The new seismic ghost cities

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ABSTRACT:
The persistent vulnerability in human settlements and their infrastructure is not limited to remote regions of developing countries but extends around the world's seismic hot spots. The disrupted cities are a worldwide problem; they may be single blocks or entire neighbourhoods awaiting demolition or repair. They are ghost cities where no one lives and the urban function is completely disrupted contributing to deterioration, abandonment and disinvestment.
Ghost cities unfortunately are nothing new, but now this concept can be assessed and estimated using the disruption index (DI), an indicator of the amount of disruption of the urban tissue caused not only by the direct loss but also by losses caused by the interdependences of urban functions (electric power, water, transportation networking, etc.) which aggravate deeply the overall seismic impact. In this paper, we apply this concept in a few places of recent earthquakes to show how DI can portray the degree of disruption.

Keywords: Urban disruption, Ghost cities, Disruption index, Interdependencies

1. INTRODUCTION

Natural disasters, civil wars, economic depressions or government decisions to maintain high economic growth (China) are the cause of the continuous increase of abandoned cities. This phenomenon occurs not only after an event but the most impressive is that many of these cities remain vacant for decades or permanently.
Cities like Beichuan in China, L'Aquila, Concordia or Mirandola in Italy, are vulnerable to earthquakes, the physical status of the buildings is very poor (without adequate building codes, laws, training, inspections and enforcement) or they are built over very hazardous sites (soft soils, high slopes, etc.), so when the earthquake shocks the built environment is reduced to rubble, supplies are disrupted, citizens have to be relocated to a new location and the dead cities sprang up.
Throughout history, the city has concentrated and centralized the many complex activities and institutions that make civilization possible. The growing interconnectedness, enabled by extensive transportation systems, networks and communications, greatly expands the impacted area of a damaging earthquake far beyond the epicentral region. Cascading effects contribute to the urban disruption in a geographical area caused by the physical conditions (damage grades) of services and networks after a disaster. The duration of a disruption is a key factor of whether the effects are temporary or permanent. If the economic activity that supported the town failed or people need to be relocated due to the absence of housing or infrastructures or other key assets (particularly electrical power, has a detrimental impact on the pace of response and recovery), it will result in ghost towns, as occurred in Fukushima (the area was, and still is, so contaminated with nuclear radiation that many of the evacuees were never permitted to return to their homes); L'Aquila, four years after the earthquake, the rebuilding of the historic centre is not started and many people live in the "New Town" (Progetto CASE) built on the outskirts, or the city of Beichuan that was moved to a neighbouring county after the 2008 earthquake, leaving the old city abandoned. These are some examples of modern ghost cities.

2. EARTHQUAKE SIMULATIONS INCLUDING CASCADING FAILURES

Sophisticated predictions of seismic response of buildings and facilities can be simulated nowadays and be used in a loss analysis, where the losses are calculated using measures such as repair cost, repair duration, and loss of life. One limitation with this type of analysis is that it does not account for the susceptibility of infrastructure systems in decreasing their reliability, which frequently leads to cascade failures. As well as, such quantitative analyses can be highly robust, but they require significant levels of information and can only be applied in a small number of situations; usually in the assessment of a small number of elements.

In this context, Disruption index (DI) (Oliveira et. al, 2012; Ferreira, 2012; Ferreira et al., 2013), can be used to estimate the potential impacts from earthquakes or other hazardous events, integrating physical, human, social, environmental and economic damage. The analysis proceeds by determining how the top failures can be caused by individual or combined lower level failures or events. It is a useful tool to evaluate the costs and benefits of risk reduction measures, as well as preparedness and response. It is also desirable for other purposes such as risk financing purposes.

In the DI methodology are included the main purposes:
- the expected sequence or chain of events that may ensue from a hazard event;
- quantification of possible interdependencies due to damaged networks;
- the distribution of impacts across the population, public infrastructure and economy, and their nature and scale.

This method generated a strong incentive to develop a process to ensure that additional management actions and monitoring systems were only implemented where necessary, and only to an appropriate level. If risks exceed acceptable levels due to their social, economic, environmental costs, clear options to reduce these risks or possibly transfer them need to be offered.

