in marine flood risk areas (45%) was observed in Saint Martin between 2010 and 2017, although it remains difficult to find any correlation between this change and the approval of a natural hazard prevention plan (PPRN in French) in 2011 [33] which aims to regulate and constrain the urban planning rules in sectors exposed to natural hazards.

In 2017, Hurricane Irma, classified as category five on the Saffir-Simpson scale, generated violent winds with an average speed of 287 km/h [38] and waves with heights reaching 10 m [39], causing marine submersion phenomena on the coast [33,40,41]. Irma was the first recorded tropical cyclone crossing the Lesser Antilles islands with such powerful winds [36,40].

The island suffered tremendously from Irma, which caused the death of eight people and the disappearance of two people on the French side [38], four deaths on the Dutch side [42], and the destruction of most of the island's infrastructure [43]. Approximately 19.7% of buildings in Saint Martin were estimated to be either destroyed or severely damaged [44]. However, the buildings, even those significantly damaged, seem to have generally fulfilled their role of protecting people. In the aftermath of Irma, Saint Martin was disconnected from the world, devoid of electricity, water, and any means of communication for several days [36], but the service was restored fairly quickly given the extent of the damage. There was then a considerable decrease in social and economic activities [45].

This hurricane highlighted the high vulnerability of West Indian societies to this type of phenomenon, particularly on the island of Saint Martin. The total cost of insured damage is estimated at 1.176 billion euros for the French part of Saint Martin [37]. Including uninsured property and the island of Saint-Barthélemy (St Barthélemy, a tiny island located approximately 50 km southwest of St. Martin, is also under the administration of France), the total cost of damage could approach 3 billion euros [46,47].

Apart from the immediate challenges faced during the emergency response after Irma, the reconstruction of buildings encountered a multitude of obstacles and difficulties in both the short and long term. These included issues related to the coordination between local actors, a shortage of resources (ex. financial, quality materials), a lack of locally available qualified skills, etc. The identification and analysis of these factors constitute the primary objective of this article, which will be presented in the subsequent sections.

1.2. Evaluation of Structural Damages after Irma

Hurricanes are meteorological events that cause a variety of different hazards. It is therefore complex to determine the cause of damage when diagnosing buildings (particularly between damage caused by wind and that caused by marine submersion).

The study of the post-Irma reconstruction process is tightly linked to the assessment of building damage, for which there is a certain level of uncertainty. Various studies have been carried out to quantify the damage to buildings (individual homes and collective buildings) and the progress of reconstruction. In particular, the study carried out as part of the European Copernicus project "Risk and Recovery Mapping" (Copernicus, 2018 and 2019) can be mentioned.

Analysis of the satellite data shows that more than 50% of structures suffered significant damage (classified as “moderate”, “severe”, or “destruction”). Nevertheless, the findings from these results are subject to various uncertainties stemming from factors such as acquisition method, image resolution, frequency of image acquisition, the meteorological context, image interpretation, and diagnostic bias [48–51]. The question of uncertainty in damage evaluation can be addressed by comparing this assessment with other estimations. With this in mind, the ANR-TIREX project [52] has compared assessments using two approaches: a satellite-based approach (Copernicus (<https://emergency.copernicus.eu/>, accessed on 10 July 2023) and SERTIT (<https://plateforme.icube.unistra.fr/sertit/index.php/Accueil>, accessed on 10 July 2023)) and a flying drone approach [53], which normally gives a better assessment of building damage. This comparison can be further complemented by the assessments carried out by M. Moulin (2018) and her team during a field mission in September 2017 [54]. As the study was carried out by a group of architects, it seems reasonable to assume that the results are more reliable [55]. Figure 2 summarizes the damage observed by these architects and the comparison with the Copernicus estimations. For instance, out of the 456 buildings categorized as “no action” by architects, the Copernicus approach considers that 55% of them have a “negligible to slight” damage, 25% have “moderate” damage, and 11.4% have “severe” damage, and it classifies 8.6% of them under the “Destruction” category.

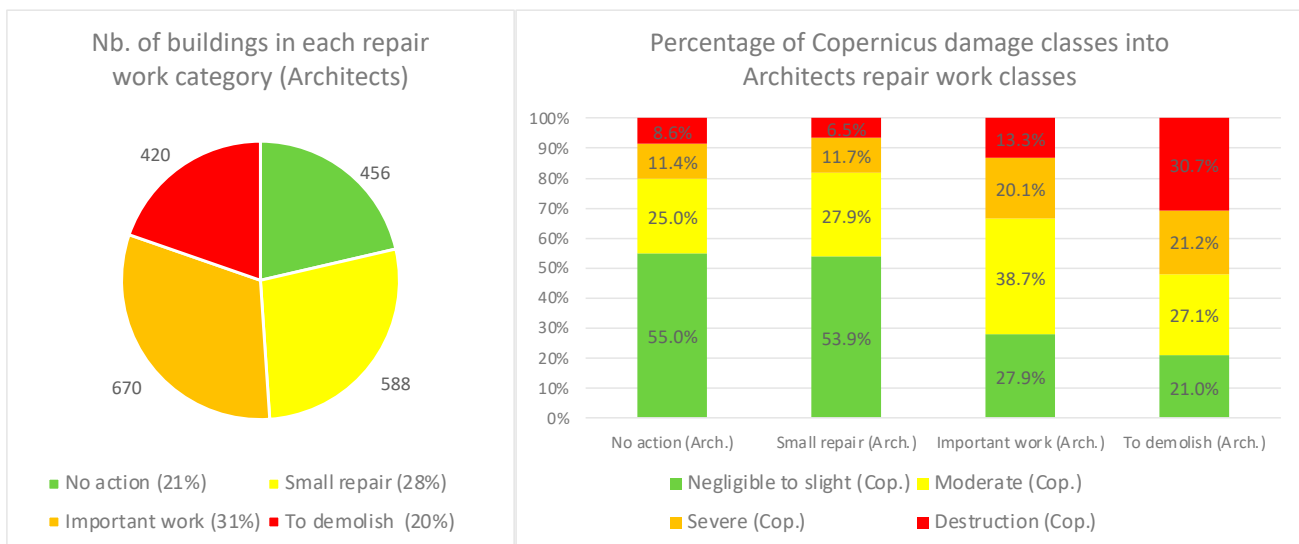


Figure 2. Synthesis of damage assessed by Moulin’s fieldwork (2018) [54] and comparison with that estimated by the satellite approach (Copernicus) [56].

