Model to Integrate Resilience and Sustainability into Urban Planning

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1 Introduction

The cities of the future must reach a higher level of sustainability and that is only possible if they are capable of being more resilient against crises produced by natural events and global change (UNISDR 2015). Because of this, it is fundamental that governments and responsible entities develop planning tools that allow developing interaction or synergies between resilient design and sustainability.

In spite of the damage that natural disasters can produce in cities, these always offer an opportunity so that an urban system is reinvented and evolves towards a new status, improving and promoting changes that strengthen its reaction capacity. This process is always accompanied by innovation.

Currently, there are numerous studies which link sustainability with resilience (Ahern 2011; Childers et al. 2015; Brand 2009), however, difficulties still persist in the definition of terms and the provision of clear examples which serve as reference. This limits the possibility of designing integration tools and strategies between both concepts when planning the city.

This research project intends on advancing towards the integration of the concepts of resilience and sustainability in planning tools. It presents the case of post-disaster reconstruction implemented in the town of Dichato in Chile, after the earthquake and tsunami in 2010. By evaluating this case study, it can be shown that there are synergies between sustainable planning and urban resilience against natural disasters. In the conclusions, some suggestions are presented for the definition of tools that will allow transforming and adapting cities to face future changes.

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2 Definition of Urban Sustainability

During the last 3 decades and after the publication of the Brundtland Report (1987), sustainable development has directed international and domestic policy, leading to multiple programs, agendas and tools that are focused on urban sustainability. This is something however, that has not always generated an effective change in the development models of the cities.

To understand urban sustainability, the city can be considered as a Socio-Ecological System (SES), which must look for balance with the surroundings that support it and in its internal structure using the following three pillars: environmental, economic and social (Naredo 2003).

Starting from the ecological approach, several authors propose an approach towards sustainability of the SESs through the evaluation of the urban metabolism (Li et al. 2016; Robinson 2011). This is evaluated as the relationship between the input flow of resources, energy and information in the system, demanded to develop its functions, and the output flow in the form of heat, waste and contaminants which are finally emitted into the environment.

In the search for a city model which balances urban metabolism with its surroundings, the compact European city is acknowledged as a good example of sustainable cities, aided by its contained structure, the mix of uses and services, and the dynamism of the public spaces which facilitate efficient transportation systems. Starting from this model, the definitions and action directives in urban planning have been strengthened, both at a city level and on a neighborhood scale (Messerschmidt et al. 2008; Fariña Tojo 2008).

2.1 Sustainability Indicators

Currently, there are numerous systems of indicators developed by different entities, some of which have allowed defining directives or evaluation systems which have been incorporated into urban design and planning. For the compact European city, one of the most relevant systems is the CAT-MED sustainability indicators system, developed through a European research project of the "Climate Change and associated natural risks program" (Marín Cots 2012). This system understands the average European city as a consolidated morphological structure contrasted against urban sprawl; a model which has increased the imbalance between built space and the environment (Marín Cots 2012; Turégano Romero 2009; Tumini 2016). These indicators are organized around four key concepts:

Compactness is the parameter which deals with the physical reality, being directly related with the building density, the soil use, the amount of green spaces and the existing roads. This parameter looks to evaluate the proximity between urban uses and functions, seeing the built volume associated to the provision of equipment and public spaces as a whole.

Complexity deals with urban organization for the mix of uses and functions in the area. Urban complexity reflects the interactions that exist in the urban space and that mirror the city's vitality. This parameter is linked to the concept of urban diversity, shows the maturity of the urban fabric and the wealth of the economic, social and biological capital.

Metabolic efficiency is a concept related to the flow of materials, energy and information that the system exchanges with its surroundings. The sustainable city must reach efficient management of the incoming resources and reduce the emission of contaminating products as much as possible.

