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Risk Analysis for Smart Cities Urban Planners

Safety and Security in Public Spaces

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1 Problem Statement & Claim

1.1 Foreword to the research

To provide an organic and general vision of the work carried out in this research project, the basic idea in a general sense will be presented in this section.

The scope of this research is inspired by an evolution of two key concepts introduced by Christopher Alexander. In his writings, Alexander was the first to state that the city was not a tree, from the point of view of its mathematical representation, but a lattice. Although this definition to date is not fully shared, and although it is only a representation in a mathematical-geometric context, it still gives an idea of what the complexity is, in terms of the interrelationships between its elements, of a city. Far from wanting to reduce the complexity of a city, from the point of view of urban planning, urban design and architecture in general, to a simple mathematical grid, the fact remains that a sufficiently detailed descriptive approach to the city is difficult. In this regard, Alexander conducted other studies that led him to publish his most famous writings, namely "The Timeless Way of Building" and "A pattern language: Towns, Buildings, Construction" where he tries to define a formal language for the description of a city. In practice, Alexander develops a generative grammar capable of formally describing complex and articulated concepts of architecture and urban planning. One of the purposes of this innovative approach, which still makes it one of the reference texts in the sector today, was the ability to define a common language that would facilitate both the participation of ordinary citizens and the collaboration between professionals in architectural and urban planning.

As will be explained later, in this research, we wanted to apply a similar approach, to make two domains communicate which, in any city but even more so in a smart City, find themselves having to collaborate very closely and for very long, although they are very distant both in lexical terms and in terms of methodologies and objectives.

The two domains we are talking about are those relating to urban planning, urban design and architecture, seen as the first domain both in terms of time and in terms of completeness of vision, and that relating to the world of engineering. The latter world ranges over the innumerable branches of an extremely heterogeneous discipline, therefore from civil engineering to hydraulics, mechanics, electronics, information technology, organizational engineering and more. In practice, there is a domain that defines the requirements and the overall vision (architecture, urban planning and design) and a domain, the engineering one, which implements them with real infrastructures and systems.

The levels of complexity of a smart city, but now also of any modern city, develop on two levels: one in terms of relationships between the elements that make it up, and the other in terms of an increase in the types of requirements that they want to satisfy. To introduce this concept, just consider that, for example, for many centuries, the aesthetic factor and the defensive factor represented the heart of urban planning, while today concepts such as livability, sustainability, and quality of life have become extremely important, resilience, which have also been extended from the city to the entire community that lives there.

The gap between the world of architecture, urban planning and urban design and the world of engineering has therefore gone on to widen further as the conceptual distance between the terms of the languages of the two worlds has increased. If in the past it was simple to translate defensibility into strength and thickness of the walls, today it becomes much more complex to associate the concept of quality of life with plant engineering and infrastructure.

To put the aforementioned two worlds into communication and allow for seamless communication that allows the concepts of the first world to be translated into those of the second, a path has been followed which follows Christopher Alexander's idea: to define a common language.

The research has simplified the concept of Smart City, from an engineering point of view to that of a system composed of hardware and software. Very complex. Incredibly complex but, in effect, similar to a software system that runs on hardware. Although the simplification may seem excessive, it has made it possible to use the recent formal descriptive theory used in software engineering as a starting point for the development of this common language. This theory foresees the rules of extension of the language which have been applied to the case in question allowing complete traceability of the requirements at all levels.

The introduction of this common language was only the first step. Since the research is focused on risk analysis in terms of safety and security in public spaces, the current existing risk models were considered which, as can be easily predicted, resulted in different results not only between the world of architecture, urban planning and urban design as opposed to engineering, but also within the engineering world itself. Depending on the branch being considered, risk management models have emerged with different approaches and above all, in watertight compartments, which ignored the interactions of one type of risk with the others.

Here too, to allow effective communication between the two domains and within the engineering domain, a specific and unified risk analysis framework has been developed.

At this point of the research, a framework capable of describing all the elements of a Smart City was needed to be combined with the common language to trace the requirements. The reason for this need is to be found in having to associate the requirements with components which, as one descends from conceptualization to implementation, change, differentiate, multiply, and interact with each other. The need, therefore, arises to define a process that allows the description of the Smart City to be constructed on a formal basis. In practice, the philosophical approach of the Vienna Circle was followed, by its manifesto on the scientific conception of the world ("Wissenschaftliche Weltauffassung") as well as its concept of "Aufbau" (Carnap, 1928).

A creative process was therefore developed, called Aufbau, which allows the construction of a detailed description of the smart city, at any level, using the common language defined upstream together with the evolution of a specific framework for modelling the smart city.

At this point, the risk analysis methodology designed ad hoc on the model of the city produced by the Aufbau was applied.

To want to use the research results in the entire life cycle of the Smart City (but also of any city), i.e. in the phases of conceptualization, planning, design, implementation, operation, and modification, concepts have also been introduced related to the level of operation of the single element considered. In practice, with this last modification, it is possible to understand how much a given architectural, urban planning or urban design requirement is operational, i.e. correctly applied in whole or in part, in a given moment. In this way, we have gone beyond Alexander's approach which was descriptive but static (in the sense of variable with the long times of a city) arriving at a dynamic description that allows us to represent not only the photo of the city in an instant but also the narration of its evolution over time, according to time scales that can also be very short, in the order of minutes or less. In this way the narration, starting from the operational state of the innumerable technological and infrastructural elements that make up the smart City, can accurately describe how much the initial requirements set by architects, planners and urban designers and, above all, the values required by stakeholders, are truly respected, moment by moment.

The impact of this research project on the world of urban planning is the possibility of creating a single model between the two worlds, leaving everyone free to express their creativity and expertise in the forms that are appropriate to them but, at the same time, to allow both to overcome the communication gap existing today. Due to this gap, Smart Cities risks will become problematic given the extreme pervasiveness of the engineering systems within it and given its very strong dependence on such systems.

This new way of planning requires adequate IT tools and takes the form, from the engineering side, of harmonization of techniques already in use and greater clarity of objectives. On the side of architecture, urban planning and urban design, it is instead a powerful decision support tool, both in the planning and operational phases.

This decision support tool for Urban Planning, based on the research results, is the starting point for the development of a meta-heuristic process, where the Urban Planning and Engineering activities are assessed from the risk perspective using an evolutionary approach. Ina few words, the risk management over the entire domain of the Smart City, from Architecture/Urban Planning/Urban Design up to the Engineering, in any phase of the Smart City's life cycle, can be considered as an "organism" that evolves to find better solutions. This metaphor recalls approaches of the past and the present but represents them in a form suitable to be managed by machines, to help professionals to manage an enormous complexity.

Before going into the merits of the speech, let's start with some historical references and an analysis of the context.

1.2 Historical background

1.2.1 Archigram utopia

In the 60s of XX century an avant-garde architectural group inside the London Architectural Association, known as "Archigram", developed many different ideas that tried to implement Le Corbusier idea that "Une maison est une machine à habiter" (a house is a machine for living in). Some members of this group, also influenced by Futurism, proposed many projects that had, as a common frame, the creation of cities or buildings using an approach based on the ability to change the space (public or private does not matter) using elements that were machines. Ron Herron's "Walking City" (a city that was able to move, even crossing rivers, to gather resources located in different places and able to adapt to new situations), Peter Cook's "Plug-in City" (a city configured as a "megastructure" with everything needed for the inhabitants, including residential and transportation services, with a permanent system of cranes to ease continuous rebuilding), the "Instant City" initiative (where the city arrives in form of dirigibles and temporarily exists as an "event") and other utopistic projects, all aimed to use machinery to change the way of building city. At the same time, Cedric Price conceived the "Generator" project. In this idea, starting from a set of orthogonal foundations, standard building blocks, all of the same measures, could be moved by automated cranes and used to continuously change the city space to adequate it to changing requirements.

Price's idea was conceived not only using traditional drawings or sketches: he involved two computer experts, John and Julia Frazer, to work as his consultants to develop software that was able to organize city layout to respond to changing requirements from "The City" or from the citizens. It also suggested that each building component should have a single-chip microprocessor to allow it to become the controlling processor.

The Generator, conceived in the second half of the ’70s (1976-1979), was influenced by the so-called Artificial Intelligence Golden Age. At the Dartmouth Conference in 1956, organised by Martin Minsky and John McCarty (young computer scientists) and by Claude Shannon and Nathan Rochester (both senior scientists), the term “Artificial Intelligence” (abbreviated as AI) was formally accepted and was distinguished from cybernetics, also defining for it a specific mission. After this conference, there was an explosion of enthusiasm among computer scientists and computer professionals, that propagated even outside their circle.

After 1974, while computer scientists started understanding that AI was not as easy as expected, the excitation about its opportunities had spread out of their control and this was the environment that allowed Archigram and Price to speculate about their architectural projects that, almost always, digressed towards something more like to science-fiction than to architecture. Times were not ready for such visionary thinkers.

Today, when talking about smart cities, the Internet of Things, autonomous vehicles, cooperative robotics, and other technologies it is inevitable to think of Archigram and Price. The Generator, in particular, but not only, contains in an embryonal form these concepts. But today’s times are not those of only forty years ago: the technologies are real, often well established or near to being mature.

What is missing today is not the technology, which is evolving very fast, but the ability to introduce formal or empirical methodologies that can help architects and engineers to build the smart city, whatever this term could mean.

As practically demonstrated by the Generator, the cooperation between the architectural side and engineering side (meaning ICT and robotics engineers) is important and can be even stated as necessary today. But methodologies to implement this cooperation are yet late. The reasons for this delay will be investigated at the end of this paper but, before, it is mandatory to understand how it can be realized today and which are the issues.

1.2.2 The Smart City is born

Smart City is now a term which is part of our contemporary language when talking about urban design and planning. These talks involve many different persons: consultants, specialists, marketing experts, corporations, city officers, and more. They define how cities are considered, planned, designed and managed. And even if one can consider this talking activity as full of nothing, it often makes a difference because it forms the theories and practices of all those that are physically planning, designing and building the city. Thanks to these discourses, new ideas are brought to concreteness through research, policies, case studies, projects, best practices, decisions and any other kind of action.

The idea that a Smart City in literature has been demonstrated by scholars like Hollands (2008) and Vanolo (2014) being made of two parallel lines. The Smart City includes both the concept of Smart Growth and of an "intelligent city". The first has been defined in the context of the "New Urbanism" movement. The second concerns the "intelligence" of a city in the sense of a built environment based on technology. However, to understand the wider meaning of the term we have to move into the public sphere by studying the mass media reports. In this section, for the research, we will focus on the term Smart City as represented in this media sphere.

From such analysis resulted that the first use of the term "Smart City" was in the '90s. The media content started using the term to mean that city was using ICT elements in some way. In practice, the most common meaning of the "smart" word was a label to mean basic usage of ICT, primitive e-governance systems or the capability to attract ICT industries to boost the economy. Smartness was a sense of technological control owned by the City, in a very wide meaning.

In this landscape, quite poor if referred to today's meaning of the term, there are two interesting examples where it is used to describe a complex and innovative case. In 1994 an "autonomous Smart City", was planned in Australia, near Adelaide. Only three years later, two Malaysian cities, Cyberjaya and Putrajaya were converted and became "smart cities". In both cases, their plans to use ICT to control and optimise the functioning of the city, aiming to automate processes, was enough to define them as "Smart".

While some of the keywords used in media coverage were still based on technology and economy, new keywords appeared associated with smartness. The terms sustainability, environmental innovations or GPS-supported public transport entered the discourse. Thanks to this idea of optimization and automation through ICT of the urban infrastructures, that is the centre today about smart cities discourse and technology, these two case studies can be considered pioneers and meaningful for the further development that has led to today's concept of Smart City. So, initially, the term Smart City was presented in the mass media as an antonomasia of cities like Adelaide or Cyberjaya.

After 2008 there has been a second phase, where private companies coming from the IT sector entered the discourse. IBM was one of them when, on 6 November 2008, Sam Palmisano, CEO of IBM, spoke at "A Smarter Planet: The Next Leadership Agenda" talking about the need for cities to become "smart". This speech had a large echo in the mass media because Palmisano stated that both the world and its cities must become "smarter" being mandatory to be both sustainable and economically efficient. At the same time as this speech, IBM started an impressive advertisement campaign on Smart Cities that is running even today.

On September 2009 IBM officially requested the term “smarter cities” to be registered as a trademark. The coordinates of this record are “Mark: 79077782; Word Mark: SMARTER CITIES; Serial Number: 79077782; Registration Number: 4033245”.

Definitive registration arrived two years later. After Palmisano’s speech, cities’ problems started to be defined in terms of being “smart”. This new born keyword was diffused worldwide thanks to IBM and municipalities' efforts. Even if IBM was not the unique contender in the smart cities business, it gained a very important position in 2008.

1.2.3 Main Glossary

In the following table are provided the definitions of the terms used in this document. Some definitions, because are part of the research project, will have a specific sub-section.

Term	Definition used in this document
Formal language	A language where the rules are structured in a way that ambiguity is not allowed.
Language	A system of communication to represent some concepts. It can be textual, graphical or of other nature, but the aim is to represent concepts. A language is, by intrinsic nature, ambiguous in some of its sentences. This ambiguity is removed in formal languages.
Methodology	The combination of a creative process to start from somewhere and provide some results and a language to describe the input context, the intermediate and the final results. A methodology will be defined giving such creative process and such language.
Risk	Risk is defined as the probability that some requirement is lost. It can also be considered as the threat of something not desired. Typical undesired effects are something being damaged, someone being injured, being liable for something, or loss of something. In general, risk means the possibility to have an undesired event caused by external or internal weaknesses.
Risk Analysis	It is the process of identifying and assessing potential events that could impact key requirements.
Risk Management	It is done to avoid risk through pre-emptive action or impact mitigation. It includes risk analysis.

Term	Definition used in this document
System	Definition 1: a set of elements operating together to provide some outcomes. Definition 2: an interconnecting network; Definition 3: a complex whole. Definition 4: a set of principles or procedures defined to perform some actions with a specific scope; Definition 5: an organized scheme or method.
System of systems	A collection of systems that put their resources and functionalities together to create a new, more complex system which offers different outcomes that, usually, are more than the sum of the composing systems. It is usually approached through Systems Engineering and requires a holistic perspective.
Technology	The branch of knowledge dealing with engineering or applied sciences.
Public Space	See section 1.2.6.5 A Smart Public Space Definition Proposal
Framework	A model that describes a Smart City and defines an operational process to develop and manage it.

1.2.4 Intelligent, smart, and cyber cities

"The cities always served human societies. They are part of infrastructures and tools we make to confront the challenges of nature and to manage living within societies." (Komninos, 2008). Starting from this assertion, a two-levels definition of what a smart city is will be developed.

"However, in contrast to well-designed tools and machines, cities are collective 'tools', whose many features simply emerge rather than being carefully planned […] In the cities and regions of the twenty-first century, a radical turn is taking place as information and communication technologies are converging with the rise of innovative agglomerations." (Komninos, 2008). Starting from this inception, Komninos develops the concept of an Intelligent City as the bridge between two worlds: physical and virtual. In his analysis, Komninos identifies five different descriptions of what an intelligent city is:

- The Virtual Reconstruction of cities is a digital model of an existing (digital twin) or not yet existing city (simulation)
- A metaphorical definition includes the intelligent city the application of ICT technologies and their systems (e.g.: wired city, electronic communities, …)
- Cities that follow smart growth, identifying them with Smart Communities: "A Smart Community is a community that has made a conscious effort to use information

technology to transform life and work within its region in significant and fundamental, rather than incremental, ways" (California Institute for Smart Communities 2001).

- Intelligent cities can be those were embedded and ICT technologies are used to enhance ordinary activities, making them user-friendly and practically invisible.
- Another definition is that intelligent cities are territories that bring, at the same time, innovation and ICT massive usage within the same locality.
- Intelligent cities (but the term can be extended to intelligent communities, intelligent clusters, and intelligent regions) can be defined as territories with a high capacity for learning and innovation. This capacity is mostly "sustained by digital spaces and virtual environments of knowledge management and innovation".