3. BUILDING THE MODEL

The disruption index is derived from established and classified functions using dimensions of human needs, being the most fundamental: environment, housing, food, safety and security, health, education and employment. Each dimension contains the functions (service components) that have impact on welfare and urban life aspects, like water, sanitation, telecommunications, electricity, transportation network and existence of debris. Figure 1 illustrates the relationship between these data elements.

Let's look at Environment to illustrate the chain of dependencies and interdependencies. The Environment depends on the Water, Sanitation and Dangerous facilities. Water depends on the operation of the Water system equipment and the Electricity supply, which in turn depends on the Electric system equipment. Similar reasoning is applied to all other boxes in Figure 3.1.

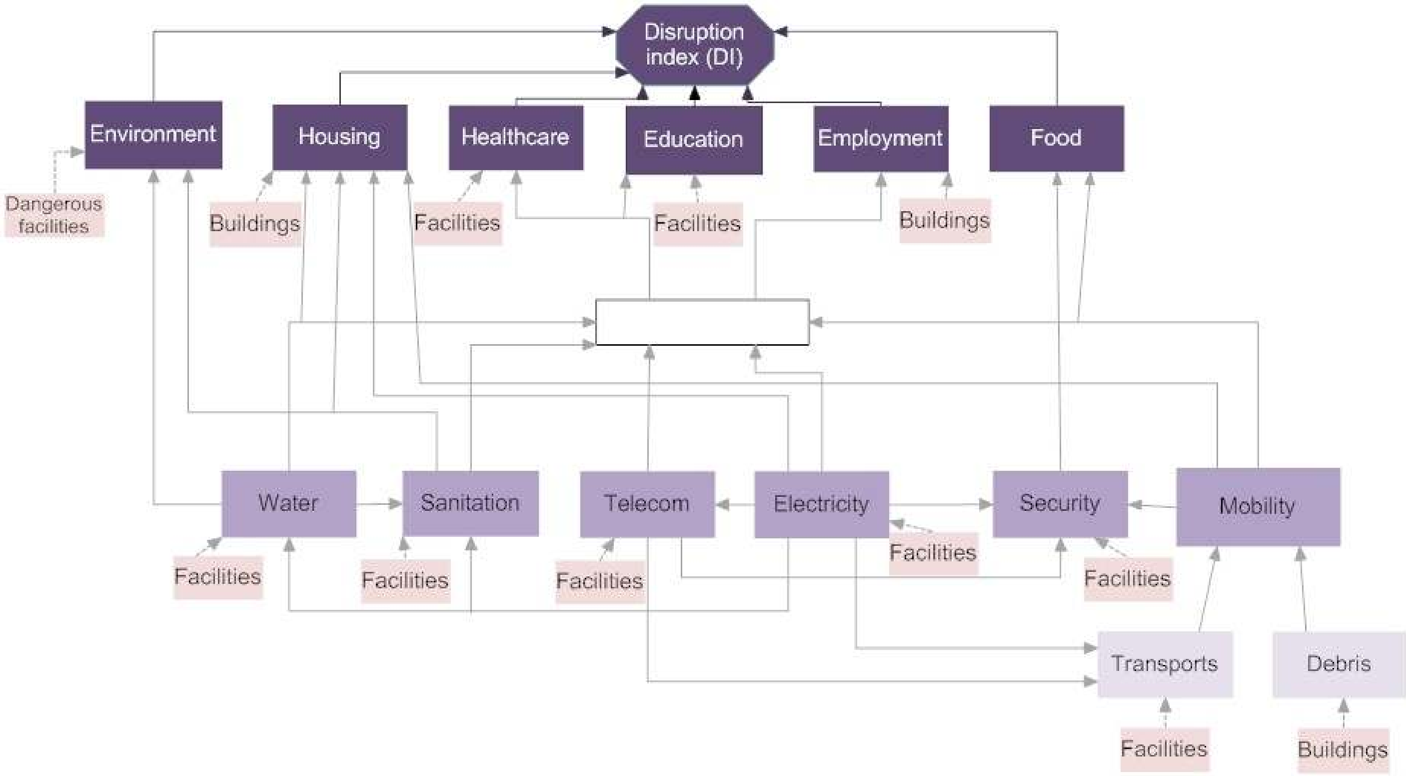

Figure 3.1. Disruption index: infrastructure dependencies and interdependencies

The propagation and cascading effects can be calculated in a bottom → up sequence. This calculation starts with the physical damages directly suffered by the exposed assets, proceeds to the impacts that each physical element experiences via the functional performance of the services/components that depend on them, and reaches the top level, DI.
All impacts are evaluated on a qualitative scale (Table 3.1.), and this is obtained combining its severity and scale (which proportion of the reference urban area is exposed to the effect).

Table 3.1. Qualitative descriptor of Disruption index, DI (impact levels are numbered in decreasing order of urban disruption/dysfunction)

Impact level	Description of the impact level
V	From serious disruption at physical and functional level to paralysis of the entire system: buildings, population, infrastructure, health, mobility, administrative and political structures, among others. Lack of conditions for the exercise of the functions and activities of daily life. High cost for recover.
IV	Starts the paralysis of main buildings, housing, administrative and political systems. The region affected by the disaster presents moderate damage and a slice percentage of total collapse of buildings, as well as victims and injuries and a considerable number of homeless because their houses have been damaged, which, although not collapse, are enough to lose its function of housing. Normal daily activities are disrupted; school activities are suspended; economic activities are at a stand-still.
III	Part of the population may permanently lose their property and need to permanent be relocated, which means strong disturbances of everyday life. This level is determined by significant dysfunction in terms of equipment's, critical infrastructures and losses of some assets and certain disorders involving the conduct of professional activities for some time. The most affected areas show significant problems in mobility due to the existence of debris or damage to the road network. Starts significant problems in providing food and water, which must be ensured by the Civil Protection.