A brief comparison of the average global damage calculated from the exhaustive Copernicus approach (13,163 structures) and that of the architects (2134 structures) shows a tendency for the satellite approach to underestimate damage (−20% approximately), confirmed by the more rigorous comparison of the 2134 common structures between the two approaches. A similar comparison, limited to 148 common structures, shows an underestimation of the average damage of around 27% for the drone approach and 36% for the satellite approach.

More in detail, while the most significant damage (destruction/to demolish) is more or less identical, it is the major damage (severe or moderate) that is underestimated by the satellite approach, in association with an overestimation of minor damage. An explanation for the overestimation of damage by architects is that damage is not assessed solely at the roof level. The expert’s assessment also considers damage to the lower parts of the building (openings, interior). A bias is therefore possible, due to the existence on Saint Martin of habitats that are sometimes very precarious and the absence of an inventory before Irma.

There are a few methodological obstacles to assessing and comparing damage. The first concerns the definition and harmonization of damage classes. The second concerns the lack of knowledge about the initial state of the buildings—some of which may be in an initial state that corresponds to the “moderate” or “severe” classes. Although it would seem reasonable to assume that every occupant would appreciate benefiting from a building of the highest possible quality, the level of damage acceptance can vary significantly depending on the socio-economic circumstances of the occupants.

2. Materials and Methods

The research is mainly based on a set of interviews with local actors (construction and insurance companies, architects, territorial services, etc.), an online questionnaire intended for habitants (180 responses), and a field survey involving the visit of 104 buildings with interviews of the occupants. The forthcoming sections provide detailed information on objectives, sampling method, and the modality of each method. The data collection took place between May 2020 and May 2022, representing the state of reconstruction five years after the passage of Hurricane Irma in Saint Martin (2017).

2.1. Interviews with Reconstruction Local Actors

To obtain the opinions of different actors of the territory concerning the factors that played a favorable or unfavorable role in the speed and the quality of the reconstruction, 13 semi-directive interviews were realized with the persons listed in Table 1. The objective was to collect the opinion of actors directly or indirectly involved in the reconstruction process of residential buildings of Saint Martin. For these interviews, a set of predetermined questions or topics was prepared, providing a framework for the discussion. However, there was also flexibility to delve deeper into the respondent’s answers, allowing for exploration and further probing into specific areas of interest.

Table 1. List of local actors who participated in the interviews.

N.	Interviewee’s Position/Responsibilities	Interview Date
1	Manager of SEICMO (design, engineering, and consulting in construction and project management company)	May 2021
2	Territorial engineer in charge of Saint Martin land use and urban planning department	June 2021
3	Head of the Saint Barthélemy and Saint Martin territorial unit—DEAL of Guadeloupe	July 2021
4	Director, Compagnons Bâtitseurs	June 2021
5	Head of Habitat Construction, Saint Barthélemy and Saint Martin territorial unit—DEAL of Guadeloupe	August 2021
6	Director of Operations, Semsamar (urban planner, public housing provider, and building promoter)	May 2022
7	Director of Tackling Insurance in Saint Martin	May 2022
8	Director, Sprimbarth Agency (estate agency in St. Martin)	May 2022
9	Ex. President of the Sandy Ground neighborhood council	May 2022
10	Architect in Saint Martin	June 2021
11	Construction company in Saint Martin	June 2021
12	Architect in Saint Martin	July 2021
13	France Assureurs—Home and Overseas Risk Manager	February 2022
14	Ex. President of the Grand Case neighborhood council	May 2022

The interviews lasted between 1 and 4 h. After conducting a few initial inquiries into the interviewees’ profiles, their positions, and their responsibilities, the discussion revolved around five key topics:

- The first one delved into the aftermath of Hurricane Irma, exploring how the interviewees coped with the event, their expectations regarding the extent of damage to buildings and the island infrastructure, and their perspective on the likelihood of a similar event in the future.
- The second topic centered around the evolution of residential buildings’ vulnerability after Irma. The discussion involved the identification and evaluation of influencing factors such as insurance, material aids, availability of resources (financial, materials, skilled labor, etc.), and administrative procedures. Regarding the evolution of the vulnerability, the interviewees were also asked if they perceived any difference between

different districts, different types of buildings, or between different building elements (roof, openings, structure, etc.). The four identified building types are presented in Figure 3.

- The focus of the third topic was on the “Guide to good practices for the construction and rehabilitation of housing” published by the Saint Martin local authority in collaboration with the prefecture (in the French system, a prefecture is an administrative division that represents the central government at the local level). The idea was to evaluate the accessibility, effectiveness, and uptake of these guides.
- The fourth topic focused on the speed and the quality of reconstruction works on the island, including the entities carrying out the work (individuals, construction companies, etc.).
- The final part of the interview addressed general inquiries regarding the interviewees’ overall perception of the current vulnerability of Saint Martin buildings, the coordination between the French state and local authorities, and other related aspects.



Figure 3. Different building types in St-Martin. (A): Individual dwelling without story, without masonry, in wood or sheet metal. (B): Detached single-story dwelling in masonry, stone, or reinforced concrete. (C): Individual dwelling with story(s) in masonry, stone, or reinforced concrete. (D): Collective housing in masonry, stone, or reinforced concrete.

A synthesis of these interviews and the key findings are presented in Section 3.

2.2. Online Questionnaire

An online survey gathering 180 responses from heads of households living in Saint Martin was carried out from May 2020 to May 2022. The objective was to assess the impact of Irma on residential buildings, household recovery, and housing reconstruction procedures.

