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THE EVERYDAY AND THE POST-DISASTER URBAN SYSTEMS AS ONE THING

A configurational approach to enhance the recovery and resilience of cities affected by tsunamis.

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ABSTRACT

Tsunamis, despite occurring with low frequency, are permanent hazards for a large number of coastal cities and their consequences are highly devastating in terms of human losses, material damages and urban structure disruptions. It is argued in this paper that the urban structure not only has to be recovered after the tsunami event, but also has to provide an important basis for the continuing activities of the city, playing a fundamental role in the resilience of the whole urban system. By adopting a spatio-configurational approach based on space syntax theories and techniques, this research focuses on the dynamics of urban structures in relation to the different scenarios that tsunami-prone cities must face. The urban resilience process in both soon-after tsunami and post-tsunami scenarios is analysed using a Chilean coastal city located in a seismically active region as case study. The resilience capacity of the city in a soon-after tsunami situation is studied focusing on the influence of the urban layout in the route-finding decision makings during the evacuation process. The analysis reveals a weak correspondence between the existing evacuation plan and natural movement patterns, affecting the process of evacuation-route identification and the capacity to rapidly react to the threat. Additionally, the urban resilience in a post-disaster scenario is analysed regarding the ability of the city to maintain the basic functions and structures in order to be able to recover from tsunami impacts. The findings reveal important disruptions in the urban system's spatial organisation, affecting the distribution of urban centralities and changing the operating patterns of the city after tsunami events. From this, the paper develops a comprehensive understanding of the different phases of the tsunami-prone city from a configurational approach, laying the foundations for evidence-based strategic proposals to enhance urban resilience capacity.

KEYWORDS

Tsunami-prone cities, urban resilience, evacuation process, Space Syntax.

1. INTRODUCTION

A large number of urban settlements are exposed to natural hazards, such as earthquakes, coastal erosion, volcanic eruption, cyclonic storms, floods and tsunamis. These extreme events could cause devastation, resulting in a loss of human lives, great environmental damage, and a partial or total loss of infrastructure (Ismail-Zadeh, 2014). Tsunami events are considered as one of the world's most destructive natural hazards (Kulikov, et al 2005), and the impacts on the urban infrastructure could be devastating. As a consequence, the disruption of the urban system could modify the structure and functioning of the everyday city.

In the context of post-disaster condition, it is important to understand that the built environment not only has to be recovered, but also it has to support the rapid restoration of the everyday life (Allen, et al 2013). Therefore, the research identifies that there is a need not only for studying the impacts of the disaster on the built environment, but also for understanding how the built environment is able to cope with the negative effects of the disaster so as to return to a normal condition. The paper focuses on the analysis of the relationship between the structure and operation of everyday cities and their behaviour in disaster situations, recognising the importance of the existing structure and its role in the resilience process in both soon-after tsunami and in post-tsunami scenarios.

In the soon-after tsunami situation, the urban resilience is related to the capacity of the urban system to influence the returning to a prompt safety condition. The appropriate decisions about evacuation process could be a key factor to minimise the social impacts, the loss of human lives and the chaotic behaviours (March and Leon, 2015). Therefore, the analysis focuses on understanding the influence of the existing built environment in the evacuation process and the efficient route-finding decision-makings, which enable the population exposed to tsunami-waves to evacuate the risk area through an autonomous and effective process immediately after the tsunami. On the other hand, in the post-disaster scenario, the resilience is related to the capacity of the affected systems to restore their normal condition, maintaining the basic urban operations and social economic functions. Therefore, it is very important to explore the performance of the urban system after being impacted or modified by the disaster. The analysis focuses on the principal changes in spatial and functional aspects, comparing the urban structures, activities and spatial properties of the everyday and post-disaster city.

1.1 THE SOON-AFTER TSUNAMI CITY: RESILIENCE AND EVACUATION PROCESS.

Since tsunamis are suddenly generated events, there is little warning time before they strike (IOC-UNESCO, 2008), giving not enough time to the population to react opportunely and take critical decisions. This is why the evacuation process often needs to be self-initiated and autonomously conducted by people (Schmidtlein and Wood, 2014). It has been argued that in these situations of chaos, during the evacuation people face problems in the route-finding decisions making, and as a consequence the evacuees tend to use the recognisable and known paths as potential evacuation routes (Proulx, 2001 and Mohareb, 2011). Since people´s evacuation behaviour has been closely related to the normal patterns of circulation (Kimura and Sime, 1989), the concept of wayfinding applied in the everyday situations could be associated with the wayfinding in emergency conditions, in order to understand the possible people´s route-finding decisions during the evacuation.

It has been demonstrated through experimental evidence that the individual spatial decision-making in the wayfinding behaviour is strongly affected by the spatial configuration of the built environment (Emo et al ,2012). In this context, Space syntax theories have sought to understand the way in which pedestrians move around their environment, demonstrating through the theory of the "natural movement" (Hillier and Penn 1993) that the configuration of the street network is itself a primary generator of pedestrian movement patterns. This argument becomes a critical issue when analysing the behaviour of people during the emergency and selecting the factors that influence their wayfinding from a spatial perspective.

Considering the strong correlation been found between observed movement flows and space syntax measures (Hillier and Iida, 2005), it is argued in this research, that the spatial structure of tsunami-prone cities could be analysed configurationally in order to identify the paths that are more likely to be selected in the everyday life. This, allows to highlight the more familiar routes, which as it has been pointed out, are more likely to be selected when evacuating the city´s exposed area.

1.2 THE POST-TSUNAMI CITY: RESILIENCE AND URBAN FUNCTIONING.

Besides the human losses, tsunamis generate serious impacts on residential areas and urban systems (Moris and Walker, 2015). Along with this, the impact of the tsunami generates disruptions on the urban structure´s functioning, seriously damaging roads and bridges, which affects the connectivity and accessibility of areas and disables the normal use of the urban structure of the city. In this context, it has been argued that after the disaster, the city's urban structure provides an important basis for the continuing activities of the city, playing a fundamental role in the resilience of the whole urban system (Allan, et al 2013). Understanding how the flood of potential tsunamis will affect the cities and how the city structure will behave, becomes a basis for the planning of coastal settlements and the design of mitigation strategies.

It has been consistently demonstrated that the built environment´s spatial structure is intimately connected to how cities function and how they are used by people (Hillier, 1999). The configurational approach of space syntax theory has allowed to identify a strong correlation between spatial patterns, human movement and the socio-economic processes in cities. It has been proved that the impact of spatial configuration on movement and its subsequent influence on land uses location plays a critical role in the formation of urban centralities (Hillier, 1999b) and the distribution of commercial areas and residential functions (Hillier and Penn 1993). From this perspective, the important role of spatial configurational analysis as a means to understand the functioning and operation of cities represents a significant tool to evaluate the impact on the urban grid patterns caused by the tsunami flood in extensive parts of the cities.