II	The region affected by the disaster presents few homeless (about 5%) due to the occurrence of some damage to buildings, affecting the habitability of a given geographical area. Some people may experience problems of access to water, electricity and/or gas. Some cases require temporary relocation.
I	The region affected by the disaster continues with their normal functions. No injured, killed or displaced people are registered. Some light damage may occur (non-structural damage) that can be repaired in a short time and sometimes exists a temporary service interruption. The political process begins with an awareness that the problem exists as well as some investments in strengthening policy and risk mitigation is/should be made.

4. APPLICATIONS USING RISK ASSESSMENT REPORTS

Potential negative effects included fewer residential units, school and business closures, loss of medical services and few inhabitants, creating the new ghost cities phenomenon.
Following the earthquakes agencies assemble teams of experts to evaluate earthquake impacts and the response to disaster. The results of the assessment missions are compiled in field mission reports. This data serve not only to inform but also to build the DI and evaluate how would be the long-term recovery process, or in other words, if we are in presence of future new ghost cities.

4.1. L'Aquila, 2009

On April 6, 2009, in the east-central Italy, the mountainous Abruzzo region was struck by an earthquake (M_W 6.2) at 3.32 a.m. (01:32:39 UTC) causing severe destruction on 26 "comuni" (localities) and claimed more than 300 lives (Ferreira, 2009).
According with post-earthquake reports (EERI, 2009) on a broader scale, high damage levels were seen in the historic city centre of L'Aquila and villages like Onna, Paganica and Castelnuovo, where more than 50% of the historic centres were damaged. The damage observed on industrial structures was generally concentrated in non-structural elements (e.g., partitions and ceiling tiles) and contents, although some structural damage to beams and columns was observed. A number of regional and

provincial roads were partially closed, mainly as a result of earthquake-induced land and rock slides and settlements.
Utility networks for water, electricity and phone services were all briefly interrupted by the earthquake. Natural gas and electricity remained off in areas of severe damage, like downtown L'Aquila and Onna, and several individual users remain disconnected because of severe damage to their buildings.
According to these descriptions we are able to fill the yellow cells (Figure 2) below which correspond to the physical damages directly suffered by exposed elements, and we can see how interactions within thesystem have implications on the whole urban system. The following figures (Figure 4.1 to 4.4) show how to apply this model to L'Aquila case.