Social cohesion refers to the capacity of the cities to satisfy their role as a motor of social progress, economic growth and as a space for the development of democracy. For this, it is necessary to maintain the social balance, both at an urban and interurban level, protecting cultural diversity and co-existence between the players. In this sense, the success of the urban space is in creating the conditions which promote opportunities for meeting and exchange, facilitating co-existence, thus making the reduction of conflicts possible. In the urban design, social cohesion can be fostered using the concept of *proximity* as an expression of the city's vicinity. Fariña (200) defines proximity as that where the urban surrounding has a domestic nature, close to the home, well distributed into urban grids, and multi-functional. An urban "proximity" design promotes a different management of the space, pedestrian movement, local stores, contact with the people and the proximity of equipment and roles (Marín Cots 2012; Tumini 2016; Rueda 2012; Fariña Tojo 2009; Robinson 2011).

3 Definition of Urban Resilience

In the literature, references of the concept of resilience can be found in different areas, each one providing a more suitable definition for its application. For the urban setting, two main approaches can be recognized: engineering and ecological. From the engineering point of view, resilience is the capacity of a system to resist a disturbance, mitigate the effects and return to the point of stability once the event has ended. This definition refers to the system's "resistance" and "elasticity" (Brand 2009).

The ecological approach is based on observing the response of the natural systems under the action of a disturbance, of how certain structures mutate, sometimes some species disappear and are substituted by others, reorganizing roles and relationships between them (Holling 2001; Folke 2006). Applied to the SES, resilience is defined as "the capacity of the systems: cities, communities or societies exposed to threats to efficiently resist, absorb, adapt or recover from the effects of the threats in a reasonable time, including the maintenance and recovery of their basic structures or functions" (Jabareen 2013:221).

Susan Cutter (2003), in her studies on vulnerability, relates resilience of the SES with the geographic conditions. Her research is based on the hypothesis that it is possible to associate vulnerability to spatial patterns and that once identified, these form the directives of the adaptability of the urban system (Cutter et al. 2003; Cutter et al. 2014); Allan and Bryant (2011) in their studies about post-disaster recovery, acknowledge that the urban setting offers a series of resources that can be used in the emergency phase and that help the recovery. Therefore, it is possible to measure urban resilience as the capacity of the built environment to adapt to the changes caused by the natural events, facilitating useful resources for the early recovery of the functionality (Allan and Bryant 2011; Bryant and Allan 2013).

The extent that sustainable urban structure can contribute to the resilience depends on its capacity of resisting and mitigating the impact of the events and its flexibility towards change, taking advantage of working in a network and the capacity of reorganizing the structures and resources available. For this, the existing models must consider the risk factors and unpredictability of the events, the interaction between levels and dimensions. In this way, tools will be generated that can evaluate the status of the system and warn about the critical aspects as well, thus aiding in making decisions about preventative actions (Milman and Short 2008).

3.1 System of Indicators to Evaluate Urban Resilience

The approach to resilience by studying the SES, proposes that the urban system is capable of providing resources for innovation, to be adaptable and/or redundant. The phase immediately after the crisis, i.e. the emergency, is where the biggest changes are produced, because the system must reorganize itself as quickly as possible to start working again.

As a result of this, resilience analysis is organized around four main attributes:

- *Diversity* in terms of structures and functions, characteristic which allows guaranteeing a diversity in the response to the disturbance, in the options and in the resources available for the recovery (Walker et al. 2015).
- *Flexibility* which describes the capacity of the urban elements to adapt to the changes and to assume new roles (Allan et al. 2013; Walker et al. 2015; Villagra et al. 2014).
- *Connectivity*, essential to maintain the functionality. In the case of the SES, it is important to maintain both the physical connectivity and the exchange of information that is produced among the individuals of the same community or between different communities.
- *Modularity* is the fourth requisite which is related to Diversity and Connectivity. Resilient urban systems must be capable of shaping themselves as a modular system, in which the modules can work independently and simultaneously be connected in a network with the others. In this way, if one module collapses due to the crisis, the others can provide resources and services for the recovery.

The evaluation of these attributes can be done through the urban design indicators where we can recognize the synergies with the key concepts of sustainability.

4 Research Methodology

The research work proposes an approach to sustainable urban planning for the cities exposed to natural risks and that due to this need to improve and increase their resilience and simultaneously assure the quality of life for their citizens.