2. DATASETS AND METHODS

For this study Viña del Mar city located in the central area of Chile has been selected as a case study. The main reasons that support the selection of this city are related to: its location in one of the most seismically active regions of the world and one of the main areas that generate tsunamis (Lagos and Cisternas, 2008), the frequency of tsunami events throughout history and the demographic characteristics.

A multi-scenario approach (Figure1) is proposed in this study to conduct a syntactical analysis of the city and construct an evidence-based understanding of the urban structure's role in tsunami events. The first studied scenario is the "Everyday City", which is the initial urban system before the occurrence of the natural event. This stage is focussed on the understanding of the structure and functioning of the pre-tsunami city, based on the analysis of the spatial properties and the distribution of urban centralities.

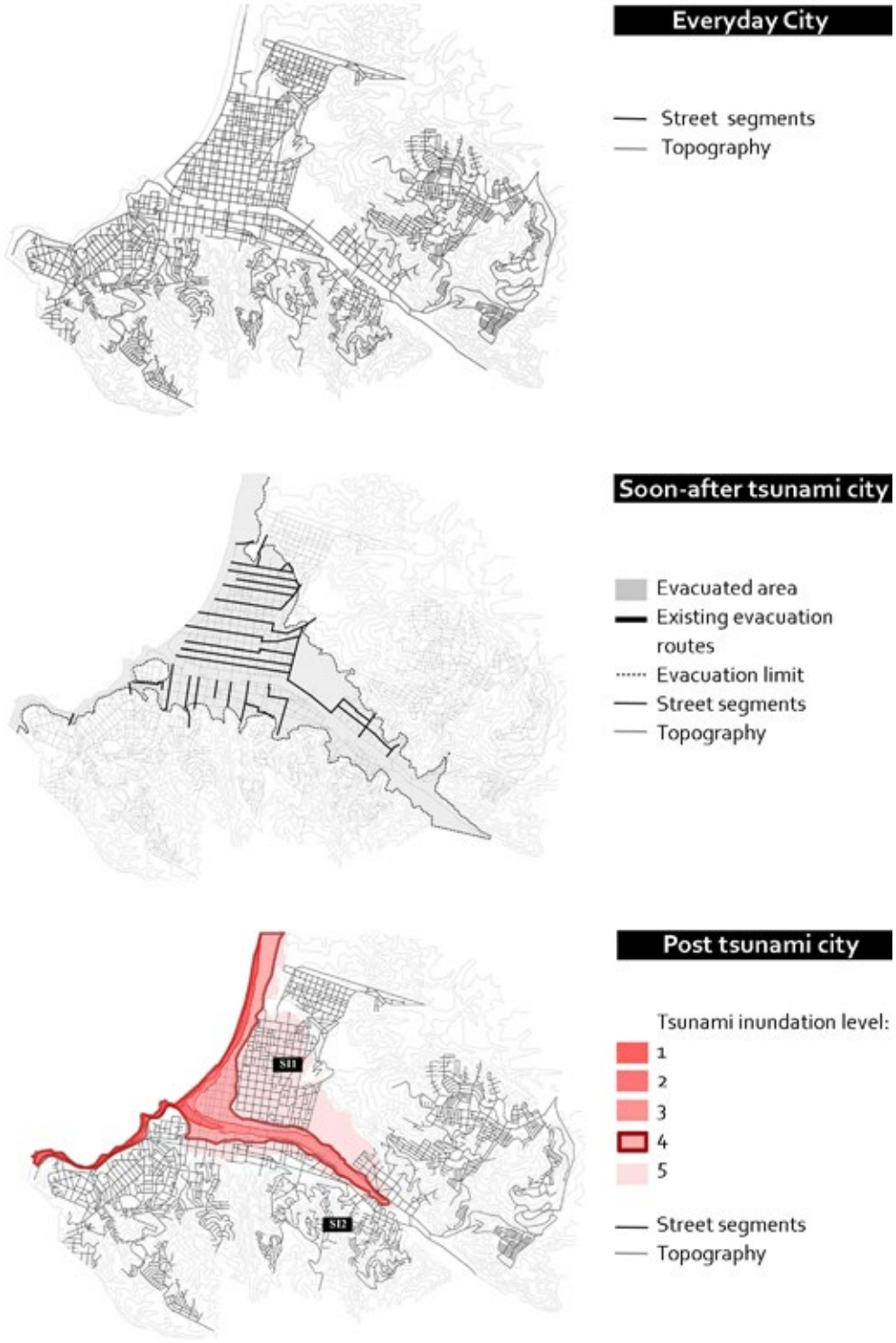


Figure 1 - Viña del Mar City multi-scenario approach.

The second studied scenario is the "Soon-after Tsunami City", which is considered as the exposed system, or the area that has to be evacuated soon-after the generation of a tsunami. This scenario is defined to evaluate the evacuation process which is considered as the most effective method to reduce the possibility of being directly affected by the tsunami. To determine the exposed area, the evacuation maps produced by ONEMI (the Chilean National Emergency Office) are used. These maps identify the exposed areas, the evacuation routes and the limit of the safe zones. The syntactical "Choice" measure is used to understand people´s route-finding decisions during the evacuation. Choice values correspond to the segments' potential movement flows of "through-movement", forecasting which routes are more likely to be selected as shortest paths from all spaces to all other spaces in the system (Hillier et al, 1987). As explained previously, people´s evacuation behaviour is closely related to the normal patterns of circulation, so the highest Choice values of the "everyday city system" are considered in order to comprehend the patterns of natural evacuation wayfinding.