Insirt the impact level	Physical elements	Description of the impact level
2	[1...3] Electric power network	Parts of many substations and power transmition lines will be damaged (moderate damage) and some of these will be incapacitated. Such effects upon these facilities will further impair transmission of power to a certain area until repairs are made.
2	[1...4] Transportation infrastructures	Moderate damage to road infrastructure, railway, airports or port infrastructures.
2	[1...3] Water equipment's	Pipeline damage extensive in areas of ground failure. Equipment restoration (repaired or replaced) as a function of time (in weeks).
2	[1...3] Sanitation equipment's	Disturbance in operations. Equipment restoration (repaired or replaced) as a function of time (in weeks).
2	[1...3]Telecom equipment's	General errors or failure to communications systems may require some repair or replacement. Problems with fixed and mobile communications.
3	[1...4] Educational facilities	Half of these facilities will present moderate to severe damaged and be unusable. Non-structural damages
3	[1...4] Healthcare facilities	Moderate damage, most present D2 and D3. Non-structural damages: mechanical and medical equipment damage which forced hospitals to sterilize off site, and disrupted diagnostic services. Functional losses are usually due to non-structural damage.
3	[1...4] Security facilities	Moderate damage, most present D2 and D3. Part of them were usable after the earthquake.
4	[1...5] Building stock	Many buildings are unusable/dangerous due to severe damages.
1	[1...4] Critical infrastructures	No damage or minor damage, fully operational.

Figure 4.1. Level of dysfunction of each element

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Impact level	Services and components	Impact descriptor
2	[1...3]Power supply	Power supply system can be quickly recovered (hours). Repair of a considerable number of equipment due to moderate damage in substations (power loss in certain sections => population affected). Repair (priority is given to substations that are near the epicenter of the earthquake, and hence more likely to be damaged) and reenergizing. Critical services are maintained.
2	[1...3] Water supply	Temporary service interruption but with critical services provided. Tankers deliver water to areas without supply.
2	[1...3] Sanitation system	Temporary service interruption but with critical services provided.
2	[1...3] Telecom supply	Temporary telecom service disruption (voice, data and internet services) (hours/days)
3	[1...4] Mobility	Local perturbation on mobility linked with landslide or major damages. Used only by recovery teams. Disruptions to commuting trips, work and nonwork trips.
3	[1...4] Security	Difficulties in rescue, restoring order, security and food distribution.
2	[1...4] Transportation	Some interruption in transport service due to dysfunction of normal operation, effecting travellers in a negative way (e.g. by extending the travel time). Traffic is slow.
2	[1...3] Debris	Some debris from buildings in some roads causing occasional interruptions (mobility, access)

Figure 4.2. Level of dysfunction of each service and associated descriptor

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Impact level	Functions (human needs)	Description of the impact level
2	[1…4] Environment	Local pollution/contamination problems. Leaks or spills of substances such as oil, waste oil, fuel, lubricants, paints. Public health problems, substances can pose risks to people
4	[1…5] Housing	Residential buildings are unusable (+40% D3 and D4-D5). Semi-permanent housing needed; a long-term relocation will be required. Displacement of residents from their homes has significantly altered traffic patterns, combined with changes to the locations of schools, businesses and shops.
2	[1…3] Food	Disruption of normal conditions for their delivery, mainly due to mobility difficulties. The supply is provided by Civil P. and/or other institutions.
4	[1…4] Education	There would be educational facilities with severe damage or collapse. Disruption of educational continuity, schools inaccessible for long periods. Students are relocated to other areas of the country. Families sometimes are not able to carry the burden of fees because of not-existing livelihoods.
3	[1…4] Employment	Interruption of most economic activity. Sales/production decrease. Large decrease in tourist inflows due to the damage observed on cultural heritage, etc.
3	[1…4] Health care	Provided only the basic healthcare. Surgery with a reduced capacity, to minimise the risk post-operative infection. Health personnel need better coordination to provide medical services and deliver the assistance. Problem of distribution, availability of essential medicines. Patients at the damaged hospitals and health centers were forced to evacuate to temporary and/or provisional medical care centers.