Following such definitions, intelligent cities (also including intelligent communities, intelligent clusters, and intelligent regions) can be, in general, defined as areas where it has been implemented a powerful capacity to learn and to innovate thanks to the use of digitalization and virtualization as tools for knowledge management and for continuous innovation. These capabilities are built on population creativity, on high-performance institutions for knowledge and the creation of new ideas, together with a well-designed digital infrastructure and a set of digital services.

In all these definitions, what seems to make a city "intelligent" is the ability and the performance in innovation.

With the revolution introduced by the Internet, the concept of Cyberspace has been introduced and it has led to the definition of Cyber-Cities. A cyber city is a virtual entity (i.e., exists in cyberspace) that is linked to the physical space and social environment of a city. Such linkage happens, essentially, in two ways: mapping and steering. With mapping, the cyber city gives a representation (using maps, text, 3D imagery and more) of the city and its social environment. With an appropriate control mechanism, the cyber city implements a strong communication function that improves governance and monitoring of processes (something similar to the once-upon-a-time-called Cybernetics). Pierre Levy has delineated four principles that describe how to integrate the cyber-city with the "real" one:

- *"Analogy in modelling the cyber city"*: the cyber-city must not be an imitation of the city, but it must allow citizens to get value and profit from it.
- *"Substitution of urban activities"*: physical activities and in-site presence are not yet so necessary and can be avoided in many or most cases.
- *"Assimilation of new networks"*: the integration between new digital networks and existing physical networks (e.g., mass transport, public illumination, …) must be the

implementation of collective intelligence that grows through a social process in which citizens are not only users but proactive actors.

- *"Articulation between the city and the cyber-city"*: due to the typical rigidity of physical processes, the flexibility of digital processes should be used not to replace them but to improve their plasticity, reduce their inertia and become the source of a continuous problem-detection-and-solving process.

All these principles are supported by the process of "dematerialisation" through the substitution of physical artefacts with digital ones.

But the cyber-city has been only the first step toward the definition of Smart Communities. Such communities are defined as "smart" if they have four core elements (Albert 2006):

- People/Users, which is the point from which the community starts.
- Technical Infrastructure, is the technological layer on which the communication network is built.
- The institutional framework is the set of: rules to be followed, targets to be achieved, problem-solving process, and agreements on infrastructure management.
- Applications, which are the core products of the community itself and define what a community can do with cybernetics and which opportunities (i.e. values) will produce.

After smart communities (or, better, in parallel) there has been the concept of Intelligent Community. These communities are Intelligent if have a powerful broadband infrastructure, if they have a high-level-of-knowledge workforce (i.e., users and members of the community are qualified in knowledge-intensive or advanced skills), they innovate (and attract innovators too), have a digital democracy (practically, the opposite of the digital divide) and, last but not least, are attractive for external people or users and provide better and cheaper services for other communities. Some of these communities (both smart and intelligent but especially the last) have led to two main phenomena: the digitalisation of the city and the creation of living innovation labs. These labs are environments that naturally grow into such communities and where creativity and innovation are hardly stimulated.

At this point, it is possible to define a more precise concept of "Intelligent City". To do this, the main aspects of human intelligence have been considered (Beckman, 2004): perception, communication, learning and memory, planning and feedback action. These features have been used to define the so-called Artificial Intelligence. Human intelligence can also be defined at different levels (individual, collective, swarm, …). For example, collective intelligence is when a large group of persons can cooperate in one single process to achieve a reliable result. This kind of intelligence has been translated into artificial intelligence too.

At the end of this reasoning about different intelligence types, it resulted that, in the first definition of an intelligent city, it is a city that has all the three above dimensions: human intelligence, collective intelligence and artificial intelligence. Then, in a few words, the Intelligent city is composed of humans (with the ability to create and innovate, using inventiveness and creativity), by the collective intelligence of the city's population (which allows them to cooperate to provide solutions to everyday problems), by using the ICT technological infrastructure that provides such Artificial Intelligence (sensors for perception, communication services, storage and automated learning, planning and reaction to events) in a digital way (that is fast, reliable, effective).

So, according to Komninos again, an Intelligent City:

"describes a territory (community, district, cluster, city, and region) with four main characteristics:

- a creative population and developed knowledge-intensive activities or clusters of such activities;
- embedded institutions and routines for cooperation in knowledge creation allowing to acquire, adapt, and advance knowledge and know-how;
- a developed broadband infrastructure, digital spaces, e-services, and online knowledge management tools;
- and a proven ability to innovate, manage and resolve problems that appear for the first time, since the capacity to innovate and to manage uncertainty are the critical factors for measuring intelligence."

[omissis] an intelligent city is a multi-layer territorial system of innovation. It brings together knowledge-intensive activities, cooperation-based institutions for distributed problem-solving, and digital communication spaces to maximise this problem-solving capability. It is the most advanced form of the territorial system of innovation we have today, a third-generation system, following on from clusters and learning regions. It consists of a series of layers, reflecting both the dimensions of intelligence and the development of innovation in physical, institutional, and digital space.

So, the Intelligent City can be split into three layers:

- city's knowledge-intensive activities in manufacturing and services are usually organised into clusters
- institutional mechanisms for knowledge creation and social cooperation in technology and innovation

- digital networks and e-services that make innovation achievement easier”

Is it possible, according to him, to measure some sort of “city intelligence”?

If “yes” is the answer to the previous question, is it possible to define a quantitative metric to assess, to measure the development of intelligent cities? The answer could be affirmative because there are many standards about them. But defining some metrics in the field of intelligent cities is determined by two main needs, that are common to any metric definition. The first one is to compare cities between them. The second one is to understand their internal dynamics and manage them, controlling issues, problems, and leveraging strengths. Two methodologies are usually adopted: benchmarking and modelling. Comparison is the main scope of benchmarking.

Models are schematic descriptions of systems and usually are enough detailed to understand the most important features of the system, their internal relationships and the inputs and outputs dependency. Understanding internal dynamics is the target of modelling.

In this research document, the Smart City will be analysed from a more specific perspective that introduces us to a second level of definition, that will be developed in the next sections.

1.2.5 Smart City definition

The Smart City is the response to an urgent need: a growing urban drift will lead to very big cities with a tenth of millions of inhabitants. These gigantic cities will have to face an incredible complexity that cannot be overcome without using advanced information and automation technologies.

The same approach will also be very useful in smaller cities to make them efficient, sustainable and to, in general, improve all city typical services.

Starting from this requirement, it is necessary to define a smart city more in detail.

European Commission's definition of Smart City is *“A smart city is a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business. A smart city goes beyond the use of information and communication technologies (ICT) for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.”*

According to studies on the evolution of the smart city definition, it has been changed many times by the EU. The first version was "*The idea of smart cities is rooted in the creation and connection of human capital, social capital and Information and Communication Technology (ICT) infrastructure to generate greater and more sustainable economic development and a better quality of life."*

Then the concept evolved to *"[Smart] cities are systems of systems, and there are emerging opportunities to introduce digital nervous systems, intelligent responsiveness, and optimization at every level of system integration. A smart city uses information and communications technology (ICT) to enhance its livability, workability and sustainability. Real-world smart city examples are rarely a city in the strictest term. Many are more than a single city, such as a metropolitan region, a cluster of cities, […]. Other examples are less than a full-scale city, such as districts, neighbourhoods, […]. Smart City consists of not only components but also people. Securing the participation of citizens and relevant stakeholders in the Smart City is therefore another success factor. There is a difference if the participation follows a top-down or a bottom-up approach. A top-down approach promotes a high degree of-coordination, whereas a bottom-up approach allows more opportunity for people to participate directly."*

Other definitions can be found in the literature but, in this research, a new one has been defined, starting from the one given by European Commission and completing it with the ability to reconfigure space usage (in bold the new addition made to the definition*): "A smart city is a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business. A smart city goes beyond the use of information and communication technologies (ICT) for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.* ***It also can temporarily reconfigure the use of its public spaces, either autonomously or in a supervised way.****"*

This last sentence will be further developed during the research project but it gives the urban planner a degree of freedom that, although is already used in urban planning and design, can have two new features that could (should) interest the planner: the autonomy of the city to quickly change the use of public space and the new ways this can be done.

A smart city can manage flows of information, people, vehicles, goods and services. And this can be done autonomously or be human-supervised. Before smart cities, urban planners and urban designers could already design conceiving multiple uses for public space (consider the medieval square, which had many uses ranging from meeting areas for business, for public decisions, for executions, for markets and more). In smart cities, public space usage can be “instantly” changed “by simply” reorganising how the smart city manages itself. For example, a road can be used as parking during normal traffic hours and as an arterial in peak hours, and this will be done automatically: smart vehicles simply will leave the road free when “The City” will ask and will park there when “The City” will allow. And this can be done better if vehicles are shared, re-allocating sharing requests on vehicles parked on such roads to move them without wasting energy and time, for example. In a few words, urban planners and designers can have a stronger degree of freedom in managing public space usage.

An interesting reading which summarizes, from an urban planner's point of view, the smart city, has been “Smart Cities” by A. M. Townsend, which is a good introduction from the perspective of an architect. In this book, Townsend has done a historical excursus of the topic and presented many authors that have, with their contributions, taking us to the smart city concept. It has also proposed a (very general) definition of a smart city.

One important book, for this research, is “A language pattern” by Alexander together with Forrester’s urban dynamics models. These books have provided another set of sources about languages to describe cities and buildings and mathematical models to simulate the dynamics of the “city ecosystem”.

Also Halegoua's book “Smart Cities” is fundamental literature for this research, due to its novelty and its wide range of information, including many social aspects.

Another set of sources is about software to simulate a city (or some aspects of it), starting from real gaming products (SimCity is the most famous) up to software tools developed in academic contexts for both urban dynamics and network simulation.

Other interesting readings are those about the self-organising city (e.g. the book by J. Portugali 2010).

1.2.6 Public Space definition (with “smartness”)

1.2.6.1 Defining the Public Space

Urban public space can be defined as the centre of urban activity. The Urban public space has many social, political, economic and historical relationships. Dovey (2016) provides a conceptual toolkit for urban design that fills the gap between theory and practice and shows that urban spaces design can be defined and shaped through the modern theories of urbanism, architecture and spatial analysis. It states that public space is the "primary site where a sense of the ‘common' becomes embodied in everyday life before it becomes ‘community'". Sennett (2017), in his reasoning about “open” and “close” cities, defines the public space as “a place where strangers meet”. Other definitions emphasize this concept affirming that public spaces are “the triumph of the public over the market” (Iveson 2007), asserting that they are “ceremonial spaces” for both celebration and protestation and are used by people to be “included in the public represented through the space”.

More in general, the concept of “public space” is intended as a space specifically conceived for the public. According to such vision, the uses and the design of public spaces are based on ideology and emotions, like what happens for the French people that are tied to their history and traditions. Then, both are essentially political, due to their ideological foundations, as well as subconscious, because they are driven by a sense of emotion that does not depend on any theological or political position but appears to be related to them (Benjamin, 1935/1999). But this vision has been abandoned in time due to the reduction of conflicts and the fall of strict ideologic positions. In this perspective, Sorkin (1999), arguing that propinquity is the main theme in urbanity (“the gold standard”), summarizes modern city planning as an activity to avoid conflicts, and that enemies of public space are those that generate the conflict, like privatization (that occupies public space making it not public anymore), identity politics (that splits public spaces into ghettos, creating divisions and conflicts in the urban tissue), and sprawl (that dilutes public spaces through its expansion, increasing entropy and contrasts). These concepts have led to the “anti-urban character” that is a main feature of the large-scale suburbanization, of closed communities, which acts as a black hole that concentrates the public space limiting it to the community, or high buildings, that develops a verticality that reduces the interaction with the street level (Dovey, 2008).

Public spaces are now facing a huge transformation led by the fourth industrial revolution that reshapes them and moves them into cyberspace (Schwab 2019). This public space reform caused by new (disruptive) technologies, implies the need to pay attention to the new opportunities and issues deriving from the massive diffusion of digital services and devices. These new elements are generating new axes in the public space that must be considered. The fourth industrial revolution is challenging humans, trying to change the ways behave in cooperation, production, in consuming, communication and in making sense of the world, leading to a trans-human perspective that is alien to the traditional modes of production, socialization and politics that have characterized the daily life throughout the centuries. In this trans-human, cyber-cultural vision, not only the human being is impacted to reengineer it (considering it as another kind of product) but also the space where it will live is massively reshaped. The slogan “you will own nothing and you will be happy” is a tremendous perspective where the public space seems to be everywhere, due to the removal of private elements, but consists in a nightmare of individuals each one closed into itself, where the closed community identifies with the individual.

1.2.6.2 *"Smartifying" the Public Space*

According to the definitions of Smart City given above, it is clear that the focus is to rely on semiotics, in the sense of data, information (relationships among data) and knowledge, generated by ICT systems. This is done to depict, arrange, and organize the whole urban environment more rationally and efficiently, to be more effective in saving resources at the same time. This is the logic of modernization, the consequence of new trends in efficiency and savings everywhere.

When digital applications first appeared, they were bounded to "cyberspace", a sort of virtual public space that soon spread everywhere becoming a new "public space of interactions". Practically, this cyberspace, became a kind of "electronic agora", where the city is redefined as a system of virtual spaces interconnected by the information superhighway, and the public (virtual) space becomes an element that "subverts, displace and radically redefines our notions of gathering place, community and urban life" (Mitchell, 1995). The digital revolution, with the diffusion of computers in a quick and pervasive way, has transformed the elements of human interaction with the surrounding environment, even giving a new, wider, sense to the term "surrounding" itself. Monitors and screens are now the new windows through which we, humans, relate with the world, observing it, and understanding it (Koolhaas, 2002). This space, according to Koolhaas, is a "Junkspace", it is what remains after modernization, what coagulates while modernization is in progress, its fallout. And, even if it seems an aberration, it is the result of the encounter between all the modern elements of a building, digital and not. But digitalization has overcome, with its assets, the boundaries of the virtual space. Digital applications are now everywhere and are even worn by people through wearable and programmable devices. And they are used to optimize both individual and urban life (i.e. urban services and urban spaces/environments). The smartphone is now the "megacity survival kit, a digital Swiss Army" (Townsend, 2013). Smartphones, but not only them, have spread everywhere and disrupted social interactions and urban services, thanks to the technological miniaturization that is allowing anything to be "smart" (e.g. Internet of Things).

This virtualisation of relationships and interactions has led to the understanding that these small and even smaller devices are sort of "black-boxes" which are "richer in functions but poorer in transparency" (Anceschi, 1996).

The same pattern is present and should be considered when designing Smart Cities.

Smart City technologies used today are characterized by being extremely pervasive. They are often invisible presences, filling all the existing urban infrastructure and services. It is very hard to detect them, to separate them from the elements and concretize them. But, even being these technologies almost intangible, daily urban life is increasingly and strongly dependent on them. In this way, the digital has begun to deeply influence public life not only on a small scale but even on a large scale. The recent COVID-19 emergency has dramatically demonstrated that we can be actively attending a set of activities at once without having to change the location (as forecasted by Amin and Thrift in 2002). According to Amin and Thrift, the city, born as "a vast narrative structure that constantly re-presents itself", due to the ability to gather citizens' data, is evolving into "something that is beginning to read us".

According to Graham (2005), the places in Smart Cities are generated by code, and they are spaces where "software and the spatiality of everyday life become mutually constituted". He defines "coded worlds" or "computerized spaces" as those that operate going beyond the virtual-only experience, applying "their power over the geographies and life-worlds of capitalism". According to him, driving towards an idealistic computer-based society, with intense CCTV control, facial recognition and other digital technologies, that will be released from typical city's problems, like crime or traffic, brings the risk to miss the "failed consumers", i.e. those that belong to demonised minorities, basing all the interactions on the existence of some biometric devices that destroy the anonymity in which most of them rely. These ideas have been also expressed by Reeve (1996) and Van der Ploeg (1999), concerned about the fact that meeting the "other" is, in the end, the essence (and the scope) of public space.