Given the island's cosmopolitan population, the questionnaire was translated into four languages (French, English, Spanish, Haitian Creole). To enhance the clarity of the questions, visual aids such as figures, photos, and comments were included.

The self-administered questionnaire consisted of four main parts: The first one comprised 23 questions aimed at gathering information about the respondents' profile and social situation. The key points covered were as follows:

- Profile of respondent, including age, sex, professional situation, nationality, monthly income, etc.
- Duration of their residence on the island, their district, proximity to the sea front, and any changes in their place of residence since Hurricane Irma.
- Details about their current residence, including facilities, equipment, ownership, and occupancy status.

The second part, consisting of 17 questions, focused on Hurricane Irma and the damages inflicted on the respondents' residences. The questions aimed to gather information on the following aspects:

- Whether the respondents were present on the island during Hurricane Irma, had experienced any other hurricane, were prepared or not to face Irma, their expectation regarding the extent of damage to their building, and their perspective on the likelihood of a similar event in the future.
- Typology of their residence based on the four categories presented in Figure 3, as well as the type and characteristics of the roof before and after Irma.
- Overall evaluation of damage to their residence using the five damage classes illustrated in Figure 4; causes of damage, including wind, projectiles, wave shock, rain-induced flooding, marine submersion, etc.
- Detailed assessment of damage level to different parts of their building, such as the roof, walls, foundation, openings, doors, windows, and blackout systems.



Figure 4. Different damage classes of residential buildings in St. Martin. **Classe 1.** No or limited damage (hardly visible from the outside/superficial damage to roof, windows, doors, or walls). **Classe 2.** Minor damage (roof affected in a few places, a few windows or doors broken/exterior walls partly in need of repair). **Classe 3.** Moderate damage (roof affected in many places, almost all windows or doors broken/cracks in walls are repairable). **Classe 4.** Severe damage (+50% of roof ripped off and structural damage/windows or doors completely broken/load-bearing walls severely damaged but not destroyed). **Classe 5.** Destroyed (foundations destroyed/roof structure and load-bearing walls totally destroyed).

The third part, consisting of 28 questions, focused on the reconstruction works carried out on the respondents' residences. The objective was to gather information about the nature, quantity, and quality of repairs or reconstruction works. It aimed to gather information about:

- Nature (repairs or reconstruction) and quantity of the required work.
- Commencement of work after Irma, estimated duration, and progress made.
- The respondents' perception of the quality of work and the evolution of the cyclone vulnerability of their residence.

- Their awareness of existing reconstruction guides.
- Their perception of the current vulnerability of their building and the entire island.
- The last part of the questionnaire focused on the identification of factors impacting the quality, cost, and duration of works (such as financial aids, insurance compensation, etc.) and assessed their significance. At the end of the questionnaire, respondents were given the option to express their interest in being informed about the project's progress and obtained results, as well as their willingness to be contacted for further sharing of information about their experience with Hurricane Irma.

Before being published through email, social media, and local journals, the questionnaire underwent a testing phase with a small group of Saint Martin residents. Their valuable feedback was considered to improve the questionnaire.

2.3. Field Survey

A field survey, conducted in May 2022, collected the opinions of 104 residents on the evolution of the reconstruction of their buildings more than 4 years after the Irma hurricane. In order to assess the evolution of the reconstruction works and the vulnerability, 104 buildings were selected in different districts considered to be representative of the diversity of buildings and inhabitants (Quartier d'Orléans, Marigot, Sandy Ground, Agrément, Grand Case, Cul de Sac) among those surveyed in 2017 by M. Moulin [54]. In sum, 35% of the selected buildings had been considered slightly damaged, 37% damaged, and 12% to be demolished just after Irma.

In this directive survey, several types of questions were addressed regarding the profile of the resident, the level of damage to the building after Irma, the quality and timeliness of the work performed, and the necessity, availability, and sufficiency of necessary resources (financial, material, etc.).

The face-to-face interviews, including the final visit, had a duration ranging from 15 to 30 min, depending on the specific characteristics of each building. These interviews were conducted by our team of researchers, who are also experts in reconstruction. Table 2 provides an overview of the surveyed individuals' profiles. Additionally, at the end of each interview, the interviewer conducted an objective visual assessment of the building's cyclone vulnerability. This assessment was based on eight criteria: number of roof pitches, roof slopes and fixings, size of openings, presence of homogeneous blackouts, quality of blackouts, shape of the building, and presence of attached elements. The main results of this field survey are presented in Section 3.

Table 2. Profile of 104 residents interviewed in May 2022.

How Long Have You been on the Island?	Native 55%	Arrived before 1986 19%	Arrived before 2006 15%	Arrived before 2017 9%	Arrived after 2017 3%
Did you experience cyclone IRMA?	Yes 90%	No 10%			
Do you think a cyclone of IRMA's intensity could happen again in the next few years?	Yes 75%	In 10–20 years 23%	No 2%		

3. Results

3.1. Synthesis of the Interviews with Local Actors

After conducting an in-depth analysis of the interviews with local actors, six distinct situations related to the reconstruction of buildings in Saint Martin were identified, each with its own characteristics and challenges. This section provides a synthesis of this analysis, presenting the key findings and insights derived from the interviews.