Figure 4.3. Level of dysfunction of each function and associated descriptor

Impact level		Description of the impact level
4	[1…5] Disruption index, DI	Starts the paralysis of main buildings, housing, administrative and political systems. The region affected by the disaster presents moderate damage and a slice percentage of total collapse of buildings, as well as victims and injuries and a considerable number of homeless because their houses have been damaged, which, although not collapse, are enough to lose its function of housing. Normal daily activities are disrupted; school activities are suspended; economic activities are at a stand-still.

Figure 4.4. Final earthquake impact (DI)

As we could observe, a high DI correlates with a larger impact and functions disruptions.

4.2. Emilia-Romagna, 2012

On 20th of May of 2012, an earthquake (M_W 5.9) occurred in the North of Italy, in the Region of Emilia-Romagna, near the city of Ferrara. On May 29th, another event of magnitude MW 5.8 struck the area of Modena, Mirandola and Agostino, Finale Emilia, etc). In total 33 “comuni” were affected: da 33: 7 in Reggio Emilia province, 14 in Modena province, 5 in Bologna province and 7 in Ferrara province. The earthquake of 29th May left 15.000 people in need of shelter.

Both the earthquakes are characterised by heavy damage and collapse to historical structures and industrial facilities (EPICentre, 2012). The historical centres close to the epicentre areas like Mirandola or Concordia suffered several damages especially on masonry buildings and historical buildings like churches or the partial collapse suffered by the Castles in Finale Emilia and San Felice sul Panaro. According to the EPICentre report, some 500 factories were damaged and access was banned to 3.000 others. In Mirandola, where four deaths occurred in factories, the Mayor signed an ordinance to interdict the entire industrial area pending evaluation of the seismic safety of buildings. Throughout the affected area, at least 15.000 workers were laid off or lost their jobs.

School buildings suffered moderate to severe damages as well as the healthcare facilities (Regione Emilia-Romagna, 2012).

The main roads connecting the affected towns were not damaged by the earthquake and remained open. Electrical substations have suffered slight damage.

From the evaluation of 67.000 buildings and according with official data, 30.000 are classified as unsafe, 16.500 are temporarily unsafe but safe after simple repairs and around 15.000 are classified as Unsafe due to external risk (e.g., damage to adjacent structure or local landslide).

The following figures (Figure 4.5 to 4.8) show the Emilia-Romagna global disruption.

Insirt the impact level	Physical elements	Description of the impact level
2	[1…3] Electric power network	Parts of many substations and power transmition lines will be damaged (moderate damage) and some of these will be incapacitated. Such effects upon these facilities will further impair transmission of power to a certain area until repairs are made.
1	[1…4] Transportation infrastructures	Normal service or minor disturbance may occur.
2	[1…3] Water equipment's	Pipeline damage extensive in areas of ground failure. Equipment restoration (repaired or replaced) as a function of time (in weeks).
2	[1…3] Sanitation equipment's	Disturbance in operations. Equipment restoration (repaired or replaced) as a function of time (in weeks).
2	[1…3]Telecom equipment's	General errors or failure to communications systems may require some repair or replacement. Problems with fixed and mobile communications.
3	[1…4] Educational facilities	Half of these facilities will present moderate to severe damaged and be unusable. Non-structural damages
3	[1…4] Healthcare facilities	Moderate damage, most present D2 and D3. Non-structural damages: mechanical and medical equipment damage which forced hospitals to sterilize off site, and disrupted diagnostic services. Functional losses are usually due to non-structural damage.
2	[1…4] Security facilities	Slightly damage to the building and minor non-structural damage , usable immediately after inspection.
4	[1…5] Building stock	Many buildings are unusable/dangerous due to severe damages.
1	[1…4] Critical infrastructures	No damage or minor damage, fully operational.