In this vision, we get a heterogony of intents, a real unintended consequence that causes the loss of connection while building a hyperconnected world. At the same time, the new virtualisation of public spaces, if used to enforce crime suppression, security, efficiency and more, will lead to a reduction of natural behaviours that protect individuals and communities from such risks. What will happen if, suddenly, such a system loses its capability to prevent undesired events in a context when no one is ready to manage dangerous circumstances?

1.2.6.3 Being 'Smart' in the Public Space

As a trendy concept, Smart City became a tag, a sort of status symbol, that many actors involved in urban planning, design and management are trying to apply to their spaces, including public ones. Anyway, currently there is yet no real place in the world that can be considered a true Smart City (Townsend, 2013). Nevertheless, academics like Sennet (2012), Hollands (2015), Calvillo et al. (2015), Albino, Berardi, & Dangelico (2015), and Kitchin (2015), (but not only them) indicate Smart Cities both Songdo in South Korea and Masdar in UAE.

Both cases are not exempt from criticism. For example, Sennett describes Masdar as follows: "There's no stimulation through trial and error; people learn their city passively. User-friendly in Masdar means choosing menu options rather than creating the menu." Calvillo describes Songdo as "a system that theoretically continues to produce wealth-without-end through the construction of huge conduits for bandwidth and of vast quantities of environmental sensors, all focused on the monitoring and indexing of its inhabitants' online and offline behaviours."

There is, anyway, an important relationship between Smart City and the public space. Digitalisation has changed the perception of the public space. With ICT, the experience of the public space has been expanded through "smart" (or, better, smartphone) applications that reform the shape of the urban space, with the intent to increase efficiency and effectiveness to an optimal value.

This expansion through digital pervasion, is impacting the physical space, transforming it, and augmenting it with new added virtual elements. But, even if real space is increasingly invaded by these virtual elements, at the same time there is also growing awareness and concern about the threats and the risks carried by intensive and extensive digitalization. This feeling is starting to impose a change on these technologies to comply with citizens' requirements like privacy, democracy or freedom.

Being smart or digital citizens requires action rather than just "following the script as smart citizens". They state that the digital citizen is one detail of the wider evolution of the figure of the citizen. This evolution is moving from the rights-bearing citizen toward the citizens that are in the act of making rights claim. Then, for smart citizens, cyberspace is a "relational space in which digital citizens come into being through digital acts" through the Internet (Işın & Ruppert, 2015). The cyberspace is not separated from the real space and it is an independent space of freedom. Political action takes place through digital space that is governed by the code. But there is an issue, surely related to the code-spaces that are smart cities: "one obeys the laws as code not because one should; one obeys…because one can do nothing else". Also, the digital divide and the normalization of surveillance and big data accumulation are problems. Consequently, these communities become vulnerable to algorithmic biases or discrimination "by design". Even if this influence on people can be hard to be demonstrated, it is a real risk. In this sense, the new digital public space suffers from the risk of hidden manipulation "by design",

Digital technologies fuel the idea that a smart city can be a powerful tool for planners and managers that that through the use of information and communication technologies lets cities work better opening an immense and promising horizon, through its augmented spaces, to transform citizenship, participation and democracy in many new and creative ways. This tool generates "a real possibility to approach a dynamic re-composition of spaces, places and territories articulated and influenced by information technologies at many different scales." (Duarte & Firmino, 2009).

Today is not clear which will be the form in which the future Smart Cities (and their public spaces) will evolve. Although it is not possible to forecast this change, it is clear that it will happen. Greenfield (2017) remarks that having successfully colonized everyday life, technology is now conditioning men's choices. Understanding how they work and which challenges they imply, for individuals and communities, is a fundamental question. But also understanding who will benefit from their adoption, practically underlines the urgent need to understand how they work, to solve critical issues caused by the new uses of these technologies. Greenfield's reasoning clarifies the relevance and the nature of the crisis we are facing and shows that understanding these technologies is mandatory even in the practice of architecture, urban planning and design, due to the widening of the areas of technological application.

The influence of the city on smart spaces is not only at the reality augmentation level but also in their function adaptation in time. As already stated before, even the physical public space can be rearranged to provide different functions in time. And this can be done autonomously by the Smart City itself, according to an automated decision algorithm that will change the use of the space concerning "Smart City needs". This concept will be further investigated later.

1.2.6.4 Imagining Smart Cities: Prescriptive versus Coordinating

According to Sennet (in the Latham interpretation 2017) "the design and architecture of cities, along with the rituals of their use play a central role in the formation of society's social and political culture". This key role of planning, design and architecture is further developed when Sennett (2018) addressed the Smart City concept as a dual frame where he prefers the "open city" against the "closed city" due to the phenomenon he calls the "over-determined form". The idea of an open city starts with Jane Jacobs in her arguments against the urban "closed" vision of Le Corbusier. A strong feeling in urban design theory has emerged and focused on the public realm in the last decades, analyzing the threats to social habits in urban areas caused by such over-determined forms. This issue has led to the need of understanding which specific urban conditions allow for the public realm to develop and extend. Sennett (2017) evidences that "the closed system has paralyzed urbanism, while the open system might free it". In his sense, "open" is not a metric of the beauty of the form, but a very specific feature of the urban form. In an open city, according to him, a more spontaneous evolution happens than the one steered by central planners. Sennett (2018) has then associated the "closed form" with the concept of "prescriptive" Smart Cities. These cities are like central processing unit that operates following a strict code and becomes "prescriptive". In his idea, prescriptive cities "does mental harm; it dumbs down its citizens". In contrast with them, Sennet was charmed by the ability to use data and information technology to coordinate what was happening in the city, generating the open form of the so-called "coordinating Smart Cities". These cities, thanks to the ability of technology to deal with complexity, "stimulates people mentally by engaging them in complex problems and human difference". Sennett notes that the city where everyone wants to live should be clean, safe, and efficient. These cities should have a well-performing economy and should offer cultural opportunities. These cities should help the resolution of social conflicts and improve equity. But in prescriptive cities, this quickly becomes a nightmare. So, he defines the aim of “sheer efficiency” as not feasible for Smart Cities, and states that this absolute efficiency for “the prescriptive city becomes unbalanced in divorcing functioning from questioning”. In his opinion, technology has to be used to coordinate the city, leaving its dynamics free to evolve but, at the same time, to cooperate in this evolution. This is completely different from control, where he sees that the produced data is “limited and un-purposed” while “comprehensive participation and decision-making are truly enabled”. The reason behind Sennet’s idea is complexity: a Smart City is an extremely complex entity. Defining prescriptive rules to model and control the entire city is an impossible task. While it is possible, in a coordinating Smart City model, to define transparent digital processes, encouraging people to get involved with them to interpret and use data. This kind of interaction of human data through processes is a “performative citizenship” model.

Sennet (2018) defines five open forms for coordinating Smart Cities.

1) “synchronic space”, like a square where people can do many different things at the same time. The opposites of them are sequential spaces (stadium, school, theatre) that have been designed for one specific function that attracts the simultaneous attention of people. He invites “ to mix rather than impose mixing”, proposing a “spatial experience both stimulating and disorientating”.

2) the “punctuated space”, he uses the punctuation marks to conceive the urban space as the music of an orchestra, where there is a synchronic space but with orientation points to coordinate people.

3) the “porous space” is a metaphor for a living form that, thanks to its metabolism, has “an open flow between the inside and outside, yet the structure retains the shape of its functions and form”.

4) the “incomplete space”. It is a form not yet completed. It starts from the observation that poor people have to live and work with incomplete forms. These forms provide both flexibility and synchronicity, porosity and punctuation. Sennet defines them as a “type form”; “a piece of urban DNA which takes on different shapes in different circumstances”.

5) “Seed planning” is an alternative to master planning. Instead of a central, master plan, an urban element is taken and put somewhere in the space, letting it grow on its own. Sennett strongly criticized master planning because it “divides a city up into a closed system where each place function relates logically to other places”. His idea of seed planning is developed in the concept of “farmed city” where it starts with an initial incomplete form (the seed) around which urban development dynamics are left free to evolve. Seed planning is intrinsically dynamic with no predefined form.

1.2.6.5 A Smart Public Space Definition Proposal

Starting from the ODPM definition "Public Realm relates to all those parts of the built environment where the public has free access. It encompasses all streets, squares, and other rights of way, whether predominantly in residential, commercial or community/civic uses; the open spaces and parks; and the 'public/private' spaces where public access is unrestricted (at least during daylight hours). It includes the interfaces with key internal and private spaces to which the public normally has free access." (ODPM, Office of Disaster Preparedness and Management, 2004) and integrating it with smart city peculiarities, the following definition of Public Space have been adopted for this research project:

> ***Public Space in Smart Cities*** *relates to all those parts of the built* ***and the cyber*** *environment to which the public has free access, although access to public cyberspace can be subjected to authentication and authorization mechanisms.* ***It is defined regardless of who owns or manages the space.*** *It encompasses all streets, squares, and other rights of way, whether predominantly in residential, commercial or community/civic uses; the open spaces and parks; and the 'public/private' spaces where public access is unrestricted (****or subjected to minor limitations****). It includes the interfaces with key internal and private spaces to which the public normally has free access.* ***It also includes the cyberspace.*** *Public Space can be reconfigured by the Smart City itself.*

1.3 Foreword

After having done a review of systemic risks in smart cities some limitations have been identified.

Smart cities include, for example, concepts such as smart transportation and autonomous transportation systems and advanced management of infrastructure like power and water supply. They also include a high degree of connectivity and a lot of data (usually called Big Data) gathered and stored. Other aspects are omitted there but they go, mostly, in the same ICT direction.

Due to this, smart cities can be considered critical infrastructures which need resilience and safety/security, and this requires a global collaboration between all stakeholders, including those that plan and design a Smart City.

One undergoing challenge is some kind of risk-based regulation focused on both traditional and emergent vulnerabilities. In this research project, the focus is on how to identify these vulnerabilities, and how to mitigate them, based on both new emergent and known scenarios across boundaries.

Existing risk analysis methodologies, essentially consider a smart city as a software ecosystem (SEC), which is defined as a dynamic evolution of systems on top of a common (often very heterogeneous) technological platform, providing a set of software solutions and services. These software ecosystems are increasingly being used to support critical tasks and operations.

Following this approach, existing methodologies about risk analysis and management in Smart Cities are focused on technological risk management, mainly on cyber-security and structural engineering, and do not take into account the original requirements and constraints coming from Urban Planners and Urban Designers. This means that the existing risk analysis methodologies and standards have been designed for ICT, civil and robotic engineers but not for urban planners. This gap is an important issue that has to be filled by developing a new risk analysis approach that also considers urban planners' and urban designers' perspectives.

The approach used up to now, that do not connect urban planning and design disciplines with others from engineering, more technologically related, generates the risk that the final risk analysis will omit some important requirements or that the urban planning and urban designing steps are not easily suitable by the following risk analysis approach to protect what, anyway, is a very complex critical infrastructure.

To exacerbate the problem, technologies used in smart cities are also, often, quickly changing technologies. Many of them are exponential or disruptive technologies and have a life cycle shorten than the smart city's lifespan.

Focusing on technologies for risk analysis causes a detachment, a gap between Urban Planners (and Designers) and Technological Engineers (civil, ICT, robotic) and can lead to wrong requirements satisfaction, systems hard to change and other issues that can be intolerable in a critical infrastructure like a Smart City is.

The research focuses on defining a new risk analysis methodology for Smart Cities that allows Urban Planners (and Urban Designers) to derive requirements that are independent of technology and that can be provided to such existing risk methodologies.

This new approach will allow important improvements in both Urban Planning / Urban Design and System Engineering, connecting them and solving the gap between these disciplines in the field of risk analysis. These improvements will be, at least: 1) continuous traceability of risk analysis from the Architectural side up to the Engineering side (bridging of risk analysis); 2) improved change management (due to this traceability); 3) Resilience to technology evolution (due to the abstraction of risk analysis from technologies).

To overcome this result, a precise definition of Smart City will be provided, a framework for the Smart City Plan & Design will be developed and a methodology (i.e. a descriptive language and a creative process) for risk analysis will be defined.

1.4 Problem statement

A smart city can be considered a critical infrastructure, even in the case of a small-sized smart city. This assertion comes from the evidence that if a smart city has a failure which impacts one or more of its services (utility supply, traffic management, healthcare management, …) this failure can have a huge impact on many people, up to some millions, and can lead to serious damages from both economic and safety point of view.

This problem has been addressed, up to now, through traditional risk analysis that considers each smart city function and analyses all reasonable threats and tries to prevent them or attenuate their impact.

Traditional risk analysis methods have, unfortunately, some weak points:

- They consider **only the technological aspect of the risk, neither the social nor the architectural**
- They have a **vision focused on isolated environments**: each function is a system that operates separately. In such a way they are missing a holistic perspective
- They **ignore the ability of the smart city to completely reconfigure some of its spaces**
- They do not deal with the fact that the **city is continuously changing over time** and, often, becomes obsolete
- They are **too tied to technology and technology changes very quickly**

1.5 Claim

The research objectives are classified as primary (i.e. mandatory) objectives and secondary (i.e. optional) objectives.

The research project has the objectives described in the following paragraphs.

1.5.1 Assumed Smart City definition

A precise and explicit definition of a Smart City will be defined, starting from already existing and explicitly including missing factors, more focused on urban planners' and designers’ perspectives than on ICT. Primary objective. This definition will intrinsically have some ambiguities that have to be managed.

1.5.2 Smart City Framework

A detailed, although not fully complete (see §38-Hypothesis and main idea for details), set of Smart City processes and functions, with their attributes, KPIs and other concepts will be defined to allow a formal description of a Smart City. The Framework will be the base for formal language to describe the Smart City. Primary objective.

1.5.3 Risk Analysis Methodology

A pair made of a "Descriptive Language" (an evolution of the one used in the Framework) and a "Creative Process" to build the risk analysis. Primary objective.

1.5.4 Case studies applications

The Risk Analysis Methodology will be applied to some case studies to improve and refine it. Primary objective.

1.5.5 Change Management of Risk Analysis

Define a change management process that fits the risk analysis methodology to manage changes from the top side (i.e. Urban Plan and Social Environment) and from the bottom side (i.e. technology disruptive change). This objective is a secondary objective and, at the time of the writing, has a major issue that must be considered: the technology caused the disruptive change is a change so big in technology (e.g. from human-driven cars to autonomous vehicles) that can impact even on the requirements derived from risk analysis that, theoretically, do not depend on technology. This kind of change is today hard to be managed and could be a very interesting objective, although at the present stage, due to time constraints, it is considered a secondary one.

1.5.6 Sensitivity Analysis

The results of risk analysis methodology are, obviously, dependent on the requirements of both Urban Planning and Social Environment. How much they are sensitive to small changes in such requirements (i.e. how sensitive the results are to small errors in requirements definition or estimation) is the target of the Sensitivity Analysis. Although this objective can be very interesting from both Researchers' and Planners' points of view (and for technicians' too), this will be considered a secondary objective due to time constraints.

1.6 Importance of the project

Today, such a perspective is missing, and urban planners and urban designers are planning cities that can be seriously jammed by deliberate attacks or natural events, even if they happen to an insignificant subsystem, due to an avalanche effect. To use a metaphor, we can consider the final scene in Star Wars where the mighty Death Star is destroyed by a single shot in a thermal discharger.

To avoid such vulnerability and manage the risk tied to a smart city (i.e. a very complex critical infrastructure) inhabited by millions of people, a risk analysis and management methodology is needed but this methodology must have all that is missing in existing:

- Start from the social and architectural vision to provide requirements to be technologically satisfied
- View from a holistic perspective
- Consider the ability of the smart city to temporarily reconfigure some of its spaces in a very short time
- Allow the city to continuously change over time, has happens in any other city, which evolves during the time, and manage such change from a risk point of view (top-down propagation of the risk)
- Allow the technology to continuously change over time and manage such change from a risk point of view (bottom-up propagation of the risk)

1.7 Literature Review

1.7.1 Relation with existing works

There are so many papers and books about safety and security risk analysis and assessment methodologies that we will not report all of them, because they are quite similar to each other: they focus on technology, not on urban and social requirements.