As a method, it is proposed to relate the concepts of the CAT-MED compact European city (compactness, complexity, metabolic efficiency and social cohesion) with the resilience attributes (diversity, flexibility, connectivity and modularity), setting out a system of urban design indicators that will be evaluated in the case of the post-disaster reconstruction of the town of Dichato (see Fig. 1).

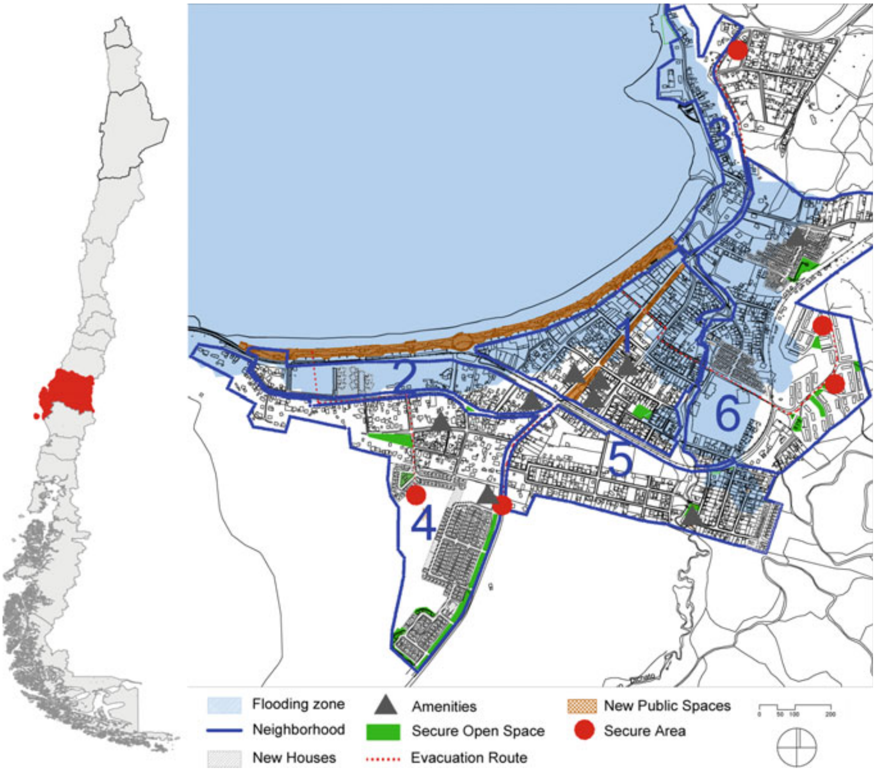

Fig. 1 Reconstruction of Dichato. Neighborhoods: *1*. Centro, *2*. Litril, *3*. Villarica, *4*. Posta, *5*. Santa Alicia, *6*. Villa Fresia. *Source* own preparation from the cartography of Tome Council and from PRBC18

Table 1 Table of resilience attributes and indicators

Resilience attributes	Synergy with sustainability	Urban design indicators
Diversity	Is mainly related with the concept of urban *complexity*. Assures *metabolic efficiency* on reducing displacements	Open spaces in safe areas: m^2 open spaces/inhabitants
		Public buildings in safe areas: m^2 built/inhabitants
Flexibility	*Compactness* in the city defines the balance between the spaces built and the open spaces, to avoid sprawl and congestion. Assures *metabolic efficiency* on reducing the displacements	Population density: inhabitants/hectares
		Urban Compactness (corrected): m^3 built/m^2 public spaces
Connectivity	Proximity between persons and services facilitates connectivity and *social cohesion* in the community Guarantees *metabolic efficiency* on promoting a more efficient mobility	Proximity Index: percentage of inhabitants with access to at least 1 utility
		Walkability Index: percentage of spaces and sidewalks over the total number of roads
Modularity	Organization in neighborhoods allows that every module is independent and can provide resources in case of crises. Improves the *metabolic efficiency* by operation in network	N° of independent and resilient neighborhoods

The table has been prepared by the authors starting from the revision of: (Allan et al. 2013; Cutter et al. 2003; Marín Cots 2012; Norris et al. 2008; Walker et al. 2015)

Through the evaluation of the resilience indicators, we wish to evaluate whether there are synergies between sustainable design and urban resilience and whether the current planning tools allow meeting this demand. A group of indicators is defined below, orientated to the evaluation of the urban design elements which have an impact on the resilience. This work is limited to the evaluation of the physical resilience dimension, because, among the different dimensions that make up the resilience of the community, this is the one that depends directly on urban planning (Table 1).