Figure 4.5. Level of dysfunction of each element

Impact level	Services and components	Impact descriptor
2	[1…3]Power supply	Power supply system can be quickly recovered (hours). Repair of a considerable number of equipment due to moderate damage in substations (power loss in certain sections => population affected). Repair (priority is given to substations that are near the epicenter of the earthquake, and hence more likely to be damaged) and reenergizing. Critical services are maintained.
2	[1…3] Water supply	Temporary service interruption but with critical services provided. Tankers deliver water to areas without supply.
2	[1…3] Sanitation system	Temporary service interruption but with critical services provided.
2	[1…3] Telecom supply	Temporary telecom service disruption (voice, data and internet services) (hours/days)
3	[1…4] Mobility	Local perturbation on mobility linked with landslide or major damages. Used only by recovery teams. Disruptions to commuting trips, work and nonwork trips.
3	[1…4] Security	Difficulties in rescue, restoring order, security and food distribution.
1	[1…4] Transportation	Normal operation or small perturbations with no adverse effects.
2	[1…3] Debris	Some debris from buildings in some roads causing occasional interruptions (mobility, access)

Figure 4.6. Level of dysfunction of each service and associated descriptor

Impact level	Functions (human needs)	Description of the impact level
2	[1…4] Environment	Local pollution/contamination problems. Leaks or spills of substances such as oil, waste oil, fuel, lubricants, paints. Public health problems, substances can pose risks to people
4	[1…5] Housing	Residential buildings are unusable (+40% D3 and D4-D5). Semi-permanent housing needed; a long-term relocation will be required. Displacement of residents from their homes has significantly altered traffic patterns, combined with changes to the locations of schools, businesses and shops.
2	[1…3] Food	Disruption of normal conditions for their delivery, mainly due to mobility difficulties. The supply is provided by Civil P. and/or other institutions.
4	[1…4] Education	There would be educational facilities with severe damage or collapse. Disruption of educational continuity, schools inaccessible for long periods. Students are relocated to other areas of the country. Families sometimes are not able to carry the burden of fees because of not-existing livelihoods.
3	[1…4] Employment	Interruption of most economic activity. Sales/production decrease. Large decrease in tourist inflows due to the damage observed on cultural heritage, etc.
3	[1…4] Health care	Provided only the basic healthcare. Surgery with a reduced capacity, to minimise the risk post-operative infection. Health personnel need better coordination to provide medical services and deliver the assistance. Problem of distribution, availability of essential medicines. Patients at the damaged hospitals and health centers were forced to evacuate to temporary and/or provisional medical care centers.

Figure 4.7. Level of dysfunction of each function and associated descriptor

Impact level		Description of the impact level
4	[1…5] Disruption index, DI	Starts the paralysis of main buildings, housing, administrative and political systems. The region affected by the disaster presents moderate damage and a slice percentage of total collapse of buildings, as well as victims and injuries and a considerable number of homeless because their houses have been damaged, which, although not collapse, are enough to lose its function of housing. Normal daily activities are disrupted; school activities are suspended; economic activities are at a stand-still.

Figure 4.8. Emilia-Romagna disruption index

4. CONCLUSIONS AND DISCUSSION

Extensive and prolonged loss of electrical power or other key services, combined with the destruction of physical elements (buildings and infrastructures), disrupt many sectors, creating the red zones and limit the capacity to recover.
A disaster often has the most significant effect on small businesses. Usually they don't reopen after a major disaster, because they have just one location and lack a backup location for operation, or cannot be reached by their customers if their customers run out of money to buy from them, etc. (The Heritage Foundation, 2012). Today's global supply chain and dependence on it, once disrupted can have a dramatic impact.

One of the main benefits of using this approach it's the significant engagement of the various stakeholder groups through the process.
The development of "online DI" tool, freely available online is crucial to develop in the near future. This tool helps emergency responders, disaster preparedness, government agencies, and the media in a simplified way to carried out their earthquake impact assessment.

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