All these kinds of risk management methodologies have been considered to further understand which kind of inputs can be provided to technology experts to allow them to proceed with such methodologies. In a few words, they are useful because they will be applied to the output of the methodology developed during the research.

Some other papers focus on systemic risks but not immediately focusing on technology. One of these is the paper from Johnsen (2018) where such risks are analysed. Starting from such risks, a methodology to face them is analysed (for some peculiar cases) and then exploited but, in the end, focuses again on technology. This approach can be a good example of how to proceed in the research project but has the weaknesses to be, again, focused on technology and not start from an urban planner or designer point of view. It's also missing the holistic view, although it tries to put together common systems as super-systems.

Other works, like the paper from Azizalrahman and Hasyimi (2019) try to provide a common framework to describe smart cities. This framework is very useful to create a basic template for the definition of the language (methodology = creative process + descriptive language) and to start thinking as an urban planner instead than as an engineer (ICT, civil, …).

In “A set of Good Practices and Recommendations for Smart City Resilience Engineering and Evaluation” from AIIC, there is an embryonic stage of the research project and it can be a good starting point for the second step of the project plan (see Table 1 - Research project methodology), although a clear relationship with Urban Planning (and Design) themes is yet missing.

Analysing ISO standards for smart cities and smart communities, further definitions of smart cities have been found and more detail about metrics and assessment guidelines have been collected. All these standards lack a tight connection with urban planning concepts and requirements.

1.8 Research Questions/Hypothesis

After defining the problem statement, it is possible to state the research problem, and the research questions to which it is aimed to answer is:

- **RQ1**: How to define a risk analysis methodology to ensure security and safety in public spaces in a smart city, starting from an urban planning and social point of view and leading to requirements that can be submitted to technological experts to develop fail-safe systems?
- **RQ2**: How to modulate the “fail-safe” feature, distinguishing between high-priority and essential functions from low-priority and non-essential functions?
- **RQ3**: How to manage changes in technology, ensuring that they will not impact such requirements or, in case they will have an impact, how to trigger this as early as possible, from both system and holistic perspectives?
- **RQ4**: How to manage changes in urban planning and urban design to ensure the adequacy of existing systems or quickly detect which are not anymore suitable for a new scenario?

All these questions can be summarized in the following general research statement:

- **RS1**: Define a risk analysis methodology to ensure security and safety in public spaces in a smart city, starting from an urban planning and social point of view and leading to requirements, including a degree of necessity, suitable to be submitted and understood by technological experts to develop fail-safe systems with a holistic perception and able to manage changes from both top-down and bottom-up.

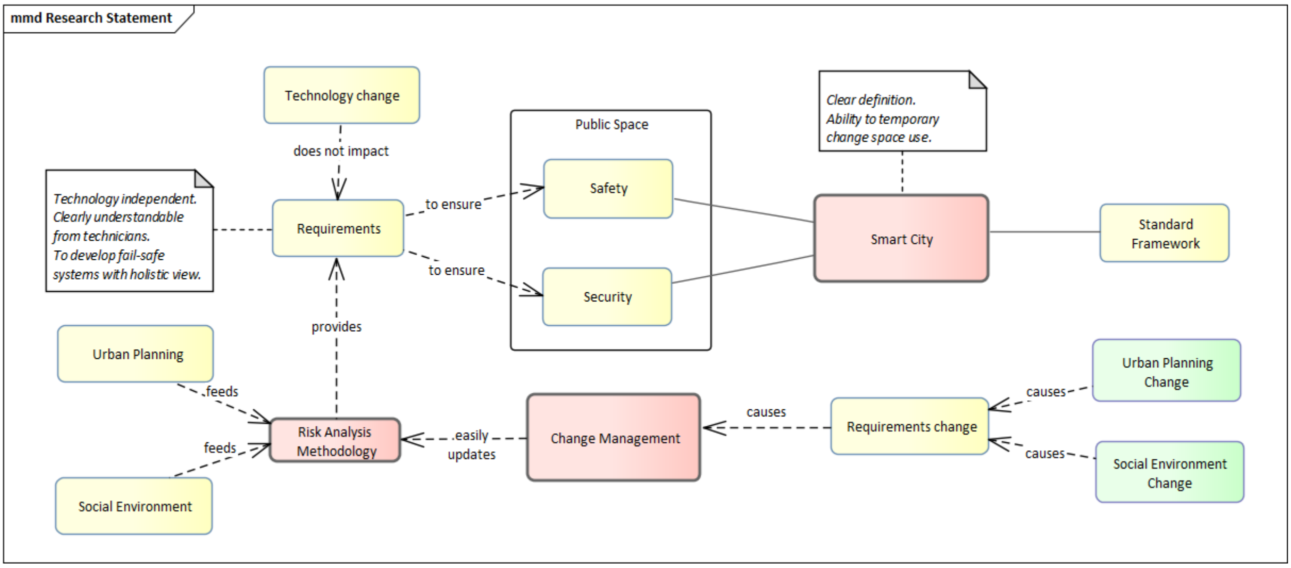

Figure 1 – Intimate structure of the research statement

1.9 Epistemological Premises, Methodology (or Methods), and/or practical-aesthetic precepts and processes – drawing, modelling and so forth.

1.9.1 Methodological constraints

To narrow the research field and make it feasible, some initial hypotheses (i.e. methodological constraints) have been considered. A sensitivity analysis of the relaxation of some of these constraints will be made in the second part of the research.

- **No slums**. The research project will exclude the slums, i.e. degraded and chaotic peripheries, although big cities often have such kinds of districts.
- **No interconnections with other neighbouring cities**. The smart city will be considered alone but not isolated. This means that a smart city will exchange energy, other supplies, persons, vehicles and more with the external world and that such flows could even be interrupted or heavily increased but the risk analysis will not manage with a super-system made by many connected smart cities.
- **Smart cities can evolve freely**. The evolution of the city has no constraints, excluding those identified in this section.
- **Only a subset of smart city functions will be considered**. Not all possible smart city functions will be considered, but only a subset of them which will include both high, medium and low priority functions.
- **Smart cities can change, dynamically, their public space usage**. The Smart city can change the use of a portion of its space dynamically, either under human control or

autonomously, to overcome its objectives. The risk analysis methodology must support this behaviour.

The main idea of the research project is to develop some sort of language to describe the smart city and, from this language, through a methodology (i.e. a creative process + a descriptive language) provide the following results:

- Resources to be protected
- Interconnections between such resources
- Threats to such resources and effects on interconnections
- Countermeasures at the black-box level (i.e. non-technological)
- Requirements for white-box level (i.e. for technological sub-systems)

At the end of this methodology, the urban planner will have a set of requirements that will not be related to specific technologies but that can be transformed into technological applications by technology experts.

1.9.2 Research Methodology

The research methodology starts considering the core concepts like Smart City, Public Space in a Smart City and Risk. After identifying and defining such elements, a review of existing Smart City (and its Public Spaces) models and frameworks will be done (about 1st year), using existing models and also ISO (or other sources) standards. Following such results, a custom Smart City Framework for Public Spaces will be defined, identifying its functions and related risks. Then a methodology of Risk Analysis that improves communication between Urban Planners, Designers and ICT Engineers will be developed.

The development of this Risk Analysis methodology will be conducted using as an example application a real-world city that is not yet a fully Smart City, Milan. This city will be used to imagine the evolution of some of their public spaces into Smart Public Spaces, analysing them from a risk point of view (using the framework previously defined), and then applying the Risk Analysis methodology to these spaces. This procedure will be done sequentially, also using some software tools ad hoc developed by the researcher to increase the depth and speed of risk analysis. These activities will be conducted mostly in 2nd year and partially in 3rd year.

An optional section of the methodology will be about change management and sensitivity analysis of the risk analysis. These sections will be developed considering two different kinds of changes: a change in requirements (i.e. a change in the Smart City Public Space framework instance) and a fluctuation in data used for the Risk Analysis (i.e. effects of parameters uncertainty).

The research methodology will be based on the following process, where the columns mean:

- **Step:** the name of the step of the process
- **Description:** the description of the step
- **Methods:** the approach used to develop the step

Table 1 - Research project methodology

N.	Step	Description	Methods
1	Inception	Looking around in literature to find a research topic	Literature review
2	Define a smart city framework	Define common processes and functions that a smart city must have	Literature review, standards review
3	Define functions	Identify and define functions that must be provided in a smart city	Literature review, standards review
4	Define risk analysis methodology	Starting from an existing standard or a mix of more than one of them, define a risk analysis methodology for defined functions.	Literature review, standards review, development risk analysis software calculator
5	Apply it to one case study	Use a case study to apply the risk analysis methodology	On-site analysis, open data analysis, maps analysis, literature review, feeding of risk analysis software calculator
6	Refine methodology	Analyse what emerged from the case study application and review the methodology	Literature review, standards review, improvement of risk analysis software calculator, development of a smart city software simulator
7	Write final results	Write the final version of the PhD thesis with conclusions	Writing a scientific essay, developing graphics to summarize results, preparing a simulator and calculator for demonstration

1.9.3 Languages and dialects used

The research will be based on existing standard languages and new-defined ones.

To model processes, we will use a graphical language called "Unified Modelling Language". In UML, activity diagrams are fully applicable to the Smart City's processes modelling.

Essence 1.2 formal theory for software engineering will be applied to our research and extended to fit the Smart City case.

1.10 Research document structure

In this section, the structure of the research thesis document is exploited, describing for each section a summary of the content, where applicable, and other information. The chapters already covered in this Prospectus Document are not listed, although they will be present.

Table 2 - Research document structure

Chapter	Title	Description
1	**Introduction**	Summary of the research and its results, history of the smart city concept, Definitions of main concepts used in the research, including the Smart City definition. Methodology. Problem statement
2	**The Framework**	Critic analysis of most significative existing frameworks for a Smart City. Definition of "public space", "risk", and "smart city". Description of existing standards directly or indirectly applicable to smart cities. Definition of an ontology to represent the Smart City. Development of the RAFT risk analysis framework. Analysis of Smart City's capability of autonomously reconfiguring the space.
3	**The Essence Standard**	Extension of Essence 1.2 Software Engineering Fromal Theory
4	**Risk Analysis Methodology**	Review of existing risk analysis frameworks and integration between them and Urban Planning, Urban Design, Architecture. Definition of the Aufbau Process to represent the Smart City using the chosen language and the selected framework
5	**RAFT**	Description of the developed RAFT risk analysis framework
6	**Application Example**	Sample application to a public park in Milan.
7	**Research Results**	Discussion of results achieved by the research and future research areas.
8	**References**	

1.11 Hypothesis and main idea

The hypothesis is that a new concept in risk analysis for security and safety in public spaces must be developed to tackle the gap between UP / UD and engineers in smart city planning and design.

This new concept should be the bridge that connects the UP/UD and the engineering perspectives.

This will be based on defining a representation of the smart city from an Urban Planning/Urban Design/Architecture point of view and deriving, from it, an engineering representation of the same idea, giving traceability from one end to the other.

1.12 Case Study

One case study has been defined to be used as an application example.

It has been used during the research to define and improve the risk analysis and management methodology.

To test the research project results, the case study has been considered. It has been defined as looking at cities with an important growth rate.

The chosen place for the first case study is Giuseppe Lazzati Park in Milan, Italy. Milan is an important and big city in Northern Italy but is experiencing an important evolution due to the massive restoration and rebuilding of entire city areas (Porta Nuova, City Life, Porta Romana, …). In this sense, it can be considered a good example of a fast-changing city.

In this case study, both the methodology and the framework will be applied and specific studies will be produced, to test them and refine and/or improve them.

1.13 Data Collection

Many Smart City projects have delivered information as Open Data like Urban Data Platform Plus from EC (https://urban.jrc.ec.europa.eu/#/en). These Open Data collections cover many different topics that can be summarized in the following list:

- Transparency
- Accountability
- Performance Management
- Transportation
- Infrastructures
- Resilient city planning
- IoT of smart cities
- Civic engagement

As it can be easily understood, these are a lot of data and, as often happens with Open Data, they are heterogeneous data sources of unknown data quality. The advantage of these collections is that they are quantitative data and can be used to mine interesting results, both qualitative and quantitative.

Other kinds of data can be gathered from other sources like literature, smart city projects and more. In this case, data are often qualitative data and cannot be used to derive quantitative results.

1.14 Data Analysis

To analyse such data, two different approaches will be used in the research project: one for detailed quantitative data and another for aggregated or qualitative data.

To analyse detailed and quantitative data, a research project database will be created using an ELK stack. ELK stands for Elasticsearch, Logstash and Kibana, which are the names of three open-source and well-known products for advanced data analysis.

These products are normally used together and are a very good foundation for data analytics and information search.

This data on the ELK stack will be used for:

- Descriptive analytics, i.e. understanding the problem and its rules
- Predictive analytics, i.e. forecasting the future behaviour of some basing on its past behaviours
- Prescriptive analytics, i.e. to define the best course of action among the possible ones

The roles of these three analytics are depicted in the image below, which describes the role, in time, of different analytics, giving on the X axis the time and on the Y axis the business value of found results.

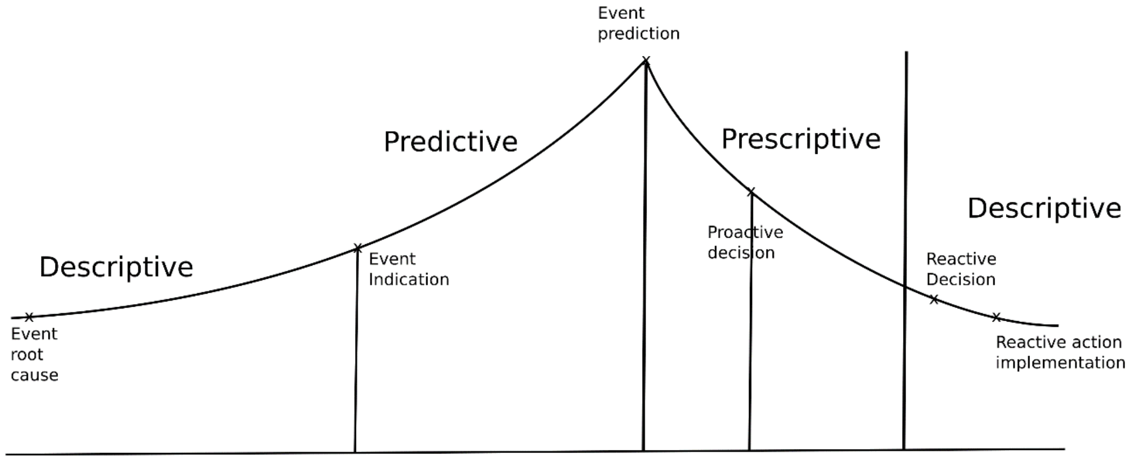

Figure 2 - Different analytics usage in the life cycle of a smart city

Outside the ELK stack, other kinds of data analysis can be done on detailed data.

Qualitative data will also be stored in the ELK stack to have the capability to retrieve them and will be used only for qualitative analysis.

1.15 Archival Research

Due to the very recent nature of the information that will be used in case studies, archival research will be mostly limited to Open Data collections and other kinds of databases, although the possibility to explore non-digital archives exists. In this case, all the retrieved information will be digitalised in some way and then inserted into the research project database.

1.16 Conclusions

The proposed new methodology will provide important results that are summarized below:

Result	Impact
Interdisciplinary risk analysis methodology	The newly defined risk analysis approach will overcome the gap between urban planning /urban design and the engineering world, connecting them with no interruption but allowing these two worlds to continue to work with their peculiarities and with enough degrees of freedom.
Smart city framework	The definition of a new description of the smart city will open new research areas for Urban Planners, Urban Designers and Engineers.
New smart city definition	A new smart city definition will provide an improved perspective and open new discussion areas about the smart city concept.

Result	Impact
Change management	Although optional, the change management approach will ease the evolution of the smart city and, in particular, the transition from a non-smart to a smart city.