A typology of identified situations leading to specificities during the reconstruction of buildings is presented in Figure 5. The six identified cases are detailed in the following:

1. Insured individual buildings: In the first case, the insurance compensation is globally very satisfactory, having allowed fairly quick compensation and repairs (less than one year). Longer duration works were possible when they concerned a complete reconstruction. However, some specific cases have been reported as buildings still in ruins 5 years after Irma, even though the owner was insured. This situation is confirmed by insurers who observe a lower rate of compensation for Irma than for other natural disasters, proof that some insureds did not request the complementary compensation (30%) which is only paid if the work is carried out.
2. Uninsured individual buildings having sufficient personal resources. The second and third cases correspond to populations that are not covered by insurance for various reasons: personal choice to “self-insure”, lack of resources to insure themselves, and lack of the legal property title that gives them the right to be insured. It should be noted that the phenomenon of “no-insurance” is quite widespread in the West Indies [57]. In the absence of insurance, the determining factor for rapid and high-quality reconstruction is the availability of personal resources to finance repairs. For households having these resources, repair or rebuild works are fairly quick overall (less than a year). The quality of these repairs appears to fluctuate significantly, as they may call on insufficiently qualified labor or engineers without consulting any architect or engineering consulting office. This situation reflects the phenomenon of self-building, particularly present in popular districts, which consists of building homes without consulting any architect or engineering company, generally using recycled materials.
3. Uninsured populations with limited resources: For the third case, repairs are largely incomplete several years after Irma, except in cases where households have been able to benefit from assistance such as that of “Compagnons Bâisseurs” (“Compagnons Bâisseurs” is a French non-profit organization that focuses on social housing and community development through construction and renovation projects), whose quality of service is unanimously recognized. However, it should be noted that the buildings concerned were sometimes already in a degraded state before Irma. This prompted us to consider the initial condition of buildings prior to Hurricane Irma in our analysis. From a purely economic point of view, the damage is higher for a well-off household than for one with limited resources. The impact of this damage on quality of life and health, on the other hand, seems to be much more significant for the less well-off households. Moreover, the populations concerned have a feeling of abandonment reinforced by the absence or delays in works that do not fall under the responsibility of the populations (for example, unrepaired pole and electrical wires or telecommunication cables still attached to a palm tree 4 years after Irma, wreckage of a ship in an occupied parcel not evacuated 4 years after Irma).
4. Collective buildings are either co-ownerships or buildings belonging to a single owner and for which the units are rented. An important distinction concerns the buildings built under the tax exemption laws (case 4). On the whole, these buildings are judged by the professionals of the construction industry as being of poor quality and globally vulnerable to cyclone risk. This poor quality is explained firstly by reasons of financial profitability, a better quality of construction being associated (rightly or wrongly) with additional costs during construction. A second explanation lies in the initial vocation of these buildings, which were to be used to develop tourism activities and therefore to accommodate occupants out of the hurricane season. This second argument seems appropriate, but the Irma event shows that the problem of the territory is not in reality that of the security of people, since the human toll was limited to a dozen people, the deaths of some of whom are attributable to carelessness (people who refused to evacuate their boat to take refuge on land). The co-ownerships resulting from the tax exemption laws today present a new problem because of housing pressure on the island. The shortage of housing, which is still felt in 2023, associated with the loss of interest of some of these co-ownerships once the duration

of the tax exemption has passed, leads to their reuse for permanent housing for rather underprivileged populations. This leads to the juxtaposition of a social vulnerability and a structural vulnerability.

5. The co-ownerships resulting or not from the tax exemption laws (cases 4 and 5) have encountered significant difficulties that have penalized the speed of the reconstruction.
6. Difficulty in making decisions at the level of the co-ownership due to the remoteness of the co-owners (non-resident or out of the territory after Irma). This situation concerns particularly the co-ownerships resulting from the tax exemption laws.
7. Difficulties for some property managers to present documents that comply with all the requirements of the insurance companies.
8. For the reconstruction (cases 4 and 5), difficulties were also encountered regarding the remuneration of the companies and the reduction of the vulnerability of the structures that could result from the works.
9. Single-owner collective buildings (case 6) fluctuate between the two aforementioned situations. One part corresponds to financial investments by owners who do not wish to invest in their property on a long-term basis. The buildings are not necessarily insured. When they are insured, the indemnities have not necessarily been used to carry out reparation works. It should be noted that the obsolescence of the mentioned buildings is not an obstacle to their renting, given the high demand on the island. When the buildings are insured, and the owner chooses a rehabilitation to reduce vulnerability, he must use his own funds. Some aids have been possible via the Emergency Housing Fund (In French: Fonds Urgence au Logement) allocated to the municipality by the state and paid back to the owners. This strategy seems to have been carried out with the SEMSAMAR (since its creation in 1985, the SEMSAMAR (Société d'Économie Mixte de Saint-Martin) has been a developer and real estate operator in Saint Martin) buildings, for which main structural improvements concern the reduction of the roof overhang, the replacement of certain frameworks, either by less inclined roofs or by flat terraced roofs, and the use of more resistant joinery. For single-owner collective buildings, another difficulty has also arisen related to the respect of the public procurement procedure. The regulatory or administrative delays between the call for tenders, the consultation of contractors, the attribution of contracts, and the starting of the works delayed the beginning of projects by several months (2–3 minimum—sometimes 6). If we understand the importance of respecting the public procurement code, we also note that this leads to a problematic delay in the reconstruction process, particularly considering the yearly occurrence of hurricane season.

3.2. Synthesis of the Online Survey

The questions on the profile of the respondents indicate that 56% of the interviewees are from metropolitan France, 21% are from Saint Martin, and 19% are from the Antilles. Only 8% are unemployed; 8% earn less than 1000 €/month and 62% earn more than 1000 € (30% did not answer); 20% are state employees and 22% are company managers or high-level executives. This means that the most disadvantaged households seem to be under-represented.

The following synthesis provides a limited part of the obtained results of the online questionnaire, directly aligned with the objectives of the present article. This synthesis focuses on the differences and similarities between owners and renters, since these typologies were identified as being different during the direct interviews with the territory actors. A more comprehensive analysis of the questionnaire results will be presented in an upcoming article.

Based on 99 complete responses, the causes of the reparation work not being carried out are, in order, lack of financial means (27%), dysfunctions at the level of the reconstruction companies (24%, disappeared company, dishonest, etc.), lack of qualified labor (20%), lack

of intention to carry out the work by the owner (18%), and lack of available materials (9%) (Table 3).