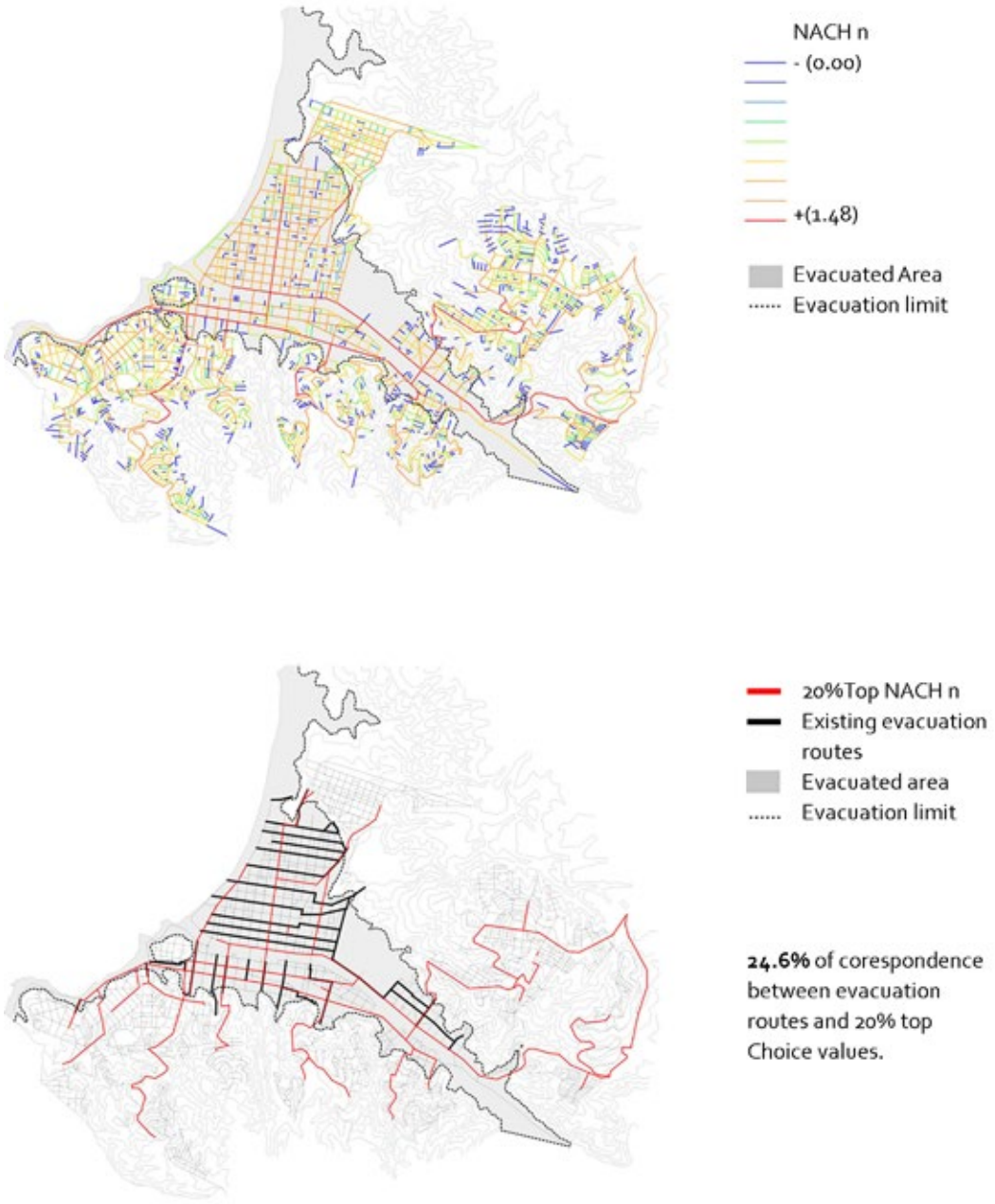
The third scenario is the "Post-tsunami City", which is defined as the possible affected system that has been disturbed because of the destruction of the urban infrastructure or the creation of non-accessible zones. To determine the possible affected areas, the Tsunami Inundation Maps for the Chilean Coast produced by SHOA (The Hydrographic and Oceanographic Service of the Chilean Navy) are used. A spatio-functional method of analysis is proposed using the "Integration" analysis to investigate the changes in the urban configuration after the tsunami, being possible to visualise the potential distribution of destination movements and point out the spatial dimension of urban centralities (Hillier, 1999). Centrality is a process with both spatial and functional aspects, therefore an analysis of the operational systems is carried out by studying land use distribution, in order to understand how configurational and functional dynamics of cities are interrelated. The changes on the spatial organisation before and after tsunami perturbations are the measures to understand the impact on the functioning of the city and the distribution of main urban centralities after the event.

3. RESULTS

3.1 SOON-AFTER TSUNAMI ANALYSIS, EVACUATION PROCESS.

The exposed area to be potentially flooded by the tsunami corresponds to the 32.69% of the total street segments' length. Practically all the areas located on the plains should be evacuated, while the ones on the hills are within the safety zone.

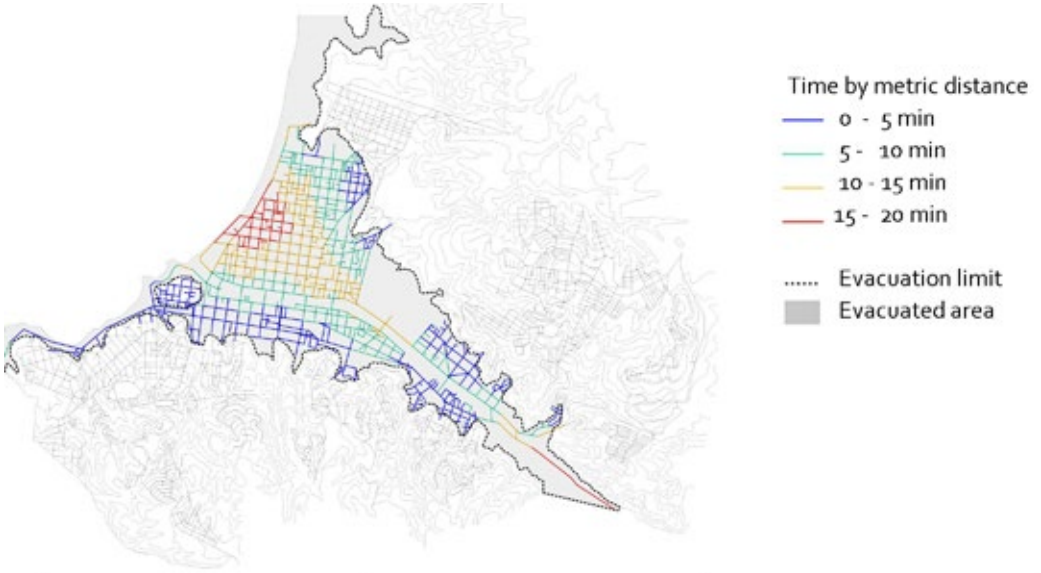
A normalized global Choice(NACH n) analysis of the "Everyday-city" scenario is introduced in order to pick out the streets which are more familiar to evacuees in daily life and as a consequence are likely to be selected during evacuation soon-after the generation of tsunamis (Figure 2). The 20% highest Choice represents the routes with more potentials to be selected. It is possible to distinguish a network which connects the city in north-south and east-west. The average NACH n values of the 20% principal routes of the system is 1.30 which is significantly higher than the NACH 1.03 of the evacuation routes. By overlapping the evacuation routes with the 20% highest Choice values, it is found that only 24.6% of the two sets of lines match (Figure 2). Based on this, it is possible to argue that the designated routes for evacuation are not strongly associated with the natural movement patterns of the everyday-life.