In addition to these results, that were originally planned, additional results have emerged during research. In section 7.1-Research results all these results are described in detail.

2 The Framework

2.1 Existing frameworks: the IBM vision

A Smart City framework is a conceptual model that defines both a main outline and a detailed view of what a smart city is, how it can be developed, and which are its operational parameters to keep it operating.

To define a Smart City framework, existing Smart City models have been analysed through a literature review, and the results of this analysis are reported in the following sections. To ensure the effectiveness of a Smart City model, the related "business model" has been evaluated. "Business model", in this case, must be considered in its general meaning of "how value, of any kind, is provided to all relevant Stakeholders". This aspect is particularly important because Smart City can be roughly considered a Software System (in the sense given in Essence OMG Software Engineering Standard) and the two (unique and) important drivers on the Customer side in such software engineering descriptive theory are exactly Opportunities (which means value provided) and Stakeholders. This connection of Smart City theory with Software Engineering formal theory (Jacobson, 2019) is not a coincidence but derives from the fact that, as already stated, and now underlined, a Smart City is, essentially, a Software System. This relationship will be further investigated later, showing how this is important to develop a methodology that connects Urban Planners/Designers and ICT Engineers.

To understand smart city frameworks, it has been analysed, as a starting point, the IBM approach to it. At the end of the '90s (up to the beginning of the 2000s) IBM was facing a huge crisis: its annual losses overcame one billion USD and this led to dramatic strategic change, moving away from hardware design and production to focus on consultancy and software. This change was caused by the IBM policy to allow clones (i.e. computers made by Chinese firms cloning IBM's hardware or blade running along the copyright infringement line): this policy made IBM's PC architecture the market leader but allowed China to develop its technological competence and, due to lower production costs and to globalization processes, it became a fearsome competitor of

IBM. In this context, IBM's PC production division was sold in 2004, to Lenovo (a Chinese company) in a deal valued at $1.75 billion. The aim of this and other changes was to move the value chain towards more economically performant fields while IBM kept an 18.9% in Lenovo, Lenovo paid $1.25 billion for the IBM PC unit and assumed its debt, inflating the cost to $1.75 billion. (McNeill 2013). Which were these "more lucrative fields"? At the time, IBM was a well-established global company and realized the importance of the new-born market of urban technologies, i.e. the application of ICT technologies and robotics to urban contexts. In 2008, IBM launched the campaign "smarter planet" following this new strategy to enter this new, growing and very promising market: internal studies done by IBM's senior management in the early 2000s have had identified (smart) cities as a huge and without competitors market (Townsend 2013). According to IBM's evaluation, its value was about 40 billion USD in 2016 and over 20 billion USD in 2020. IBM developed a detailed and focused strategy to get the largest possible share of this market. It's strategy was based on two elements: contracts and free consultancy. IBM developed a "full-scale contracting" designed for city governments passing through two important contracts for Rio de Janeiro and Singapore (McNeill, 2013); and its Smarter Cities Challenge, a bright idea to provide free (pro bono) consultancy made by IBM experts to about 100 municipalities all over the world, to both try to acquire new flagship contracts and to claim that IBM's knowledge was based on 2000 cities all over the world. notes, "This strategy has paid off, generating some 3 billion USD of income and representing currently 25% of IBM's operations" and made IBM the market leader in the business of smart urban technologies for both sales and strategy. (Hollands, 2013).

Then IBM designed the 100 million USD "smarter cities campaign" (Townsend 2013) to give it global visibility in the urban technologies market providing both the translation of the smart city into a unitary language and its conversion into a "transformative narrative". In this sense, it has been considered as the starting point to define a smart city framework. Following these two aspects is evident in the evolution into a smart city framework, starting from a generic, simplified perspective (organicism, system of systems) into a more tailor-made vision.

IBM's (smart) urban theory is based on two main assumptions: the three pillars and the system of systems.

The first assumption is that the (smart) city is based on three "pillars":

- services for planning and management
- infrastructure services
- human services

Services for planning and management are further partitioned into public safety (to ensure safety and security), smarter buildings and urban planning (to provide intelligent buildings and support their integration into urban planning), and government and agency administration (to provide services for management and policy makers).

Infrastructure services were divided into four main utilities that were energy, water, environment, and transportation. Energy and water were grouped to keep the similarity of three sub-pillars for each pillar.

Human services were also divided into three parts: healthcare, social programs, and education.

The composition of these three by three pillars is what changed the city into "The City".

In IBM's vision, all these nine sub-systems should be monitored and controlled by IBM's "Intelligent Operations Center". This "central nervous system" was first deployed in Rio de Janeiro but soon became an essential element.

These pillars are simply the rewriting of the typical administrative departments of a typical city in the world, letting the just-defined framework as a very primitive one.

Any of these pillars can be considered a whole system and, consequently, the (smart) city is a "system of systems".

Systems thinking has not been only used by IBM to model complexity (i.e. the smart city) but also has been a tool strongly wanted by IBM's service provision, as explained by Justin Cook, manager of IBM's Foundational Research Team, "we want to help these people become systems thinkers [...] to help them see relations". Cook was talking about the Portland project but this strategy was present in any other project.

This framework based on a system of systems was considered a necessary element: data and systems analysis because they were considered the means through which municipalities can move subjective and improvised decision-making into more objective and data-founded decision support.

But IBM's vision based on a city considered through systems thinking was not new to urban planning. Many scholars defined the city as a system. Systems thinking about cities arises from organicism, especially from William Harvey's theory of blood circulation. Harvey, in the 17th century, researched the functions of the cardiovascular system, and his results were applied not only to the body as a system of circulations, the system of systems again (Sennett, 1994). Urban planners were fascinated by this research and started looking at cities with a different eye. Sennet (1994) reports that "Enlightened planners wanted the city in its very design to function like a healthy body". In this vision, they applied (as it is yet today) the terms arteria and vein to streets. This vision, in the 18th century, was to change the growing traffic issue from an entangled element into a more ordered one with the parallel of the blood system of the human body (Sennett, 1994). Organicism also gave the urban design a new perspective moving away from traditional geometric models of spatial organization (Mehmood, 2010).

The common idea of the organicist approach in urban planning was a holistic view. The cities have begun to be seen as composed of functionally related parts, again as a system of systems but also as function compositions. Systems thinking applied to urban planning is the evolution of organicism into a new metaphor based on the computer model. In this model, the whole city is seen as a complex formula processed by a sophisticated calculator and not anymore as a biological, living, entity.

Systems theory has influenced urban planning theory since the 1960s, (Healey and Hillier, 2010), with the famous sentence by Berry (1964) “cities as systems within systems of cities”. This idea was the same that IBM developed in its systems model for smart cities.

Churchman, in 1968 (Mehmood, 2010) classified four different approaches in systems thinking. The first one was efficiency but, in his perspective, it was at the same level as the other three. In Churcman's vision a scientific approach to urban planning, a humanistic one and an anti-planning were considered worth at an equal level. IBM’s approach was to give priority to the first one. So, the efficiency approach was leveraged in “reducing waste” (Mehmood, 2010). Waste was on various dimensions, from time to resources. IBM’s approach is derived from Jay Forrester's studies. He, in 1969, was a computer engineer and provided important work on urban dynamics. Even if applied with no success in some cases (New York and Pittsburg) at the end of the '60s and beginnings of the '70s, mostly for a lack of computing power, urban dynamics was reconsidered decades later by Justin Cook, the famous IBM smart city strategist. Cook met at MIT Forrester as a professor and understood the potential of urban dynamics (Townsend 2013). There is something weird in this resurrection as it gives a sense of travelling back to the heroic times of post-war cybernetics, in the first Golden Age of Artificial Intelligence. If urban dynamics is considered as a translation deception for new storytelling on which base the new urban systems theory. It translates any kind of urban phenomena into data and puts this data in relationships that can be managed with a traditional systemic approach. In system theory, each system is composed of elements, connections, functions, feedback loops, delays, sources and wells. Strong mathematical support was available to study the stability and the trends of the system, even if very strongly not linear (Chaos Theory from Edward Lorenz and Lyapunov stability theory). This translation metaphor can be used also to map from organicism to systemic theory, letting it become a sort of passe-partout to describe the whole framework evolution (Lynch 1988). In a few words, urban dynamics can translate the city into a single language, independently from the originating model, organic, mathematical, and urban. This language is a core point of IBM's approach to smart cities: the smart city is made to speak the language of IBM. In this way, the IBM vision is founded on nine elements (the sub-systems / sub-pillars) which can be developed using traditional system theory development processes and a domain-specific language which is IBM's translation of the city into its vision. In this way, IBM is defining a first (informal) methodology, i.e. the sum of a creative process and of a language to describe the phenomenon (i.e. the city). In this research document, one of the objectives is the definition of such methodology and, for this reason, the IBM experience has been considered the starting point of the framework definition.

Two critics have been made on how urban systems are described by IBM (Söderström 2014).

First, IBM's vision takes for granted that infrastructures already existent. It does not consider the case (actually very frequent) of real cities where their lack is the norm. Infrastructure can be failed, worn, and often not centrally managed. And the same is for urban systems, especially in the Global South (Beall and Fox, 2009). Bakker (2011), for instance, proposes the term "network", for water supply systems rather than the metaphor of the archipelago. About the Global South cities decline from the infrastructure point of view, the IBM vision becomes a North-centric framework, not suitable for the Third World.

The second critics is about the real suitability of systems theory as a metaphor. In IBM's vision, cities are data processed inside systemic processes and all its pillars are conceived to get the biggest advantage from the data-based systemic analysis. This view results in a mechanical view of the city and removes the need of having urban experts but relies only on data mining, big data interconnections and data analytics.

IBM considers the city as a formula with three components: instrumentation of urbanity (sensing the urban reality and transforming it into data) + interconnection of data (creating, managing and maintaining relationships between data) + the Intelligence (through software algorithms). Complexity and multiplicity are simplified into systems. Marcuse (2005) observed that both the organic and systems metaphor also creates a technocracy, i.e. the city as a virtual entity that looks for political consensus.

This approach is presented as a way to provide efficient urban management that passes through conditions with the structure of the "if ... then ... " instruction.

This form was recurrent in the smarter cities campaign but means that the ontological transformation becomes the source of the framework's epistemological power. It is as if the only use of systems thinking solves the difficulties of interpreting the city. Simply translating it into data and systems, the city becomes clear, speaks in a way we can understand, and becomes selfexplanatory. But this is IBM's smarter city marketing approach. It is the translation into an engineering epistemology that can be easily addressed by IBM's technologies and services. This is an "engineering fiction" that melts nature and culture in the engineer's mind. But combining the pillars to make the city smarter means that urban management is reduced to systems engineering.

The results from IBM's approach to smart cities can be easily found in other approaches: the ontological change in the city representation filtered through the engineering mind is a more general issue of the research question which is the objective of this research project. This wider issue is to consider also non-engineering elements in the smart city framework to:

- Define an interdisciplinary model of a smart city where it is possible to move from one discipline to engineering and vice versa in a seamless way without losing traceability from non-engineering requirements and non-engineering elements.
- Define creative processes to plan, develop, manage and change a smart city, without losing connection with non-engineering elements.
- Define descriptive language which can be used to describe the smart city model and instances at any instant of its life cycle, from conception to disposal.

In the next sections of this chapter, different models and elements of smart cities will be analysed to define a new smart city framework which solves this general issue but is limited to the peculiar case of risk management in public spaces. This limitation is essential because allows this work to be constrained into an outline of feasibility, avoiding being lost in a topic that is too extended.

Analysing Smart City models, those suitable to be considered frameworks (i.e., defines, even in a few statements, the processes to develop and operate it) have been analysed and results are summarized below.

2.1.1 Smart City Stakeholders

Smart city stakeholders change from one case to another. Politics, institutions, industries, start-ups, citizens, planners and others are all components of the driving forces shaping the cities.

As just seen above, in the beginning, being "smart" meant being provided with modern ICT infrastructures. It was a concise engineering term to identify the existence of some "systems". The term evolved later, extending to other disciplines different from engineering: being a smart city now requires that political, business and civil society stakeholders can cooperate in an innovative way to win the city's challenges.

No stakeholder can be defined as more important than the others but all of them are considered as necessary elements for the achievement of the building of the smart city project. Then, the interaction between them should be eased by connectivity, on both senses of vertical decision-making and better access for all to public services.

Stakeholders can be sometimes grouped.

The smart city can be considered as Software System and then, can be designed and managed according to Software Engineering Essence Theory (Jacobson 2019). From the Essence perspective, in the Customer Area of Concern, there are two elements (alphas, Jacobson 2019): Stakeholders and Opportunity.

Stakeholders are formally defined as (Essence Specification 1.2, 2018, Object Management Group):

- The people, groups, or organizations who affect or are affected by a software system. The stakeholders provide the Opportunity and are the source of the requirements and funding for the software system. The team members are also stakeholders. The stakeholders should be involved throughout the software engineering endeavour to support the team and ensure that an acceptable software system is produced. Stakeholders are critical to the success of the software system and the work done to produce it. Their input and feedback help shape the software engineering endeavour and the resulting software system

The Opportunity is formally defined as (Essence Specification 1.2, 2018, Object Management Group):

- The set of circumstances that makes it appropriate to develop or change a software system. The opportunity articulates the reason for the creation of the new, or changed, software system. It represents the team's shared understanding of the stakeholders' needs and helps shape the requirements for the new software system by justifying its development. It consists in a commercial, social, or business opportunity that has been identified and that could be addressed by a software-based solution.

Opportunity will be further detailed later in this chapter. This section is about Stakeholders and will focus on them.

The smart city carries with it a set of very complex issues. The expertise to build it is held by diverse stakeholders and their engagement requires the time of building and appropriating a common language that needs to imagine new ways of working and communicating all along with the project.

Even though all stakeholders don't have the same relevance with regards to decision-making, none of the actors will be able to achieve smart or sustainable cities without support from the other stakeholder groups: engaging all the stakeholders in their area of influence seems to be the best way for getting success in urban projects (e.g. smart city) implementation.

2.1.1.1 Governmental & Public Sector

Cities are facing a new urbanism that leads to relevant population growth. This growth increases social pressures and economic issues.

The smart city paradigm allows new forms of government to manage future evolutions of the city enabling virtuous stakeholders' behaviour, through their awareness and a reliable decision support mechanism.

Also, participation is fueled, increasing bottom-up communication. New services and new lifestyles can also be provided to citizens in a value chain that is strictly tied to its capacity to gather, group, organize, process and understand data from various elements of the city. In the past, these activities have been designed, managed and operated in a traditional approach based on a siloed approach but new big data availability produced by IoT and, in general, by intelligent devices, leverage the infrastructures and allow them to satisfy, in an efficient way, community needs.

So, one key stakeholder is the City, in the sense of the Municipality governing it. For this reason, it is mandatory to get their commitment through the entire smart city project life cycle, starting from promotion up to operation. This is the only way to achieve improved public services, that is the key to smartness. Administration can also contribute to managing the resources.

Engaging political stakeholders in sharing their experiences is another important element (Fernandez-Anez et al. 2016). Moreover, political institutions have an impact on governance.

Policy making and its implementation are also needed for transparency and accountability but also for sustainability. So, policy makers are another kind of stakeholder.

Smart cities are very expensive to be implemented and also to operate and require appropriate financial suppliers (other stakeholders). In obtaining funding the investors will require and adequate ROI and so they become stakeholders too.

Other stakeholders are Financial partners that support businesses and governments by sponsoring and investing money in smart city projects. They can be both public and private (further analysed later) and will choose profitable projects to invest in.

Finally, also governments are stakeholders because they are in charge of knowledge creation and capitalization, fundamental in smart cities.

2.1.1.2 Universities, Academies, Research & Innovation Organisations

Academic research aims to create new solutions for intelligent cities, moving from basic TRLs (Technology Readiness Levels) from prototypes and models to applicable solutions.

Academic institutions and Research institutions are giving a strong contribution to smart cities and their growing interest has generated numerous pilot projects for smart cities. But they are also important in planning and developing strategies.