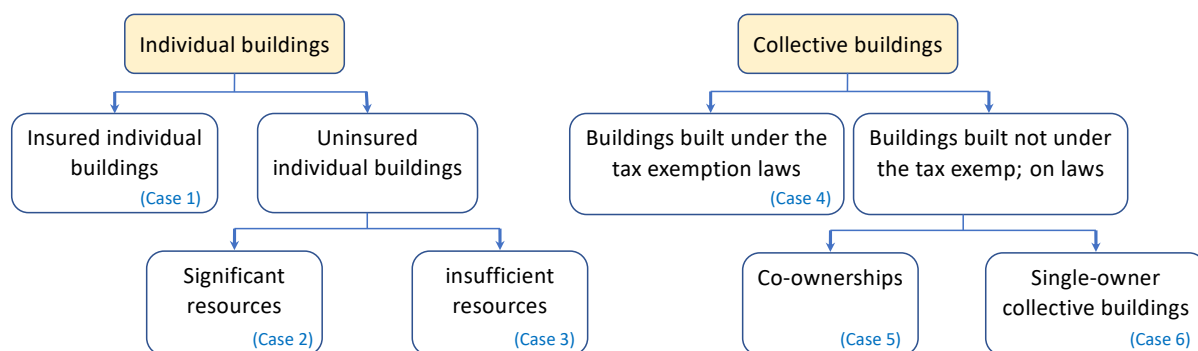


Figure 5. Different identified situations leading to specific features that explain the speed and quality of reconstruction on Saint Martin.

Table 3. Synthesis of the online survey—differences and similarities between owners and renters.

Are You. . .	Yes	No
satisfied with the reconstruction of St. Martin? (115 responses)	19%	79%
satisfied with the community’s management of the reconstruction? (113 responses)	15%	81%
satisfied with the government’s management of the reconstruction? (11 responses)	17%	73%
Do you think that..	Yes	No
the residents of Saint Martin are generally better protected than before Irma? (114 responses)	10%	66%
the authorities of Saint Martin are better prepared to deal with natural disasters? (112 responses)	17%	58%
a tool such as the PPRN (natural hazard prevention plan) is needed to ensure that construction is more adapted and better located? (111 responses)	75%	8%
the prevention of natural hazards is compatible with the economic development of Saint Martin? (109 responses)	61%	22%
	Owner	Renter
% having completed repair/reconstruction work (127 replies)	68%	51%
% having started work after 2 years following Irma (95 responses)	7%	18%
% covered by insurance at the time of Irma (111 responses)	84%	46%
% of uninsured who have taken out insurance since Irma (38 responses)	67%	65%
% having confidence in the reduction of their dwelling vulnerability after reconstruction/repair (108 responses)	59%	36%
Satisfaction with the insurance compensation amount (score out of five; 68 responses)	3.2	2.7
Satisfaction with delay of insurance payments (score out of five; 68 responses)	2.7	2.7
Feeling of safety in dwelling with regard to cyclonic hazards (score out of five (five: very satisfied); 115 responses)	3.2	2.8

3.3. Synthesis of the Field Survey

According to the testimony of the inhabitants, 81% of the buildings were damaged by Irma. This is consistent with Moulin’s evaluation (84% for these buildings) carried out 6 months after the passage of Irma [54]. The perception of the cyclone hazard shows that a significant proportion (25%) considers that a hurricane comparable to Irma may not happen again or not before a period of 10–20 years. On the contrary, a very large majority is certain that an equivalent cyclone can occur “any time”.

The damage (related to both wind and flooding) had been much greater than they expected (Table 4). Regarding the wind damage, Table 4 shows a discrepancy between the perception of the damage for their own building and for the whole island. While the majority of the respondents underestimated their own vulnerability (52%), it seems that they underestimated the vulnerability of the island even more (78%).

Table 4. Given Irma’s intensity, what do you think of the damage to your home and to St. Martin?

	Less Important than I Expected	As Important as I Expected	More Important than I Expected
Wind damage to your building	18%	30%	52%
Damage to your building due to marine submersion	15%	23%	62%
Wind damage on the island of St. Martin	7%	15%	78%
Damage to the island of St. Martin due to marine submersion	7%	24%	68%

Regarding the quality and speed of reconstruction (Tables 5 and 6), opinions are diverse. Even if 55% of the damaged buildings were repaired or rebuilt in less than a year, 5 years after Irma 21% have not yet finished the work. These situations still correspond to uninsured individuals with low financial resources. These trends are coherent with Copernicus assessments that show a particularly significant reconstruction activity until May/June 2018.

Table 5. What do you think of the speed of your repair/reconstruction work?

Duration of Repair/Reconstruction Work on Your Building? **	Over 5 Years	2–5 Years	1–2 Years	6–12 Months	Less than 6 Months
	21%	10%	15%	16%	39%

** 81% of the visited buildings (85 out of 104) had been damaged.

Table 6. What do you think of the quality of the repair work? **.

	Very Dissatisfied	Somewhat Dissatisfied	Neither Satisfied nor Dissatisfied	Somewhat Satisfied	Very Satisfied
Quality of repair of damage to your home	4%	12%	36%	29%	19%
Overall quality of St. Martin reconstruction	1%	4%	51%	35%	9%
Overall speed of St. Martin reconstruction	29%	29%	24%	11%	7%

** 81% of the visited buildings (85 out of 104) had been damaged.

Even though the evaluation of the quality of the work shows that the people interviewed consider that their residence is rather more resistant than before, they believe that the island as a whole is only moderately more resistant than before Irma. There is also a significant level of dissatisfaction with the speed of reconstruction. This point is linked to the significant presence of still undemolished buildings on the island. As an example, during the field mission in 2022, it was observed that in Agrément quartier, around 20% (7 out of 37) of the buildings heavily damaged in 2017 were still in ruins (Figure 6).

The most damaged parts of these buildings are the roof (covering and framework), openings, and attachments (Table 7). Most of the reconstruction and repair work was carried out by both private individuals and professionals. The survey did not allow us to specify the level of qualification of the professionals.