Total system street length	% exposed street segments length	Avg. NACH n total system	Avg.NACH n 20% top Choice values	Avg. NACH n evacuation routes
316,297 m	32.69%	0.8187	1.307	1.033

Figure 2 - Relationship between natural movement and existing evacuation routes. (Up: normalised Choice analysis, Down: correspondence between existing evacuation plan and 20% highest NACH segments)

Based on metric step-depth analysis (Figure 3), which measures the distances to reach all segments in the network from an indicated origin, the segments that could be evacuated on time are studied using the evacuation limit as a destination and all exposed segments as origins. To determine the appropriate time for evacuation, the ONEMI's recommendation for Chilean cites of 15 minutes in a speed of human walking is considered (ONEMI, 2014). The moderate walk speed of 1.22 m/s is defined for the analysis. This analysis shows that about 9.15 % of the street segments could not be evacuated within 15 minutes at a moderate speed walk.

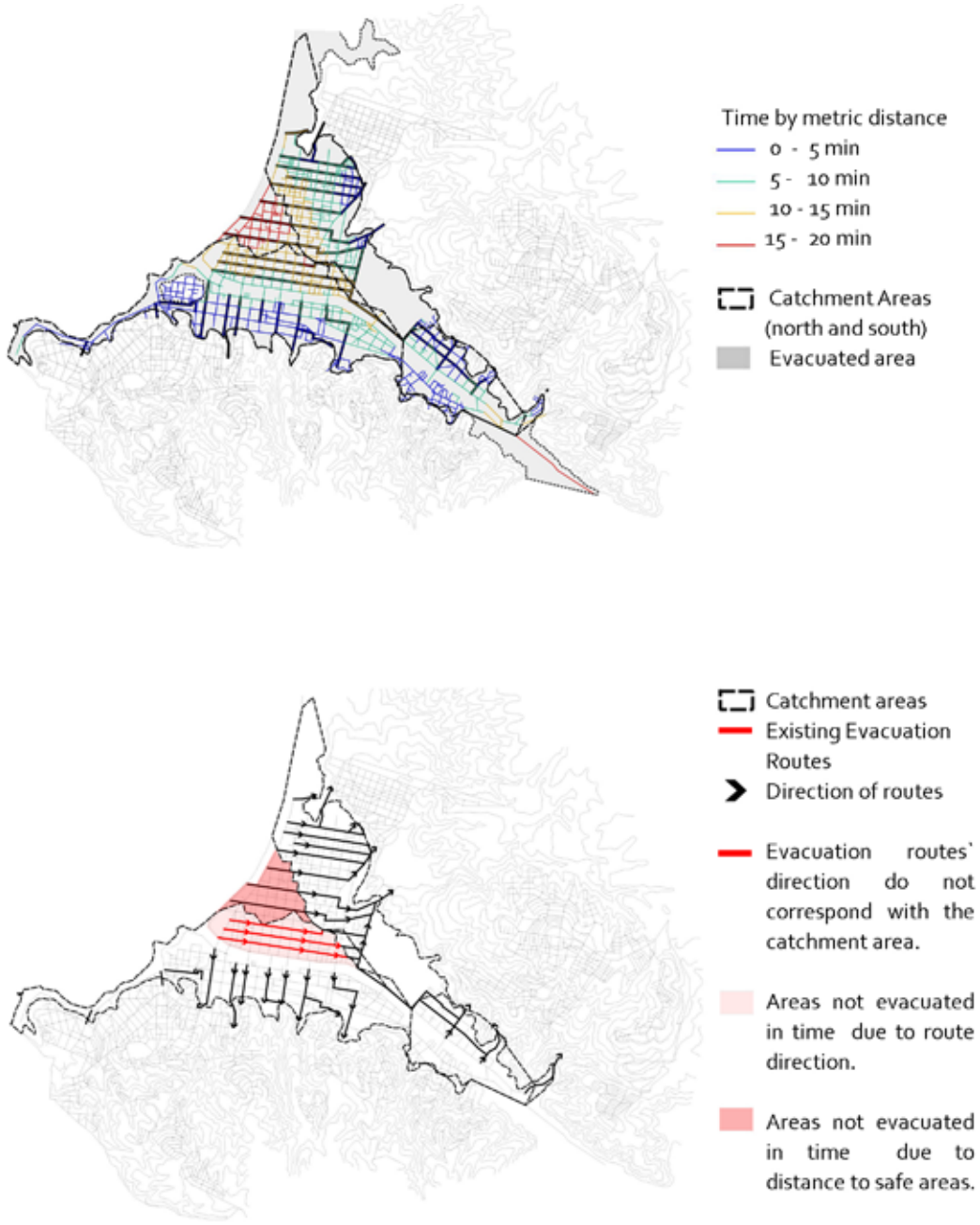


Exposed system segment length	Segment length not evacuated within 15 min	% Segment not evacuated within 15 min
103,416 m	9,459	0.8187

Figure 3 - Evacuation time for segments based on metric distance to evacuation limits.

After the full catchment analysis where the segments that have difficulty in being evacuated because of the distance to safe areas were identified, a differentiated catchment analysis is carried out to define the best route´s direction for evacuation depending on the destination. A catchment analysis from the different evacuation destinations, in this case northern and southern evacuation limits, is performed (Figure 4,Up).

As a result, the exposed area that should be evacuated to the northern limits, and the area that should evacuate to the southern limit are visualized. Comparing the direction of the evacuation routes with the catchment analysis, it is possible to observe that the directionality of 15.30% of the routes does not match with the catchment areas, therefore an important number of segments are being evacuated to the northern limit instead of evacuate to the south (Figure 4). It is possible to conclude that the current routes do not guarantee a safe evacuation since the whole exposed area cannot be evacuated in time.