Because the success of the transition from a city to a smart city is the awareness and understanding of the citizens, academic research and generated know-how will allow cities to evolve aiming at their full efficiency in the short, medium and long term. But they can also propose new kinds of regulatory frameworks, define innovative od adapted business models, and conceive advanced kinds of services and applications.

But the most important challenge is to make people proactive, changing from consumers to prosumers.

Research application increases the understanding of the city's complexity and becomes able to predict the feasibility of these applications before fully developing them. Innovation clusters allow efficiency also in research.

Academic Organisations are then new stakeholders.

Another stakeholder is made of R&I networks: with their research facilities collect data, information, knowledge, and gather experience on many projects. R&I networks also can demonstrate, through simulated scalability, the large-scale feasibility of solutions.

R&I networks provide environments to share and validate experiences, good practices and results from different cases. Their strength is mostly the connection of different stakeholders.

Scientists and experts of the smart city concept are stakeholders too due to their engagement in smart city processes and innovation.

2.1.1.3 IT & Construction Companies, Private Sector

Small businesses and enterprises involved in realizing infrastructures and implementing smart solutions are stakeholders too.

The progress of smart city projects is based on technical and software infrastructure realisation.

Real Estate and Property Developers (typically big companies) have stimulated, and continue in stimulating, architects, engineers, and construction companies to promote improvement according to the 4.0 industrial revolution directions. Smart cities are often theatres of conflicts where property developers ask for innovation and technicians try to satisfy them. Real Estate and Property developers can be then considered stakeholders due to their innovation pressure.

Urban planners are another kind of stakeholder due to their impact on the design and effectiveness of the smart city.

Energy suppliers are also important stakeholders in sustainability.

For sustainability, it is necessary to have also a sustainable society. Social cohesion, equity and other values are mandatory and they can be assured through urban planning. From this perspective, sustainability is not only and energy balance improvement but also a social balance enhancement.

Existing residential units are often not sustainable due to inefficient energy usage. A progressive programme is required to drive the transition towards sustainability.

Public social housing means the capability of developing policies and projects on and adequate number.

Another kind of stakeholder is made by innovative companies like eCommerce and start-ups that are usually technology enthusiasts in developing and using smart city services and applications, developing new business models and increasing user-friendliness of technology. Through exhibitions, they can be put into connections.

Also, information operators are important and supporting their agencies (online newspapers, business magazines, …) dealing with smart cities topics is essential.

ICT companies are, obviously, another stakeholder.

2.1.1.4 Civil Society, Social & Third Sector

Citizen participation is a need for any urban regeneration, meaning challenging social exclusion, poverty, lack of services and unemployment. Then, citizens are surely stakeholders, the main type of stakeholders due to their high number. They must experience urban space and report issues and have a key role in urban planning.

Community involvement is the way to change citizens from consumers to proactive consumers, the prosumers, that not only use data but also provide them.

Grassroot movements, associations, and non-profit organizations are other civil forces that are impacted by smart cities and are stakeholders.

NGOs and the Third Sector are other stakeholders because they have a strong influence on politics and society.

Promoting new models of civic participation, protective and inclusive, effectively meeting social needs is mandatory in smart cities. Social entrepreneurs and community-led initiatives can be enabled by digital technologies and also new forms of partnership can arise.

Innovation Tourists look for cities famous for innovation and carry with them networks and new contacts, generating and looking for business opportunities. They are stakeholders.

2.1.1.5 Media

Media can influence a smart city project through the coverage of problems and the advantages of a smart city. The influence can be positive or negative. Thus, they are stakeholders in the sense that, at least, can provide such influence and so must be considered into account.

2.1.1.6 Forces which define other stakeholders

A more general theory explains the most relevant forces shaping a smart city and they are two: technology-push and the market-pull (or demand-pull).

Behind the smart city, there is a very dynamic market of "smart" products. The technology-push implies that a new solution/product is immediately pushed into the market without considering the explicit needs of the community. The market-pull is a solution developed and commercialized as a response to a demand from the community.

In technology-push, any advancements make possible the development of solutions and products enabling the smart city. Another effect is the increasing number of technology vendors and consultancies.

Market-pull causes competition to attract people that have a stronger ability to innovate, individually or in groups, generating a collective intelligence that empowers innovation.

In the smart city paradigm, innovation and sustainability for the local economy are based on connectivity and local social innovation. In this case, both the technology-push and market-pull forces drive a surprising evolution where both influence smart city growth with a dynamic balance of supply and demand.

Combining both forces, that are technology and human capital development, together can give a city the power to increase innovation, generate new solutions, increase participation and solve problems in a better way.

2.1.1.7 The Market and Civil Society agreement

To explain smart city economy dynamics it is possible to refer to Adam Smith's "Invisible Hand" concept. He states that the actions of many self-interested actors combine to create larger common benefits for society. Making available beg data and real-time information empowers stakeholders improving the city's overall performance.

But this Market — Civil Society deal renews the issues of representativity, legitimacy, and responsibility of these stakeholders in the co-construction of public interest, raising the need for a frame to drive them in the right direction ins transforming cities.

2.1.1.8 Hybrid Stakeholders: Public-Private Partnerships

A Smart city cannot be developed without private investments: it is too expensive.

The most successful development model for smart cities seems to have large participation but strong governance. A typical structure used for this purpose is Public-Private Partnership (PPP).

Public-Private Partnerships summarize a large number of cases of cooperation between the public and private sectors, all ensuring the following constraints:

- There is a long-term contract between public and private parties
- Financing, building, and maintenance of public infrastructure is held by the private party,
- Payments for the use of the infrastructure during its life, even if made by the public sector party, are sent to the private sector party
- At the end of the PPP contract, the facility ownership is of the public sector

2.1.1.9 Stakeholders summary

The following table has reported the list of Stakeholders for a Smart City according to the main frameworks from IBM's perspective. Although this list is very good and complete, we will use a different, shorter list, coming from Ramaprasad because we will adopt his ontology. Nevertheless, we report the list below:

- City or Municipality
- Local or Regional Government
- Financial or Funding Partner
- University
- Research and Innovation
- Experts
- ICT Company
- Real Estate Company
- Construction Company
- Urban Planners
- Utility Suppliers
- Citizens

- Civil Society
- Innovation Tourist
- Media
- Technology Company
- Markets
- Public-Private Partnership

2.1.2 Smart City Business Models

Business model concerns quite a recent concept and although it is broadly discussed, a common definition is missing (Morris, 2006). A business model describes the rationale of how an organization creates, delivers, and captures value (Söderström, 2014). One of the most widely accepted definitions comes from Turban (2012), according to which a business model concerns, is “an architecture of the products, services and information flows”. This definition recognizes actors, roles, potential business value and the source of revenue.

Although there could be various value propositions, business models can be classified into five patterns according to Osterwalder and Pigneur (2010):

- Unbundling business models can be utilized by firms that perform all three fundamentally different types of businesses: customer relationship; product innovation; and infrastructure businesses (i.e. private banking).
- The long tail business model according to which a firm tries to sell less for more. This model can be addressed by offering a large range of niche products, each of which sells relatively infrequently (i.e. LEGO).
- Multi-sided platforms, which bring together two or more distinct but interdependent groups of customers (i.e. game console production vendors).
- A free business model continuously benefits at least one substantial customer segment from a free-of-charge offer (i.e. cell phone operators).

Before proceeding to the identification of existing smart city business models, the smart city components need to be mentioned. Almost all well-managed and large-scale smart cities follow the multi-tier architecture (Anthopoulos and Fitsilis, 2014) in their attempt to integrate the physical with the ICT environment. However, another interesting approach appears to be adopted by smart cities and concerns the Internet-of-Things (IoT), meaning that many smart cities could utilize data from sensors, buildings and users as-sensors with their applications, without necessarily installing networks from scratch or other large-scale infrastructure. Potential business models could refer to any or all the smart city components. For instance, smart city vendors develop and deploy facilities;

operators earn from facility utilization or service provision; service providers earn from their service delivery etc.

To this end, various contemporary business models can be utilized in a smart city.

Teece and Pisano (1994) have identified a change of perspective in technological development: initially conceived as an event that happened inside a single factory, it has been widened considering that the effects of technology and its development are the result of the interactions between many firms. Consequently, the competitive approach has been considered outdated and detrimental, leading markets to become complex networks of relationships between different actors.

Since then, the meaning of business modelling has started to shift from closed business models (i.e., a single-firm approach) where there is little use of external ideas and technologies, to a mixed, networked model where some services are private, and others are public. The natural evolution of this vision was, then, towards an open, eco-systemic business model view that benefits from the large community (Casadesus-Masanell et al., 2011). Thus, the concept of the business model has changed over time, mainly due to market pressure (Iivari 2016).

As already stated, a business model is a key concept when studying smart city frameworks, especially about smart city development and operation.

Open innovation requires that the organization defines the ways to create, deliver and capture value in cooperation with partners that are part of the open innovation economy (Saebi and Foss, 2015). Then the definition of business model can be considered as the "content, structure and governance transactions made inside an organization and between it and its external partners who support the organization's value creation, delivery and capture" (Zott and Amit, 2010).

Currently, unfortunately, there is no widely accepted definition of the business model for the smart city context but, in cities, given a particular business model it describes the architecture or design of value creation, delivery, and capture mechanisms it employs (Teece, 2010).

Following the evolution of the business context change, it is possible to define three different types of business models: closed, mixed and open.

- Closed business models are founded on value chain thinking. They are characterized by competition among different actors. The size, complexity and interdisciplinarity of a smart city do not allow closed business models application to the entire city but only to a part of it.

- Mixed business models are founded on the network approach. They are characterized by coopetition, which is a kind of cooperative competition.
- Open business models are rooted in the sharing economy. They are characterized by cooperation.

According to Schaffers et al. (2012), for the smart city concept, eco-systemic thinking is particularly relevant. The city may attempt new market creation in the ecosystemic business model approach if it enables the evolution of the innovation ecosystem and adopts the rapid shift of organizational and industrial boundaries that can create new kinds of business opportunities (Hirvonen-Kantola et al., 2016).

Urban areas can build a sustainable competitive advantage through the business model approach and a maturity model is a useful tool in the guidance of regional network development (Pikka, 2007).

2.1.3 Smart City Values

According to OMG Essence standard for software engineering, the Opportunity alpha defines the value that is delivered to Stakeholders through software engineering. So, most software engineering work is initiated by the stakeholders that own and use the software system. Their inspiration is usually some combination of problems, suggestions, and directives, which taken together provide the development team with an opportunity to create a new or improved software system. Occasionally it is the development team itself that originates the opportunity that they must then sell to the other stakeholders to get funding and support. In many cases the software system only provides part of the solution needed to exploit the opportunity and the development team must coordinate their work with other teams to ensure that they deliver a useful, and deployable system (Jacobson 2019).

In all cases understanding the Opportunity is an essential part of software engineering, as it enables the team to (Jacobson 2019):

- Identify and motivate their stakeholders.
- Understand the value that the software system offers to the stakeholders.
- Understand why the software system is being developed.
- Understand how the success of the deployment of the software system will be judged.
- Ensure that the software system effectively addresses the needs of all the stakeholders.

It is the opportunity that unites the stakeholders and provides the motivation for producing a new or updated software system. It is by understanding the opportunity that you can identify the value and the desired outcome that the stakeholders hope to realize from the use of the software system either alone or as part of a broader business, or technical solution (Jacobson 2019).

According to Ramaprasad (Ramaprasad 2017), the outcomes (i.e., the values provided by a Smart City) are:

- Sustainability
- Quality of Life
- Equity,
- Livability
- Resilience

2.2 Smart Cities Standards

International standardization bodies have proposed various standards for sustainable cities and communities and many of them can be applied (and are applied) to smart cities, even if a common, definitive, definition of smart city has not yet been achieved.

According to BSI, standards for smart cities can be defined at three different levels in its 2014 view. These levels are strategic, process and technical specifications.

At the strategic level, standards provide high-level guidelines aimed to support governments and other organisations on how to conceive and develop smart city strategies. At this level, priorities are identified, roadmaps developed and progress can be monitored in its evolution along the roadmap.

Standards at the process level provide good practices in project procurement and management for projects that are achieved in smart cities. They contain best practices and guidance also about funding and financing.

The last level, the technical, contains all specifications (i.e.: technical requirements) for both products and services needed to implement smart cities projects.

Following such schema, the standards have been grouped and classified as follows:

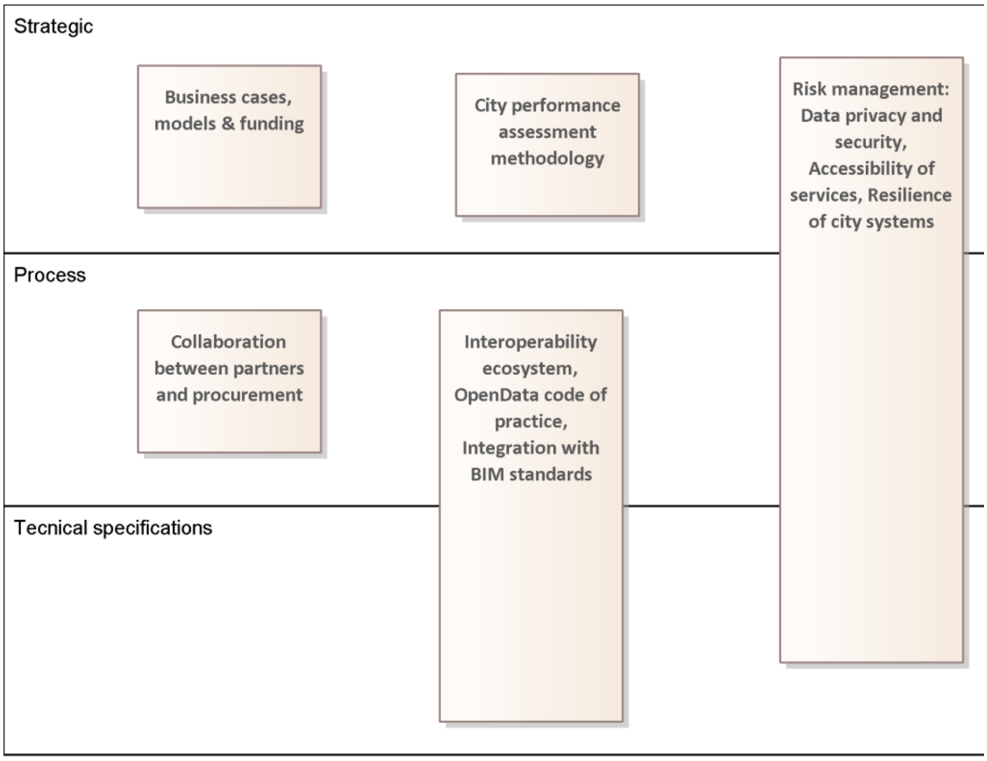

Figure 3 - Level of standards according to BSI 2014 (image of the author)

The three levels talk different languages and do not have a formal descriptive common language that, indeed, could be very useful to allow easy tracing of requirements implementation from one level to another. Even the risk management group, which spreads over all three levels, is described in different ways through the layers.