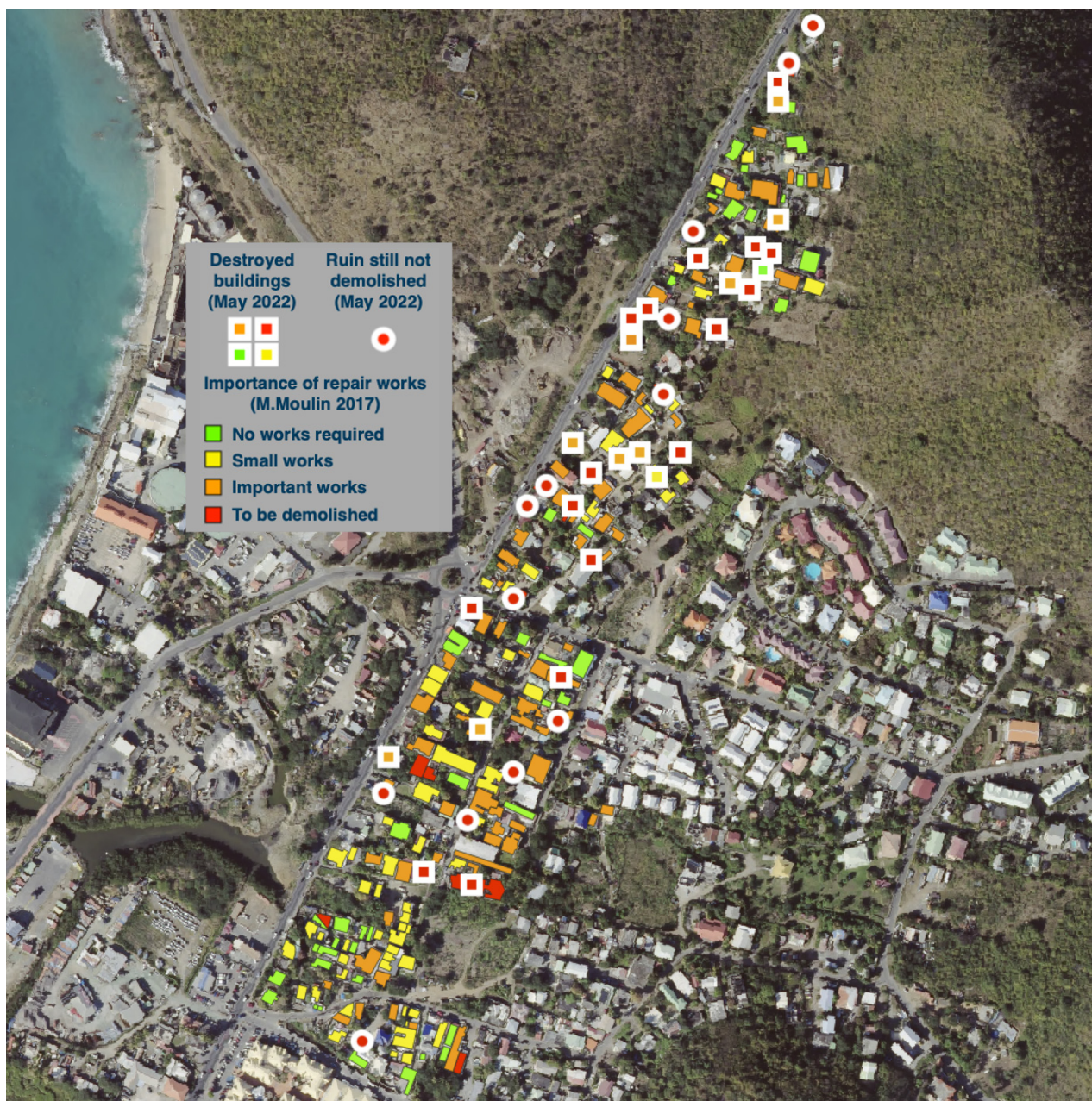


Figure 6. Agrément district in St. Martin—presence of a significant number of ruined buildings that have not been demolished by May 2022.

Table 7. In the case of damage, who carried out the repair work?

	% of Buildings Requiring Repair (x/104) **	Individuals	Associations	Professionals	Not Carried Out
Roof-covering works	71%	38%	4%	58%	0%
Roof-structure works	48%	32%	2%	66%	0%
Opening/blackout works	54%	43%	4%	52%	2%
Window/opening works	58%	45%	2%	52%	2%
Structure-wall/partition works	24%	48%	0%	52%	0%
Structure-foundation works	3%	67%	0%	33%	0%
Structure-added element works	35%	42%	0%	58%	0%

** 81% of the visited buildings (85 out of 104) had been damaged.

It should be noted, however, that according to the testimonies, the most intense episode of the hurricane was after the passage of the eye, even if its duration seemed short compared to the cyclone Luis (1995). The testimonies are generally unanimous in considering that the number of victims and the amount of damage could have been higher if the cyclone had had a lower speed of movement.

In the case of damaged buildings, several questions were asked about the necessity and availability of the resources needed to carry out the works (insurance compensation, personal resources, materials, ...; see Tables 8–10). Despite a few unfavorable opinions, insureds are generally satisfied with the amount and timing of insurance payments. The majority consider that this has led to a reduction in their structural vulnerability (Table 8). The values are significantly higher than those in Table 8, showing that people who had recourse to their personal resources are less confident in the vulnerability reduction of their house. A total of 36% expressed dissatisfaction, which can be partly explained by a lack of resources to carry out the work correctly. The use of loans is rare among respondents, many of whom lack the necessary solvency. Various forms of assistance appeared to be available but were far from sufficient to satisfy needs. The results relating to associative help should be interpreted as follows: Those who were able to benefit from help were very satisfied. Others regret not having received help.

Table 8. What do you think of the influence of these factors on the completion of work and changes in the vulnerability of your dwelling (for damaged and insured dwellings)?

	Very Unfavorable (Increased Vulnerability)	Somewhat Unfavorable	Useless or without Influence	Somewhat Favorable	Very Favorable (Decrease in Vulnerability)
Insurance indemnities (amount)	7%	17%	24%	21%	31%
Insurance indemnities (payment dates)	4%	15%	30%	11%	41%

Table 9. If your home is damaged and uninsured (or the amount of compensation is insufficient), how do you assess the influence of these factors on the completion of the work?