Segment length not evacuated because of distance	% Segment length not evacuated because of distance	% Segment length not evacuated because of routes direction	% Segment length not evacuated because of routes direction
9,459 m	9.15%	15.830 m	15,30%

Figure 4 - Areas not evacuated in time. (Up: correspondence between existing plan and catchment evacuation areas. Down: direction and distance of evacuation routes)

Since the evacuation process must be performed autonomously and in a short time, it is expected that the percentage of correspondence between the natural movement system and the evacuation routes increases in order to develop an evacuation plan that follows the logics of natural movement, reducing the problems in the route-finding decisions during the evacuation process. Strategic proposals are developed in order to decrease the evacuation times and simplify the route-finding process (Figure 5). These proposals seek to improve the process of resilience soon-after the tsunami generation, which is associated with the effective response to the disturbance in evacuation processes.

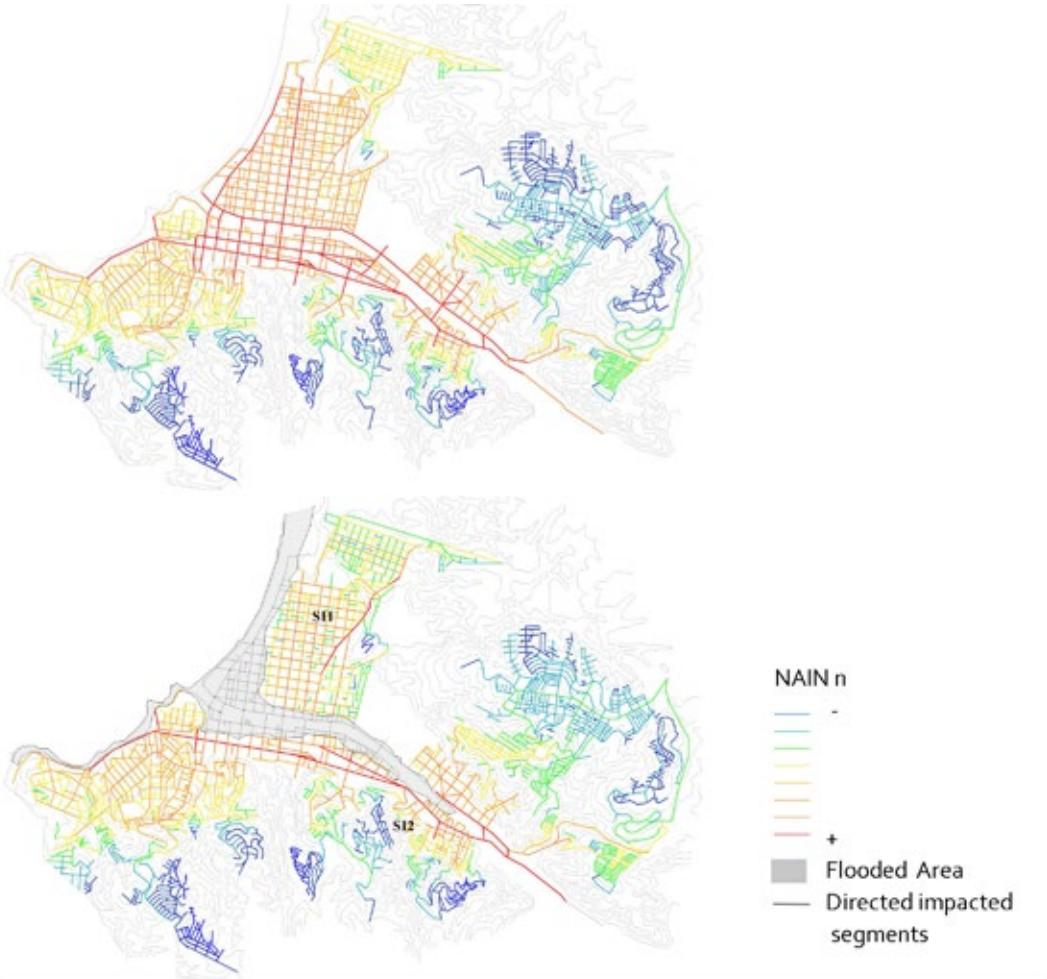
To define the evacuation routes, the proposal follows the configurational properties of the street network, considering the syntactic measures, the catchment areas defined by the proper time to reach the evacuation limits, and the physical characteristics of the routes. The main purpose is to generate evacuation systems structured by a network and not by disconnected routes, increasing the correspondence with natural movement patterns. Viña del Mar proposed evacuation plan shows an average NACH of 1.21 which compared with the 1.03 of the current plan reflects a major propensity to be selected as evacuation routes (Figure 5). This becomes clearer by measuring the correspondence of the proposed evacuation routes with the 20% top Choice values, showing a 51.06% which contrasts to the 24.6% of the previous plan. The direction of the routes is proposed following the logic of the catchment areas, providing better time responses.

	Existing	Proposed
Average NACH n evacuation system	1.03	1.21
% correspondence of evacuation routes and 20% NACH n	24.6%	51.06%

Figure5 - Correspondence between proposed evacuation plan and 20% top NACH segments.

3.2 POST- TSUNAMI ANALYSIS, URBAN STRUCTURE AND FUNCTIONING.

In order to understand the configurational urban impact on a post-tsunami scenario, the syntactic properties of the current city pre-tsunami are analysed using the Integration measures to define the structure of the urban centralities (Figure 6). The global core of integration is located in the central area along the river as a point of convergence of the southern and northern parts of the city. The analysis also picks up another structural line which runs from north-south direction in the northern area. The affected city is defined based on the Tsunami Inundation Maps 4th flooding level. In these circumstances, the 8.69% of the segments are directly affected by the flood. This percentage is obtained by calculating the ratio of the total length of the system to the total length of the affected segments. By removing the segments directly affected by the 4th level of floods, a breakdown occurs in the structure of the city, fragmenting the whole system into two new systems and severing all connections between them. These two new configurational systems: superior system (SI1) and inferior system (SI2) are located on both sides of the river. These extreme morphological and configurational changes strongly impact the distribution of global centralities, and an important part of the global integrated core disappears for being directly affected by the flood.



Average NAIN n Pre-Disaster City	Average NAIN n Post -Disaster City S1	Average NAIN n Post -Disaster City S2
0.476	1.162	0.376

Figure 6 - Distribution of global centralities and accessibility before and after tsunami. (Up: normalised integration analysis pre- tsunami. Down: normalised integration analysis post- tsunami)

The new Integration averages of the affected systems differ from the pre-tsunami system´s average (0.476), while SI2 Integration values average decreases (0.376), the SI1 average increases (1.162).Despite this sharp increase, it is unwise to argue that the system SI1 is affected positively, because it is completely segregated from the rest of the whole system.