4.1 Case Study: Dichato

On February 27th 2010, an earthquake of 8.8 on the Richter Scale and a tsunami generated by this, affected five regions of the central-southern zone of Chile. Many of the coastal cities were severely damaged by the event, along with small fishing villages and touristic areas, which were the zones that saw the greatest destruction.

After the catastrophe, the Government set a reconstruction process in motion in these coastal areas. In the case of the Biobio Region, the process was organized and handled by the Regional Government, which proposed an integrated management program with the idea of rethinking the cities from a more complex and cross-sectorial view (Baeriswyl 2011). The city of Dichato experienced major intervention, becoming a reference of the Coastal Reconstruction Plan (GSAPP 2015; Bio-Bio Gobierno Regional 2010) (Map).

Dichato is part of the district of Tome and is set in Coliumo Bay. Its geography makes it especially vulnerable to tsunamis due to a combination of geographic factors, including the low altimetry of the town center and the form of the bay which amplifies the hydrodynamic effects of a tsunami. Likewise, the low resistance of the buildings, mainly consisting of wooden one story houses with no foundation, increased the town's vulnerability.

The losses were substantial, both in number of homes and in urban services and infrastructure. Along with the material losses, the production sector, mainly associated to fishing and tourism, was seriously compromised. The town's reconstruction was a greater challenge due to the urgency of acting in an integrated manner in the urban system, mobilizing the resources needed for the economic and social recovery of the affected communities (Cartes Siade 2013; GSAPP 2015).

The reconstruction project proposed the replacement of the existing equipment and a significant increase of the green areas and public spaces. Different mitigation measures were prepared as a coastal defense, a promenade and a mitigation forest, with the purpose of reducing the hydrodynamic force of a possible future tsunami and thus, its impact on the city. The Master Reconstruction Plan proposed changes in the soil use, relocating critical equipment into safe areas (schools, fire station, police station and health services). In the case of the residential areas, when their relocation to a safe height was not possible, resilient homes were proposed which comply with higher structural design standards to facilitate their reconstruction (Baeriswyl 2013).

For the evaluation of the case study, the indicators in six neighborhood units of the city have been analyzed: Centro, Litril, Villarrica, Posta, Santa Alicia and Villa Fresia. The data used only considers the infrastructure above the flood zone, as all the infrastructure below this height cannot be considered as a useful resource for recovery (see Fig. 1).

5 Results and Discussion

The values collated are presented in Table 2 and refer to the configuration set out in the Master Reconstruction Plan. The data provided by the 2002 census, information collected onsite, cartography of the Tome Council database and the information provided by the PRBC18 Coastal Urban Reconstruction Plan were used to prepare these values. The data has been prepared using the GIS program.

The data shows that after the reconstruction process of the Centro neighborhood, it is still the one with the highest urban density. Litril, Centro and Villarrica, located in the flood zone and greatly affected by the 2010 tsunami, in spite of not seeing

Table 2 Collation of indicators in the dichato reconstruction phase

Indicador	Litril	Centro	Villarrica	Posta	Santa Alicia	Villa Fresia
Population Density (inhab/h)	18.71	41.13	82.94	18.89	35.84	50.18
Open Space (m^2/inhab)	0.00	0.00	3.89	38.84	19.80	11.28
Public Buildings (m^2/inhab)	0.00	0.00	0.00	0.72	0.00	0.00
Urban Compactness (m^3/m^2)	0.00	0.00	0.02	0.37	0.18	0.18
Walkability Index (%)	0%	0%	0%	100%	100%	100%
Proximity Index (%)	0%	0%	0%	86%	23%	0%
Population Density (inhab/h)	18.25	91.84	21.58	10.12	29.17	38.34
Open Space (m^2/inhab)	0.00	3.36	3.89	46.63	1.04	3.53
Public Buildings (m^2/inhab)	2.60	1.10	0.00	46.17	0.80	1.70
Urban Compactness (m^3/m^2)	0.00	9.07	0.00	9.13	101.10	12.35
Walkability Index (%)	100%	100%	100%	83%	100%	100%
Proximity Index (%)	100%	100%	100%	100%	100%	100%