The technical committees' framework proposed by BSI in 2014 was organized as follows:

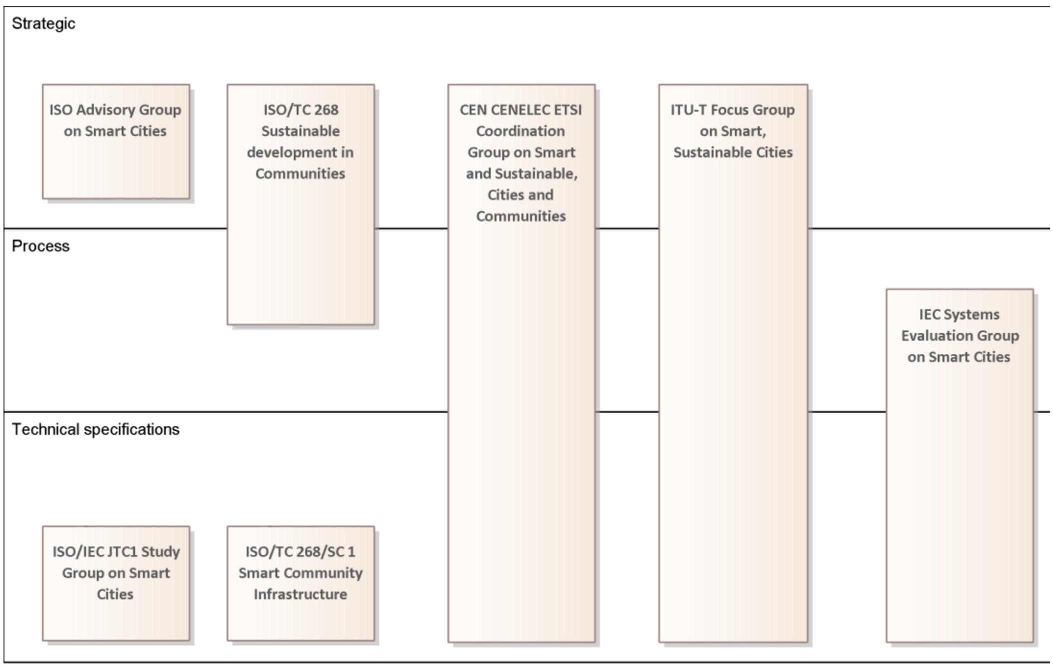

Figure 4 - Technical committees framework according to BSI 2014 (image of the author)

Let's consider, as an example, the ISO/TC 268 managed standards. The typical applicable ISO standards coming from ISO/TC 268 and suitable for smart cities are shown in the following picture:

Figure 5 - ISO/TC 268 suitable standards for smart cities (image of the author)

ISO 37120 is the central, key, standard and, even if not specifically designed for smart cities but for a wider concept (sustainable cities and sustainable communities). It defines methodologies for a set of indicators that can be used to drive and measure the sustainability of the city/community. Sustainability is defined, in this case, in terms of the city services' performance and quality of life.

ISO 37122 and ISO 37123 are complementary sets of indicators that provide a wide range of capabilities to measure the "smartness" of a city and its "resilience". ISO 37122 goes further than the simple KPIs list and also provides important methods and practices that can have a serious impact on the smart city context (i.e.: its social environment and its sustainability from economic and environmental points of view).

ISO 37101 provides requirements for the development of a management system to continuously improve the sustainability dimension of the community. As with any other ISO management system requirements set, it contains the foundation principles that must be satisfied in such a management system. Using this standard with the other three described above usually gives the ability to implement it effectively and efficiently. ISO 37101 can also be used not only to improve sustainability, smartness and resilience through an interdisciplinary and holistic approach but also to create clearness and consensus about the need (and the opportunity too) to implement sustainable development in a community.

The standards above spread from strategic to process level but they have some common issues.

The first issue is about ISO 37101, i.e.: at the strategic level. Its requirements are in a general form and do not provide enough details to implement and measure the progress other standards have been used for doing this task. ISO 37101 is too general and does not take care of the existence of a custom or peculiar requirements like democracy or social engagement.

The other standards define the level of the implementation through indicators that are correlated with the required feature (e.g.: sustainability) but that do not measure it. In a few words, KPIs have been defined to measure, in a quantified way, something that, often, is not quantifiable. Some examples of these KPIs are reported below with explicit criticism of their limits.

For example, ISO 37120 indicators are partitioned into two levels: core and support indicators.

Environment core indicators are particulate matter concentrations and greenhouse gas emissions per capita. Environment support indicators are concentrations of NO2, SO2, O3, noise pollution and relative changes in native species (% of number). Although these parameters are important from the environment point of view, they are not enough to quantify the environmental dimension of the community.

But the real issue comes when a more complex (and effective) model is considered. If the discourse is moved towards Green Urbanism, it becomes clear that something is missing. Not only in the indicators that can be updated or increased in number and detail but in the real approach.

2.2.1 Smart City Framework

2.2.1.1 The Ramaprasad approach

In the paper "A Unified Definition of a Smart City", Ramaprasad tries to address the definition of a framework to describe a Smart City (Ramaprasad 2017). He states that the Smart City is a function of two variables: the Smart and the City. So we can write:

$$Smart\ City = f(Smart, City)$$

The City is defined by Stakeholders and Values (Outcomes).

Stakeholders are Citizens, Professionals, Communities, Institutions, Businesses, and Governments.

The Values are Sustainability, Quality of Life, Equity, Livability, and Resilience.

The Smartness of a City can be defined as being able to intelligent sense and response through semiotics. The concept of Semiotics will be clarified later but it is an iterative process that generates and applies intelligence. Semiotics is Data, Information, and Knowledge. Data is the symbolic representation of sensations and measurements. Information is the relationship among the data elements. Knowledge is the meaning of the relationships among the data elements.

According to Ramaprasad, Smartness is a function of four variables:

$$Smart = f(Structure, Functions, Focus, Semiotics)$$

Where Structure, which is the structure required to manage the semiotics, can be: Architecture (the overall architecture to manage the semiotics), Infrastructure (physical and virtual infrastructure to manage the semiotics), Systems (computer, social, and paper-based systems to manage the semiotics), Services (computer, social, and paper-based services to manage the semiotics), Policies (on managing the semiotics), Processes (to manage the semiotics), Personnel (people responsible for managing the semiotics).

Functions, which are the functions required to manage the semiotics, are defined as Sense (to sense the semiotic elements), Monitor (to monitor the semiotic elements over time), Process (to process the semiotic elements), Translate (to translate the semiotics into action/control), Communicate (to communicate the semiotic elements).

Focus (of intelligent sense and response, the "smartness") is defined as Cultural (cultural dynamics of the city), Economic (economic dynamics of the city), Demographic (demographic dynamics of the city), Environmental (environmental dynamics of the city), Political (political dynamics of the city), Social (social dynamics of the city), Technological (technological dynamics of the city), Infrastructural (infrastructural dynamics of the city).

All these framework elements can be used as an ontology to describe the smart city. Combining the various elements of the framework, it is possible to generate a high number of "illustrative elements" that represent single aspects of the smart city.

A single illustrative element can be generated by combining the framework's elements according to the following schema:

<Structure> to <Functions> + <Focus> + <Semiotics> by/from/to <Stakeholders> for <Outcomes>

An example of an illustrative element obtained by applying the above schema could be "Services to Monitor Demographic Data from Citizens for Resilience".

The Structure variable has 7 possible values, the functions variable has 5, the focus variable has 8, the semiotics variable has 3, the stakeholders variable has 6 and the outcomes variable has 5. The possible combinations according to the illustrative elements generation schema is 7*5*8*3*6*5 which is 25,200 different illustrative elements. The real number is higher due to further possible combinations (e.g. the from/to alternative, different ways to implement the same variable, …).

In the following sections, Ramaprasad’s framework will be customised and improved to fit the need for public space safety and security in a smart city. This new framework will be named “RAFT” with the meaning of “smaRt spAce saFety securiTy”. The term raft is the survival emergency boat made with wood, or the emergency inflatable boat but can also mean a large amount. In these meanings the acronym has been considered representative: it is a way to survive to emergency prevent and manage it and also it must consider a huge number of parameters due to the complexity of the smart city context.

2.2.2 Analysis of the Ramaprasad’s framework

To manage, for example, the health factor of the individual, a set of illustrative elements can be designed through the framework. A result of such a design is shown in the following table:

Element	Description
Infrastructure to sense environmental (health) data from citizens for QoL	An infrastructure must be provided to measure the health parameters of the citizens (both resident and from abroad), to use them for QoL
Infrastructure to monitor Environmental (health) data from citizens for QoL	An infrastructure must be provided to monitor the health data of the citizens (both resident and from abroad), to use them for QoL
Systems to monitor Environmental (health) information from citizens for QoL	Systems are to be provided to monitor information about the health of citizens
Systems to process Environmental (health) information from citizens for QoL	Systems are to be provided to process information about the health of citizens
Policies to sense / monitor/process / communicate data/information from citizens for QoL	Policies are needed regarding the privacy rights, reliability and safety of the overall management system regarding health
Processes/personnel to monitor / process / communicate/translate environmental (health) data/information/knowledge from citizens for QoL	Processes and personnel are needed to actuate the health management system that handles data, information and knowledge about health gathered from citizens

Element	Description
Architecture to process environmental (health) data/information/knowledge to citizens for QoL	Physical spaces and proper forms of the space must be arranged to process the data, information and knowledge to provide healthcare to citizens
Architecture to Communicate social data/information/knowledge to (between) citizens for QoL	Physical spaces where people can socialize and communicate. In this case, it is possible to evidence of the lack, in the framework, of a “between” preposition in addition to from/to/by

In this example, a set of illustrative elements have been derived from the framework using its generations formula. All these elements are needed to ensure an appropriate level of healthy quality of life for groups of citizens. Obviously, in these elements, the individual perspective is already present, even if they have been considered at the group level.

These elements are not all those needed but they are enough to evidence some issues.

The first issue is that the selected framework has a level too high: in fact, has been necessary to adapt the environment variable specifying it was related to health aspects because there was no applicable focus in the original framework statements. This means that, even if in this case the framework has not been modified, an evolution of it is needed to better represent the possible focuses of a Smart City.

A second issue is that semiotics is, in the framework, limited to data, information and knowledge. This is another limit because an action can be associated with the semiotic element. For example, some semiotic elements are gathered, and others are acted, i.e. they are used to generate actions. These actions can be realized by actuators (mechanical, display, acoustic, …) and others are provided by personnel. So, what seems to be missing in the framework, is the capability to distinguish between concepts (data, information, knowledge) and actions (described by data, information and knowledge). And these actions can be executed by personnel or systems. A partial resolution of this issue is, anyway in the framework, considering, for human actions, illustrative elements in the following form: personnel to process <some focus> <some semiotics> from professionals for <some outcomes>. For system actions a similar shape can be considered: personnel to process <some focus> <some semiotics> from <stakeholders is missing> for <some outcomes> but in this case, there is no feasible stakeholder.

A third issue is about the “architectural” component of the framework. This component should be able to map urban planning illustrative elements and this means that, even if the term

“Architecture” should be considered in a wide sense, some other ontological elements are missing. For example architecture to provide movement data/information/knowledge

After having defined all the illustrative elements, they are the detail of the Vision, that is the final expected result, where all these illustrative elements will be implemented at the expected grade. To define the grade of the implementation (needed and then realized during the development of the smart city), an approach based on the customization of a formal descriptive theory for software engineering has been adopted. This standard is Essence 1.2 and it has been approved by the Object Management Group, one of the most important worldwide authorities on software and computer systems. The use of this standard is out of the scope of this paper and will be omitted but it has been considered because, as an extreme simplification, a Smart City can be considered a product of Urban Planning, Architecture and Information and Communication Technology. Using Essence, in a customized application, customized through customisation rules already present in the standard, has allowed the definition of a common representation that can bridge the three disciplines together in the description and progress measurement of a Smart City development, in any instant of its life cycle.

Having a Vision then possible to define a Strategy. The Strategy is a sort of generic roadmap to arrive at the Vision.

To better structure, the framework, further detail has been added to its outcomes. The chosen sub-elements of each outcome have been considered after a literature review. The resulting sub-elements (that will become the sub-alphas) are listed in the table below:

Table 3 - Values and sub-values for the Smart City

Value	Sub-values
Sustainability	optimize current use of fossil fuels, eliminate waste, recycle, recover energy, save time, and reduce, or eliminate, pollution
Quality of Life	wealth, employment, the environment, physical and mental health, education, recreation and leisure time, social belonging, religious beliefs, safety, security and freedom
Equity	Absence of unfair, avoidable or remediable differences among groups of people, The groups are defined socially, economically, demographically, geographically or among another dimension (sex, ethnicity, disability, …)
Livability	safety, mobility options, employment and educational opportunities, public space, and political stability

Value	Sub-values
Resilience	local knowledge, community networks and relationships, communication, health, governance and leadership, resources, economic investment, preparedness, mental outlook

2.2.3 Customisation Schema to define the RAFT Framework

After the analysis done in the previous section, Ramaprasad's framework needs to be tailored and adapted to the specific application of safety and security in public spaces.

To customise it, the following process, after various trials, has been adopted:

1. Redefine the ontology to describe the elements of safety and security as outcomes
2. Redefine the ontology to include the kinds of public space as elements
3. Use a risk analysis approach to further refine the ontology, adapting to the possible risks
4. Essentialize the resulting framework to bridge Urban Planning/Urban Design/Architectural world with ICT/Engineering world

After these steps have been done, the framework will be ready to be used as a generator of illustrative elements that can be applied to Smart City design and development.

2.2.3.1 Ontology to describe the elements of safety and security

In this step, RAFT is widened to better and explicitly include the safety and security elements with the relationships among them and with the other elements of the framework.

2.2.3.2 Ontology to include the kinds of public space as elements

In this step, RAFT is reshaped to explicitly include the public space types in both real and virtual contexts.

2.2.3.3 Refine the ontology adapting it to the possible risks

In this third step, RAFT will include the risk analysis and management aspects.

2.2.3.4 Essentialize the resulting framework

All the elements are essentialised using a customised Essence 1.2 approach.

2.3 The RAFT Framework – part one – include safety and security

2.3.1 RAFT spaces contexts

The RAFT framework splits the public spaces of a smart city into two different spaces: the real, concrete, public space and the virtual, ephemeral public space.

These two spaces are interconnected but have completely different characteristics and risks.

The real public space is a public space, in reality, it is made of concrete, tangible, elements and is lived by flesh and blood persons, that is, by physical individuals.

A virtual public space is a space in cyberspace and people can attend it through different kinds of software applications. Most of the attendance types imply connections with other persons but these connections can be done maintaining a defined level of anonymity. These interactions are only virtual and can be considered without direct risks to safety, although they can maintain a high risk of security.

In virtual space reciprocal support can be considered absent: each individual is practically alone and, to get support, he or she must return to real physical space.

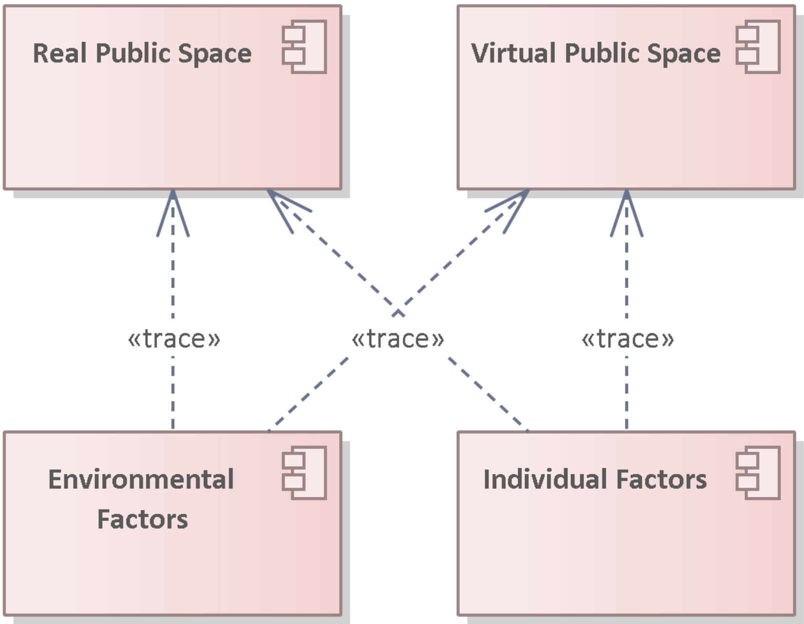

Figure 6 - Types of factors influencing safety and security in public spaces

Each one of these public spaces can be influenced by two kinds of factors: one type related to the environment (physical or virtual is not important) and another related to the individual.

2.3.2 The real public space

The real public space is the physical one that has been always intended as a place in the space. We will describe factors impacting its safety and security. But there is another public space that is the virtual one, generated by cyberspace elements.

2.3.2.1 Factors influencing safety and Security in real public space

Providing a public space is essential to the existence of a well-functioning city because these public spaces connect different areas of the city or create areas where people can meet.