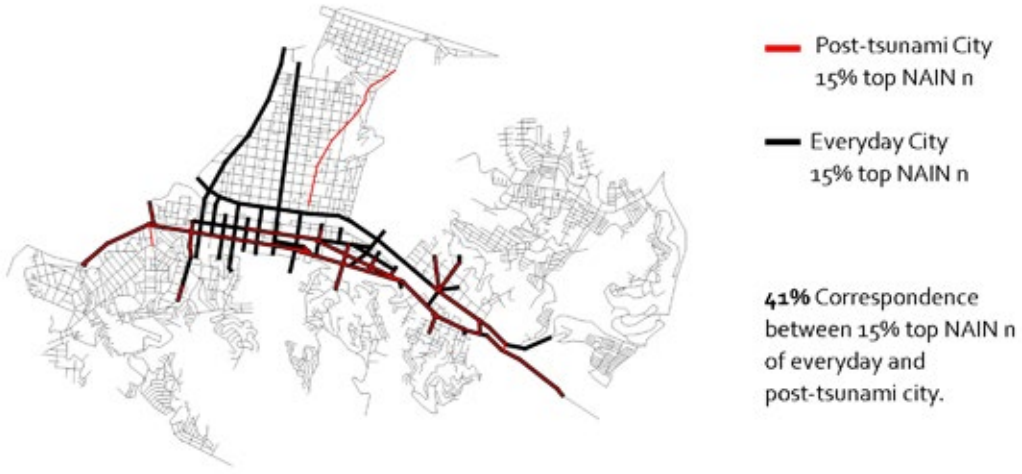


Figure 7 - Correspondence between global centralities of everyday city and post-tsunami scenarios

The outstanding effects on the total organization of the urban system change the whole pattern of global centralities dramatically (Figure 7). The percentage of the post-tsunami integration core which overlaps with the pre-tsunami city corresponds to a 43% .In the northern system, the global integration core shifts to the east presenting a linear structure, whereas the southern core maintains its location along the river. However, the dominant route of the SI2 core moves slightly to the south since the rest of the area is flooded by the tsunami.

On the other hand, from a functioning analytical approach, the land uses are analysed to understand their distribution and relation with spatial centralities. In the everyday city functioning, the retail activities show a strong dependence on the highest Integration values of the urban structure (Figure 8). The services follow the same pattern concentrating mainly around global centralities. The areas with lower Integration values mainly located on the hills, maintain a land use focused primarily on residential activities. The frontages of the 15% more globally integrated segments are studied observing that there is more than 50% of correspondence with non-residential uses, most of which belong to the retail sector. The functioning of the city in the post-tsunami scenario is modified, not only by the disabling or destruction of flooded buildings, but also by the change in the relationship between activities and structural centralities.

With regard to the relationship between active frontages and the 15% highest Integration values, it is possible to observe an increase in the percentage of residential uses, and decrease of active frontages with retail and services. Based on this, it is possible to conclude that after a tsunami, cities can be highly affected, not only in terms of the direct damage on the urban infrastructure, but also in regards the modification of the indirect impacted areas dynamics.

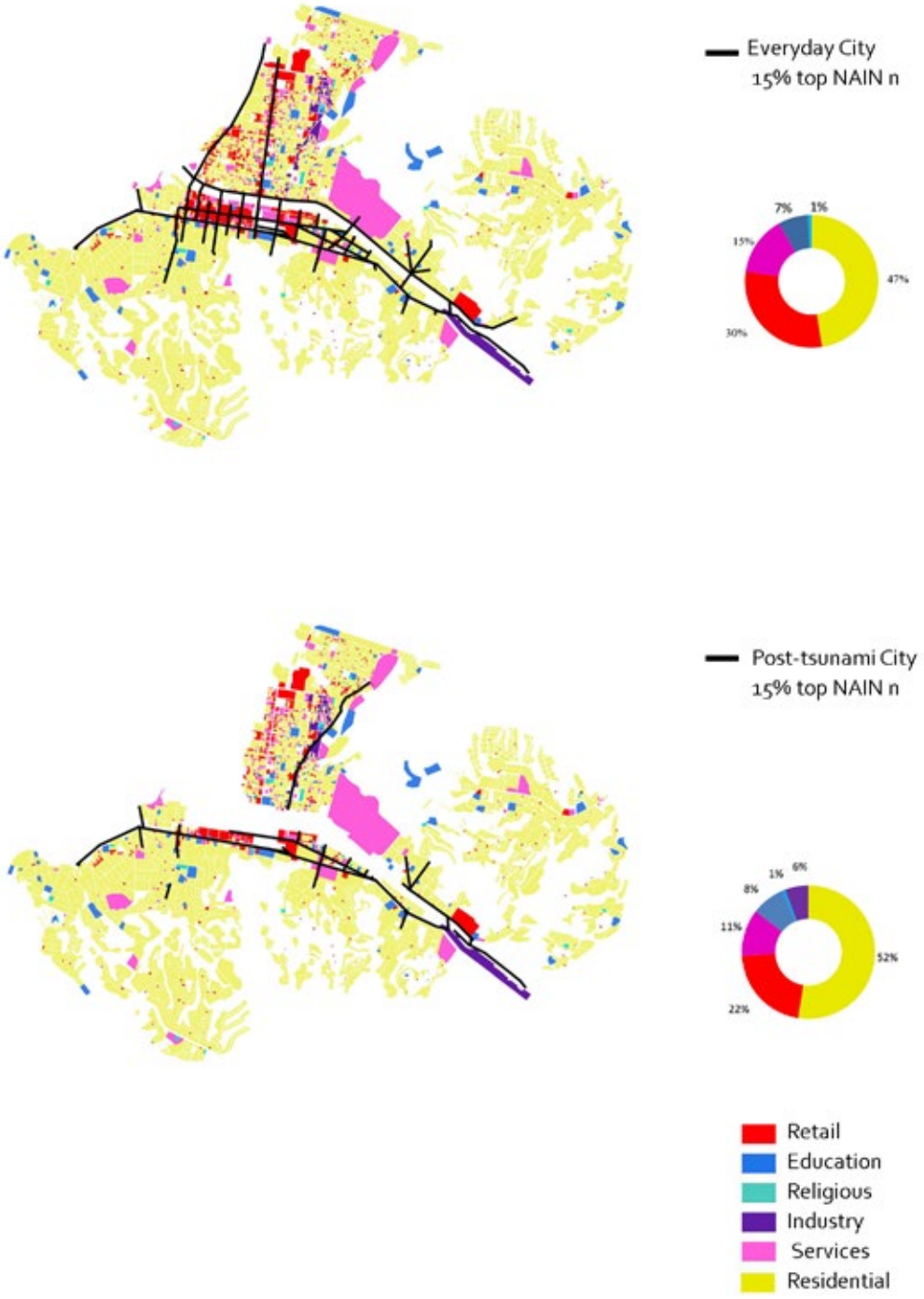


Figure 8 - Relationship between global centralities and land uses distribution. (Up: Correspondence between pre- tsunami 15% highest integrated routes and land uses. Down: Correspondence between post- tsunami 15% highest integrated routes and land uses.