Pre-tsunami and post-reconstruction

Own preparation from the data provided by the Master Plans and the Tome Council. The pre-tsunami values are presented only as references because the objective of paper is assessed the synergy between sustainability and resilience in the reconstruction project

major changes in the population density, have not improved in terms of equipment. In the neighborhoods located at higher levels, like Posta, Santa Alicia and Villa Fresia, these received new buildings and thus increased their population density.

In terms of the amount of open spaces and public buildings that are useful for the emergency, the values are very low and insufficient still for the resident population in five of the six neighborhoods analyzed. The data shows that the location of the new equipment has been set up in the Posta neighborhood. The highest number of open spaces and services is concentrated in the Posta neighborhood; this is because the neighborhood is in the safety area above the flood zone.

In the evaluation of the corrected urban compactness, Litril has a complete lack of open spaces and Villarrica a lack of public buildings. Santa Alicia has a very high urban compactness value, because it has a high volume of constructed buildings and very little open space. In a post-disaster scenario, the population of Santa Alicia would have great difficulty to organize the emergency. From the point of view of sustainability, the green space greatly reduces the environmental impact produced by the urbanization, while it provides meeting places and spaces for social cohesion.

In regards to connectivity, the neighborhoods comply with the proximity and pedestrian route requirements, demonstrating good connectivity both inside the neighborhood and in the rest of the system. The Posta neighborhood has limitations in terms of pedestrian connectivity when compared to other neighborhoods of the system.

Thus, the assessment shows that the only Posta is sustainable and resilient neighbourhood, because it provides open spaces and basic services useful for emergency activities and recovery. Despite, the lack of connectivity with the other neighbourhoods could limit the networking capacity by providing spaces and services to citizens that live in less resilient neighbourhoods.

In terms of the objectives of the Master Reconstruction Plan in regards to environmental improvements, this has been partially met from the perspective of this analysis matrix. Although the reconstruction process implied a considerable increase of the amount of services and public spaces, the locating of these was not balanced in the whole urban area, producing big contrasts between neighborhoods and something that without a doubt affects the city's resilience and sustainability conditions.

The neighborhood which has the best behavior in terms of its resilience is Posta. In fact, in case of emergency, this neighborhood could continue working and provide useful resources for the recovery of others with fewer equipment; however, the lack of connectivity may be an important limitation. In terms of the modularity and operation in the system's network, the town of Dichato maintained its original fabric after the reconstruction process, as such it did not improve this aspect, which could have been provided a greater resilience.

6 Conclusions

The work presented proposes a quantitative approach to analyze sustainability and resilience in the urban space. Through the analysis of the post-disaster reconstruction of Dichato, the idea is to demonstrate that sustainable urban design also contributes to improving the resilience of risk-exposed towns, placing value on synergies between the two approaches.

From the results obtained, it can be concluded that there are synergies and differences between the two approaches, as such it is necessary to adapt the tools and models orientated to sustainable design in order to integrate the concepts of resilience and adaptability to facing natural events.

In the case analyzed, a general improvement of the sustainability and of the resilience of the urban whole is obtained, underlining some disagreements in concrete aspects. The first is the imbalance in locating public spaces and green areas, which are mainly concentrated in the Posta neighborhood. On considering these spaces as useful resources for the recovery (Bryant and Allan 2013; Allan et al. 2013; Villagra et al. 2014), it is necessary to even out the amount of equipment in all neighborhoods. The second is related with the deficient connectivity in this neighborhood, which could make it difficult for them to provide services and resources to the others in case of emergency. This leaves it clear that, to reach the resilience goals, sustainable design processes must also incorporate the vision of modularity and operation in the urban system network (Walker et al. 2015).

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