	% of Dwellings That Needed/Asked for This Resource	Very Unfavorable (Increase in Vulnerability)	Somewhat Unfavorable	Unnecessary or without Influence	Rather Favorable	Very Favorable (Decrease in Vulnerability)
Sufficiency of personal resources	70%	15%	21%	16%	29%	19%
Sufficiency of loans	15%	25%	31%	6%	31%	6%
Sufficiency of mutual financial assistance	23%	21%	0%	8%	33%	38%
Donations of materials	16%	53%	6%	6%	29%	6%
Material aid from associations	19%	40%	5%	5%	15%	35%
Material aid from the district council	13%	69%	15%	8%	8%	0%

In 2017, the local authority of Saint Martin introduced a simplified procedure called “prior declaration of works after Irma” for a period of one year. This exceptional procedure aimed to simplify authorization requests for residents in anticipation of the next hurricane season. Table 10 highlights the fact that the simplification of building permits has been judged positively overall. A total of 38% consider that it has helped to reduce vulnerability, which raises the question of whether this score does not correspond more simply to a level of satisfaction with the measure. Although the interviews with construction professionals highlighted a problem of manpower (quantity and quality), the people interviewed seemed to be fairly satisfied. Concerning the rules of good building practice, the responses show a high level of confidence in the companies’ expertise.

Table 10. What do you think of the influence of these factors on the evolution of your dwelling's vulnerability?

	Very Unfavorable (Increase in Vulnerability)	Somewhat Unfavorable	Unnecessary or without Influence	Somewhat Favorable	Very Favorable (Decrease in Vulnerability)	Number of Answers to Question
Building permit simplification	3%	0%	44%	15%	38%	39
Other (administrative)	6%	6%	72%	17%	0%	18
Availability of quality building materials	0%	13%	21%	27%	39%	71
Availability of labor (quantity)	1%	10%	33%	34%	21%	67
Availability of labor (quality)	1%	8%	19%	41%	30%	73
Familiarity of residents with good reconstruction practices	5%	9%	14%	32%	41%	22
Good practices of specialists/companies (engineering skills)	0%	2%	20%	43%	35%	46

The analysis of the objective estimation of buildings' vulnerability conducted during the field survey show that 58% of the buildings surveyed in 2022 show significant elements favorable to their resistance, 28% some unfavorable elements, and 14% a large number of unfavorable elements. These findings are fairly consistent with the respondents' feeling that their homes are more resistant after reconstruction works. In terms of perceived vulnerability, 51% of respondents considered their buildings to be very safe and resistant, 34% deemed them as relatively safe, and only 15% considered them as not safe. Further analysis of the field survey data demonstrated that 23% underestimated the vulnerability of their residences, 63% had a realistic perception, and a mere 14% overestimated the cyclone vulnerability of their buildings.

4. Discussions

The comprehensive analysis of the obtained results from the online questionnaire, the interviews, and the field survey (outlined in Section 3) highlighted a range of factors that have played a significant role, either positively or negatively, in the reconstruction process of residential buildings and the reduction of their structural vulnerability. The key factors include (1) access to financial resources, (2) the insurance situation of the building, (3) the functioning of insurance companies and their flexibility in indemnity payments, (4) restrictions imposed by the local urban regulations, and (5) the quality, cost, and availability of materials and labor. While some of these factors may be specific to the context of St. Martin, they provide valuable insights for improving post-catastrophe reconstruction and risk mitigation in any other communities facing similar challenges. In the subsequent section, these factors will be examined in greater detail and their implications discussed.

Based on the obtained results, the quality of the reconstruction seems to be very much linked to the insurance situation of building in cases where the owner seeks to carry out repairs. An insured structure benefits on the one hand from indemnities related to the damage and on the other hand from a regulatory framework favorable to good reconstruction: diagnosis by an expert (even if the quality of the experts has been questioned in view of the number of cases to be treated), appealing to companies having to justify ten-year guarantees, and appealing to competent "structural" design offices. These buildings constitute a part of the ruined structures of the island. Others were sold as they were and then rehabilitated. The absence of insurance makes it more likely that people with uncertain qualifications will be called in, whether for project management or work. The absence of insurance makes it more frequent to call upon people of more uncertain qualification, whether for the supervision or the execution of works. It should be noted, however, that some owners were self-insured with a real financial reserve that allowed them to complete a potentially quality reconstruction.

Regarding the vulnerability reduction through reconstruction, although insurance compensation is not intended to improve buildings, flexibility in the distribution of expenditure items between the initial expertise and the work carried out seems to have been an important factor in reducing vulnerability. For example, we can cite the example of roofing work that was less expensive than expected, allowing for electrical compliance or the reinforcement of facades. There are significant discrepancies between the practices of the insurers, ranging from the greatest understanding, allowing the acceleration of the work and flexibility in its implementation, to the strictest application of the rules, leading to delays and blockages in the implementation of work. In the absence of flexibility, the buildings are likely to be rebuilt identically, which allows a satisfactory reconstruction from an architectural and functional point of view, without real reduction of vulnerability to cyclone hazards. It should be noted here that insurers are not the only ones to monitor expenses. The state, as unlimited guarantor, controls the insurers' practices by being attentive to the financial balance of the CatNat ("Cat Nat" is a term used in the French insurance system to designate a natural disaster, allowing affected individuals and businesses to access specific insurance coverage and government assistance for recovery. <https://www.catnat.net/> accessed on 10 July 2023).

Ericksen et al. (2020) emphasize that the significance of insurance in disaster risk reduction should be comprehended by policymakers and emergency management practitioners. The authors emphasize the potential for insurers to play a more active role in mitigation efforts by educating inhabitants. This education can serve as a catalyst for encouraging the widespread adoption of improved reconstruction techniques and materials. Additionally, insurers may explore engagement programs, such as providing premium reductions for retrofitted homes, to incentivize and promote resilience-building practices [58].