In the case of Viña del Mar the effects of tsunamis on the organization of the urban system, both in configurational and functional terms, could impact the socio-economic processes after the event, weakening the resilience capacity of cities. The disturbances in the syntactical patterns of the street network and the shifts of the urban centralities result in a weak correspondence between pre and post-tsunami integration cores, which affects the natural patterns of interrelation between the urban structure and the operational functions, hindering the maintenance of the basic functions of the city during the resilience process. There is a lower density of active frontages of services and retail activities along the new integration centralities, compared to the pre-tsunami situation. As a result, the new centralities show a greater dependence on residential land uses that does not coincide with the natural logics of urban centres, losing their economic significance. The most determinant changes in Viña del Mar are results of the fragmentation of the whole urban structure into two new unconnected systems. This disruption changes not only the syntax of its urban structure but also its operability as a total system, altering the spatial accessibilities and the connectivity of the street network.

Evidence-based proposals have been developed in order to improve the urban performance in the post-tsunami scenario (Figure 9). The main objective is to re-establish the patterns of functioning of the everyday city after a disaster, increasing the correspondence between pre and post-tsunami integration cores to maintain the basic operation and the structuring centralities. The two main actions are as follows:

3.2.1 ACTION (A1):

To ensure the operation of the structuring route in north-south direction, in order to maintain the functioning of the system as a whole. This action keeps the distribution of the structural centralities and also allows the distribution of mainly commercial activities along these centres.

3.2.2 ACTION (A2):

To connect east to west the two affected systems. This allows the population of the eastern areas to have accessibility to the services located in the centre of the city where the economic and administrative activities are concentrated.

The proposed actions allow the urban system to restore normal operating conditions to a higher extent compared to the post-tsunami situation. In the case of Viña del Mar is not possible to generate a comparison based on the new average Integration values due to the anomaly in the post-tsunami figures caused by the fragmentation of the system in two new systems. However, it is possible to argue that the new values are very similar to the ones in everyday city and a strong correlation between pre and the proposed post-tsunami scenarios is observed, going from 41% of correspondence to 64% with the proposal (Figure 9).

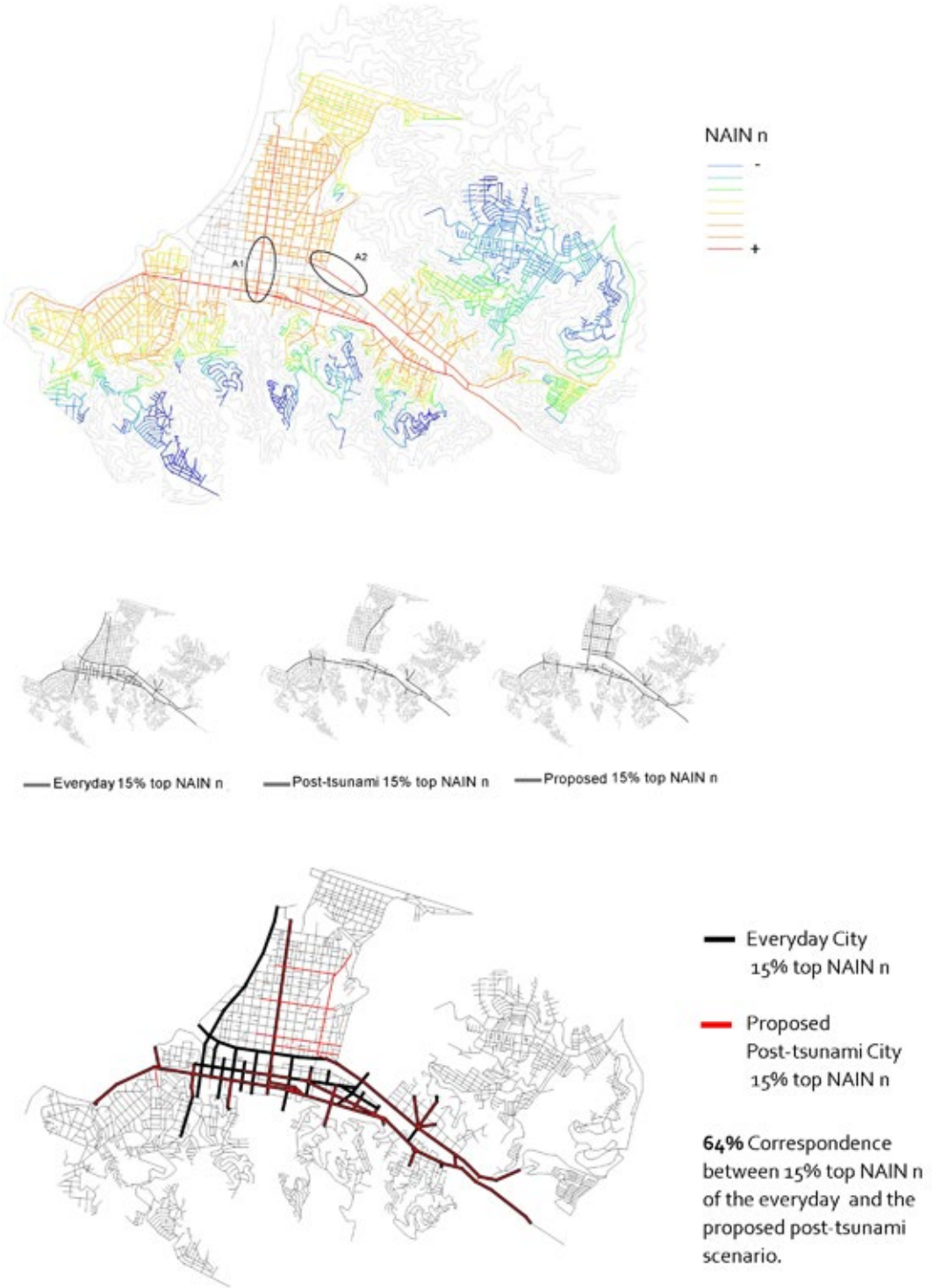


Figure 9 - Proposed actions and post-tsunami distribution of global centralities (Up: Proposed action and normalised Integration analysis. Down: Correspondence between global centralities of everyday and proposed post-tsunami scenarios.

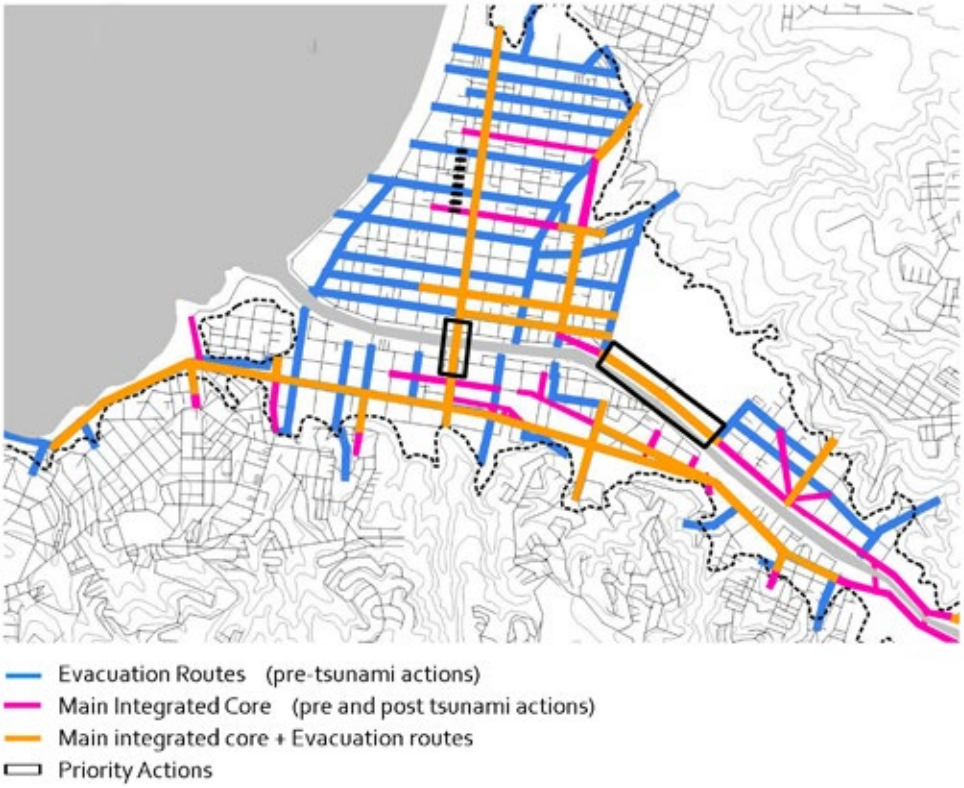


Figure 10. Basis for the Integrated response plan for Viña del Mar.

4. CONCLUSIONS

4.1 INTEGRATED RESPONSE PLAN

The research has attempted to present a new approach to the concept of urban resilience by considering the configurational properties of the built environment. The applied methodology enables to understand the role of the built environment and the particular importance of the spatial configuration on the rapid-recovery and resilience processes. This configurational approach permits the development of an Integrated Response Plan that considers both the evacuation and the post-disaster conditions. An integrated response plan for the tsunami-prone cities could be a support platform for future planning decisions, allowing to prioritise actions and define what should be done before the tsunami (if they are indispensable for the evacuation system) and what could be generated immediately after the event (to allow post-tsunami operations).

It is possible to overlap strategic proposals for both the soon-after tsunami and post-tsunami scenarios, in order to understand the principal actions to be carried out to ensure a better response to disasters. For segments used in the evacuation, pre-disaster measures should be taken into account so as to maintain the proper condition of the routes and the buildings to prevent their collapse and obstructions. In the case of the segments that structure the post-event urban system, prior actions could be taken to allow immediate operation of the routes considering tsunami-resistant measures or to evaluate repair actions that allow the operation of the routes in the shortest time possible. This plan could be considered as an important tool for making urban design decisions, preventative strategies and repair actions.

4.2 FINAL COMMENTS

The concept of resilience related to natural disasters is very complex and needs to be evaluated from multiple viewpoints. In this research, the focus was on the role of the physical environment from the perspective of urban resilience. The main principles of the theory of space syntax and its methods of analysis were useful to develop an understanding of the role of the cities' configuration in the process of enhancing resilience for both, the soon-after and post-tsunami scenarios.

In the case of soon-after scenarios, the configurational approach was used to investigate cognitive issues related to the role of urban structure during the evacuation, so as to understand the route-finding decision makings. Based on this analysis it is possible to conclude that current plans do not include configurational notions in the process of defining the evacuation routes. The existing plan does not form an interconnected system or a network of evacuation, but is only based on the determination of an origin and a destination without a greater understanding of the relationship between these routes and the whole system. Considering that the evacuation process must be performed autonomously, it is expected that the evacuation plan should take into account the logic of the natural movement based on the urban network configurational properties, in order to develop a rapid resilience capacity soon-after the generation of the tsunami, to rapidly react and cope with the threat.

In addition, it was possible to generate a study to deal with post-tsunami scenarios, where the configurational analysis was critical to understand not only the role of the area that is directly affected by the tsunami, but above all to assess the functioning of the system that is indirectly impacted by the disaster and should continue operating after the event. The indirect impacted area suffers disturbances in its system which are visible when generating syntactic measures. In this way, it was suggested to analyse and visualise how the wider impact of the tsunami on the urban street network modifies the system operation after the disaster and impacts the resilience capacity.

It is possible now to argue that even though there are different studies of tsunami affected cities, it is necessary to create an integrated understanding of the process of resilience, considering the analysis of soon-after and post-tsunami conditions from the configurational perspective, in order to generate an action plan consistent with the requirements of both phases. This could provide a guideline to local authorities to ensure that the pre and post-tsunami activities are seamlessly maintained. To understand that the analysis of the post-disaster situation should consider the analysis of the everyday scenario is fundamental to the development of projects that successfully respond to the post-disaster requirements as well as influencing the city planning for normal situations, improving day-to-day conditions.

Finally, as a further study it is proposed to incorporate into this model of analysis other variables that complement the study of the spatial configuration. Physical environment variables such as the level of maintenance of routes and buildings, the presence and location of the strategic urban functions and the location of the rescues, could be incorporated in order to have a more comprehensive understanding of the physical environment during disasters. It would also be important to consider population characteristics, which could contribute to the understanding of the communities to be evacuated, as well as their requirements for the further phases. Since this analysis was based on one of the riskiest scenarios, an analysis of each of the possible degrees of inundation is also recommendable to generate a plan able to respond efficiently to all needs.

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