Concerning remuneration of the companies, opportunistic or even fraudulent behavior by certain companies imposing very high down payments or taking insurance indemnities without carrying out the entire work has been noted. The extent of this problem has not been assessed in this project. The interviews also show that the functioning of the insurance companies has raised difficulties for the payment of the works. Indeed, the insurers pay the indemnity in two steps: a first immediate payment of 70% (without justification of work), then a second deferred payment (30%) on justification of the work carried out. The logical functioning of a co-ownership requires that a fundraising of the amount of the deferred indemnity be requested from the co-owners in order to pay the construction company. The paid invoice then allows the co-owners to recover the deferred compensation from their insurer. The amounts being sometimes very important, some co-ownerships found themselves unable to realize this fundraising. The solution is then a risky arrangement between the company and the co-ownership in order to issue a paid invoice before the real completion of the work.

It is apparent that there are still significant numbers of ruined buildings after 5 years, some of which seem to be repairable. They represented about 20% of the buildings in the Agrément district in 2022 (Figure 4). They constitute a danger to their environment in the case of a new cyclone (as they can be turned into projectiles that can impact neighboring buildings). One of the causes of this phenomenon has its source in the specific context of Saint Martin. Some individual buildings are co-ownerships resulting from inheritance. It seems that a lack of compromise between heirs, combined with a reluctance to sell a family property, is a frequent situation. In the absence of a detailed survey, it is not possible to know to which case these buildings correspond (1 or 3 probably, in reference to Figure 5).

The interviews and field visits also highlighted the issue of the use of concrete slabs as a technical solution to the cyclone hazard. The subject appears to be divisive and requires a cross-examination. The use of concrete roofs is currently prohibited by urban planning documents (there are some exemptions). The origin of this prohibition would be, on the one hand, the will to maintain a Creole type of architecture with an inclined roof, and on the other hand, to respond to the issue of seismic risk, since a poorly designed concrete roof constitutes a real danger. The buildings that had a concrete roof nevertheless exhibited

an incomparably better performance than those with a frame and cover. It should also be noted that some collective buildings have a concrete slab at the top level, covered by a frame and cover. As a result, many residents prefer the use of a concrete roof. From a structural and normative point of view (Eurocodes 2 and 8), it is not impossible to design a concrete roof compatible with the seismic hazard. However, this requires careful dimensioning and implementation (reinforcement, ties), which is not facilitated by the local urban code, which limits the use of an architect to projects exceeding 170 m².

Regarding the availability of the reconstruction materials, the high demand and the island situation of St. Martin have led to a significant increase in the cost of materials. These costs may have raised difficulties with insurers, as they exceeded the estimations considered by the experts who calculated the insurance indemnities. The second is related to the quality of materials, as the presence of the Dutch part of the island allows access to materials from the American continent which do not have CE certification. Although the CE marking is not in itself a guarantee of quality, it nevertheless constitutes a filter and therefore contributes to quality. Some of the imported materials could thus be of a lower quality than that limited by the CE marking.

Regarding the workforce, the reconstruction created a windfall effect for many companies not traditionally working on Saint Martin. These companies called on a more or less qualified workforce (re-employment of local workers previously employed in the catering and hotel sectors) and had themselves more or less technical skills in relation to the hurricane hazard. As a result, the interviewees consider that the quality of the reconstruction is probably quite heterogeneous on the island. This windfall effect seems to have not benefited the local construction industry.

One of the objectives of this study was to analyze the perception of residents affected by Irma in Saint Martin regarding the vulnerability of their buildings after reconstruction works. A similar study conducted by Ballesteros et al. (2022) revealed that following Hurricane Irma and Hurricane Maria in 2017, many homeowners of Puerto Rico complained about the poor-quality reconstruction and a lack of sufficient resources to rebuild their homes. So, despite contributing to a greater percentage of construction completion, inferior reconstruction quality failed to make inhabitants feel safer in their homes [59]. However, our study of the residents of St. Martin demonstrated that a substantial majority, near to 85%, perceive their buildings to be relatively safe or even very safe following reconstruction works.

Numerous researchers have explored sustainable and cyclone-resilient housing solutions, offering guidelines for reducing storm impacts on buildings (resilient design) and minimizing environmental effects of reconstructions (sustainability) [60–63]. These guidelines address critical factors such as the shape of buildings or house plans, roof design, building height, building structure, energy efficiency, and resource utilization [64]. However, the application of some guidelines may face barriers and cultural suitability challenges in specific territories [65]. Although this article does not focus on studying the most sustainable materials and cyclone-resilient construction typologies on Saint Martin Island, we acknowledge the importance of conducting further research in this area. Understanding and developing sustainable and resilient housing solutions are critical for the long-term resilience and well-being of the island's communities in the face of future cyclonic events.

5. Conclusions

The study of the structural recovery after Irma reveals that the reconstruction in St. Martin is progressing more or less rapidly and makes it possible to identify points of vigilance and issues for reflection.

Concerning the reconstruction of residential buildings, the question of having access to financial resources is central. Post-Irma reconstruction has left out individual buildings belonging to people with limited financial resources (no insurance, no resources of their own, no access to bank loans, etc.). This creates a sense of inequality insofar as the tourism and hotel sector is perceived to have benefited from aid motivated by the desire to restart the

tourism business. Even 5 years after Irma, there are still significant numbers of unrepaired buildings. They constitute a danger for their environment in the case of a new cyclone (as they can be turned into projectiles that can impact neighboring buildings).

For the insured buildings, the question of reconstruction to the identical is posed. A reduction of vulnerability generally imposes additional costs which are not covered by insurance. In the long term, it would be interesting to consider the economic impact of direct aids, in addition to the compensations, to ensure a more resilient construction. The public investments associated with the tax exemption laws could also be questioned with regard to the associated negative consequences (low quality buildings in particular). Finally, the building stock of Saint Martin appears to be slightly more resistant than before Irma, while presenting a great heterogeneity of situations.

Author Contributions: All the authors had a contribution to the “Conceptualization, methodology, validation, writing and visualization” of the article. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the French National Agency for Research [ANR RELEV-ANR-18-OURA-0004]. We express our gratitude to the ANR for their support in enabling this research.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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