In any case, the quality of the public spaces can be different and their attractiveness can be variable according to many factors. but the main factor that seems to influence this attractiveness and this quality es they sense of safety. but with the word safety it is commonly intended what in this document will be called security.

With the term safety we are intending risks to health coming from infrastructures or devices ordered by machines while with the term security, we intend the protection against risks to health and goods from malicious people.

In this document, as a general meaning, the lack of safety or security will always be reported as “unsafe” or “insecure”, for both the safety and security terms, without distinction. But in some cases, when a more specific indication is needed, it will be specified as “hazardous” meaning lack of safety and “risky” meaning the lack of security.

If people feel unsafe in some public space their behaviour and their sense of comfort will change and, for this reason, we have two understand how people perceive their safety. understanding this perception can tell a lot about the way people make use of these parts of the city. gathering this information can be very useful for urban planning purposes about public spaces, to design places safer, more secure and then more comfortable and popular.

Being aware of factors that people find most important about their safety and security in public spaces, will allow us to design a specific risk management methodology.

If a public space is perceived as safer it could be potentially considered as comfortable because if the individual perceives the area as non-threatening, this will positively influence the perceived level of comfort. but this is not enough because only safety end security is not enough to define a place comfortable. Sunlight and other elements concur with this feeling.

So, even if public space is open for everyone to make use of it, real leaders will be some groups of people that will use it and some other groups that will not use it. for the scope of this document, this is not important but it could be an improvement if the risks that are considered are also related to the real users of the public spaces.

For both safety and security, it has resulted that darkness is an unsafety factor. because the darkness is related to the season some elements of public spaces can be felt safe and secure during some seasons because of the longer duration of the light of the day while in other seasons they can be considered dangerous. an example could be a public park that in winter is considered unsafe because it is dark after sunset and in summer is considered safe and secure because the daylight ends very late. this time factor should be considered when analysing the safety and security of public spaces. the darkness factor as the seemed to be more impacting on women that are more sensible to it.

Another factor that influences safety and security, especially the second one, is the presence of security personnel or devices but this element can be even considered as a reducing factor for safety and security.

People can feel secure in a public space if there are enough, and visible, surveillance cameras or police and security personnel patrolling the area. Overdoing this can, on the opposite side, generate the idea that the area instead of being secure is unsafe because the presence of “huge” law enforcement agents and security devices can mean that they are needed. After all, without them, crime would prevail (Mehta, 2014). A further factor is the number of persons (visitors) present in the public space and security. If there are enough people within the public space, a kind of “self-securitization” can be considered by the people, creating the idea that each individual is watching the other. This means that the evident security made by agents and devices is not needed anymore and, often, even unwanted. If the public space is frequented by many people can then be considered secure and, partially, safe. If the people are too many, this can impact safety, because where there is a dense crowd there are some risks.

Another aspect of space safety and security is maintenance.

Maintenance of public spaces means both the cleanliness and the state of integrity/functionality of an area.

Having failed devices like elevators or having an unclean environment can be a suggestion that the place is unsafe or insecure. An example is reported in the images below taken at Rome Anagnina Metro A multilevel parking, where dirt and low maintenance level, with insufficient lighting, generates a sense of unsafety and insecurity.

Figure 7 - Example of lack of cleanliness at Anagnina underground station in Rome

Having evident failed or dirty security devices can be also meaningful in a risky area. An example is the SOS totems that are often available in public spaces like parks or parking. Often the lack of maintenance causes doubt that the device is working.

An important element that can impact the maintenance state of the public space is vandalism and a stog effort must be done to proactively prevent and repair vandalism in a public space.

Vandalism can be explained as graffiti or damaged elements in the public space area and is a very important factor that determines not only the aesthetic value of a space but also its attractiveness and the sense of safety and security. Vandalized areas are considered less attractive, less safe and less secure. People keep away from this area and reduce (for the above factor about the presence of other visitors) the overall safety and especially security.

The so-called “broken window” effect is easily applied in this case meaning that if vandalism is accepted, people perceive the area as dangerous while if there is no sign of vandalism, the area is presidiated and secure.

In the image below a building where the broken window effect can be seen: two identical buildings in the same area have different levels of maintenance and care. Simply adding grates to the rightmost and repairing its windows (that were broken too) has left them intact while the leftmost is continuing to be hit by rocks to break residual glasses. It should be noted that the grates are not so dense to avoid rock damage, simply no rocks are thrown because the building is intact.

Figure 8 - "Broken window" effect

There is, then a strong relationship between vandalism and a 'sense of danger' perceived by people because the observation of vandalism acts, like any other kind of violation of law, will lead to the concept that the space is unlawful and in people raises the idea that there is no control in such area and that they are vulnerable to be victims of crimes or to hazard coming from things. They are also feared to be witnesses of crimes and to be involved, in some way, in the crime risks. This fear of crime is a concept that has been induced and spread among people by media and movies that, often looking for sensationalism through dark and fearful stories, provide a narrative that is also empowered by people telling to other people.

These stories soon become urban legends or are strongly exaggerated, or even could be completely invented, but they still have a strong impact on the way people perceive public spaces so, in defining what impact on the sense of security, considering these dynamics is important.

People can manifest their feeling unsafe in many different ways, but when they hear from other people or from media or movies that something dangerous can happen in some spaces, they derive that the probability of happening in some parts of a city is more than in other areas of the same city and record in their minds about these ideas. When they are about to traverse similar areas they can feel unsafe and avoid the area.

Going deeper into the “broken window theory”, a badly maintained public space is related to bad people's experience in the area.

So, up to now, is evident that some environmental factors, which are determined when planning and building a public space, are essential for the perception of its safety and security. But not only for the perception of it: having streetlights or clear paths is an improvement in security and safety. Effective streetlights have a real impact on improving security and the absence of spaces for ambushes is determining better security. Also, the presence of security devices and personnel is a deterrent for crime and, then, an advantage in terms of security.

In a few words, the above factors are real security and safety improvement factors and not only elements that improve the sensation of security and safety. They are real tools for safety and security and, for this reason, will be included in our model.

But, first, the design of a public space is done following specific requirements, with a scope in mind. Then, as a second aspect, safety and security should be ensured not only in the normal operation of the public space but also in emergency or non-routine moments.

Also to be considered is that, often, some additional design elements are added to improve security and safety. For example, some benches have a design that does not allow people to lie down on them to avoid that some people can use them, for example, for sleeping. These security enforcer design methods are often used in public spaces that have reported the presence of homeless people, trying to move them away making their life impossible in such spaces. Even if this does solve the homeless issue, it is, again, on the line of the broken window theory because people perceive their safety and security as lower the more homeless they meet. It is clear that public spaces with graffiti or panhandlers are associated with a lack of maintenance and surveillance and then with a loss of security, first, and safety then.

Allowing vandalism, ignoring the presence of homeless people or lacking maintenance, induces into people the idea that any sort of illegal activities cannot be prevented or managed, putting at risk their safety. Cleaning green areas, putting trash bins and some other trivial activities have been demonstrated having an impact on the overall perception of security and safety.

But this perception is not only speculative, it affects also criminals and malicious people. If an environment seems secure, people will be discouraged from performing crimes, really making the place a more secure space.

Feeling unsafe and being unsafe are two different terms and two different concepts. Being unsafe means being at real risk of being the victim of a crime. It is important to underline that this is an objective statement, not based on the feelings or emotions of people. On the other side, feeling unsafe is an emotional concept, that could even be imaginary. Usually, it consists of many real factors and emotions. And it can impact the trust that one individual can put in other individuals. Because the main goal of public spaces is to offer a space for people to get together and socialize, the perception of fear of individuals in public spaces can put social cohesion at risk.

In the following diagram a main architecture of factors impacting safety and security in the public space and their relationships:

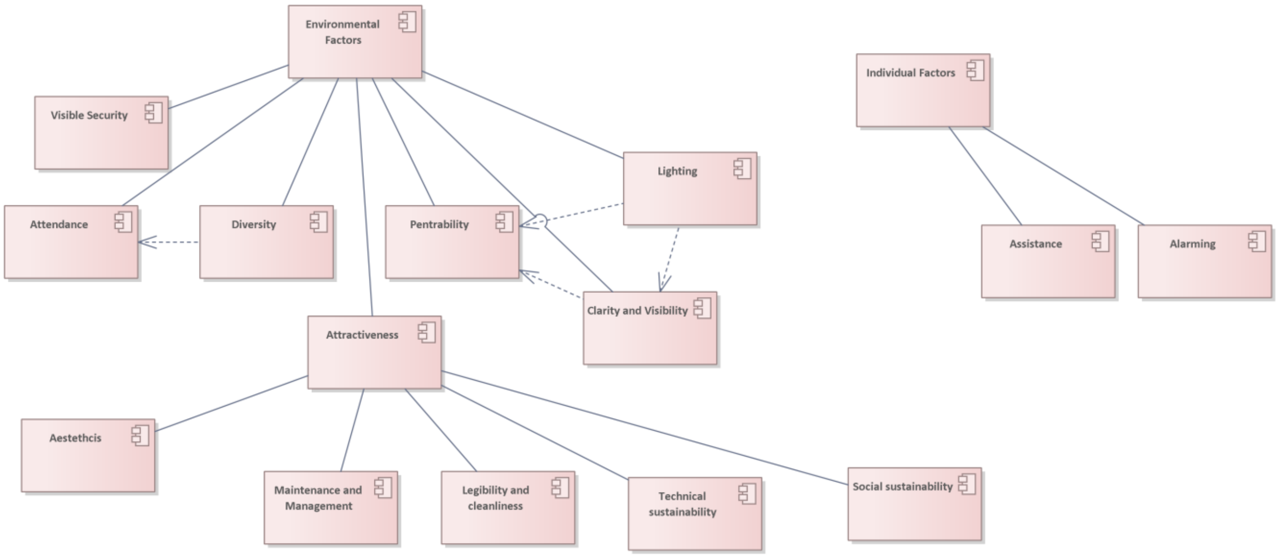

Figure 9 - Detailed factors influencing safety and security in public space

2.3.2.2 Attendance of the real public space

The number of people using, the same time, the public space seems to be the most important factor to ensure security. Many individuals present, at the same time, distributed in several places, also, their distribution over time (in different hours) has a serious impact on the users' security perception. Filling the public space at different times of the day and night creates a continuous, random movement that reinforces social control and positively influences effective security. In a few words, attendance enforces not only the individual feeling of security but also the overall, real, security of people in a real public space.

Crowding and attendance are two different features that both contribute to the safety and security of the real public space. Crowding needs to be balanced because excessive crowding will negatively influence safety and, in some cases, generate security threats too (e.g. terroristic attacks). In this study, crowding means the contemporaneous presence of persons while attendance means the continuous presence of persons during time.

To increase crowding and attendance is important to create a space that attracts many users. To achieve this result usually is preferred to have multifunctional space but, in many cases, also a monofunctional can be considered.

A monofunctional space is a place that is used by people only at certain times of the day (or on some days) and is empty on others. A multifunctional space, instead, has a relevant probability of being used at any time.

In a monofunctional space, security can be at risk at the empty periods, due to the lack of social control. In a multifunctional space, the continuous presence of people will act as a deterrent and make the place more secure. It also will introduce better control over space that can be:

- Direct (police, law enforcement, military personnel on duty, …)
- Semi-direct (guards, doormen, …)
- Indirect (neighbours, passers-by).

While direct control is based on planning made by local authorities, semi-direct and indirect control is tied to human activities and presence in space. Usually, a very frequented place has a relevant grade of a semi-direct and indirect form of control.

As already introduced above, technological devices, such as CCTV and SOS totems, can extend this control in the first two forms (direct and semi-direct), giving a more perceived sense of security. These devices must comply with specific rules in order not to infringe on the privacy of the citizens in the space. A specific section about visible security and virtual space will further detail this topic.

It must be considered that the ability of a smart city to reshape the space can increase its diversity, make it more attractive and, in general, increase attendance, often avoiding excessive crowding. So, this ability can be considered important to improve the attendance quality of the public space.

2.3.2.3 Diversity of the real public space

A factor that encourages the use of a real public space is its diversity. Diversity, it is meant that the space contains different elements that can attract people.

Diversity can be considered through two different perspectives: human activities diversity and human kinds diversity.

It is important, from the security point of view, to promote a space that contains different activities. Sometimes this will negatively influence security. For example, an alcoholic beverage shop along a motorway can increase alcohol abuse for drivers with augmented risks to the safety of drivers.

Usually, the contemporaneous presence of houses, shops, offices, pubs, restaurants, gyms, schools, museums, libraries, and similar elements should be easily reachable by walking each other. In this way, citizens will be attracted to attend the place at different times, making it very live and increasing its security.

From the urban design point of view, to develop a secure urban space, the concentration of different kinds of activities (housing, employment, recreation) in a given area should be empowered to attract different kinds of people at different times of day and night. In this way, paths connecting the various centres of activity will be generated if they are at walk distance. This "walk district" should not be confused with the "15-minute city": in the first case the driving reason is to increase security and there is no need to have all the needed services available in the area but only to ensure their attractiveness at any time of day and night (or for most of this time), in the second the requirement is stronger and aims to have all needed resources at a walk distance. For this research, the "walk district" is enough to ensure attendance and, then, security.

From a security perspective, it is important to avoid a strict separation between residential and recreational or working areas. Housing above shops or public buildings such as gyms, swimming pools or libraries in residential areas is advisable. It is also important to create rest areas, where people can meet, relax and talk.

Putting working spaces with residential spaces should be further explained. Some kinds of working places are not compatible with residential use: they can be noisy, smell or require heavy traffic. But some of them (like small and medium offices) are very useful from the perspective of improving attendance (and security). The first reason is that they are used in times when residential activity is at a minimum. A second reason is that their presence will attract people to get their services, and this increases the crowding of the place.

Dynamic urban furniture (e.g. fountains, children's playgrounds, …) can be elements for creating "movement" in a space, but special attention must be paid to their shape and materials because these elements should be kept clean and will require regular maintenance and this is another factor that influences security (and safety too).

As stated above, there is a second type of diversity that depends on the types of people. Usually, it is important to extend this concept to population age: older residents and younger families living in the same area usually reduce the feeling of insecurity experienced by elder people. Moreover, this generational difference in neighbourhoods enables intergenerational interchange reducing prejudices between them.

2.3.2.4 The penetrability of a public space

The penetrability (Valerio, 2020; Mahdi, 2016) of an area depends on the number of paths leading to the destination. A city is characterised by a high level of penetration if its layout allows citizens to go practically anywhere without too many deviations. Thanks to penetrability citizens can avoid risky places (dark, noisy, with unknown or potentially dangerous people, …) by taking a different path. This creates a positive sense of security and reduces low-security situations. In addition, it creates alternative escape trails to run away from danger. But penetrability has a negative face: the probability of arresting criminals after a crime decreases because of the number of escape ways.

To improve penetrability, various approaches can be followed. The most effective is the use of small buildings. Small buildings create more penetrable spaces. Because it is not possible to change the real distance between two points, a way to improve the penetrability is to reduce the "perceived distance", i.e. the distance that depends on the individual feeling when experiencing it. To reduce this distance, the journey must be as pleasant as possible. This travel pleasure can be improved by:

- providing secondary functions along the trail (for example empowering attractiveness, social control, activities, …)
- providing a clear definition and an evident structure of the area of travelling
- ensuring adequate lighting

2.3.2.5 Clarity and visibility of the real public space

The clarity of an area depends on its structure and its signage. A clear (i.e. evident, easily understandable, not complex) structure and clear signage increase the security feeling of users.

Visibility is a quality that is related to "seeing and being seen". The verb "see" must be intended more as "know" than "watch". The inhabitants of a place (in a broad sense, including those who work there or stay there for enough time but are not residents there) want to be able to know and to see everything that happens in their neighbouring. They will feel secure if other citizens are continuously informed about what is happening. So, the "seeing and being seen" concept should be interpreted in a broader meaning as that a sufficient number of people must be "present" (in the sense of being able, even if not physically present) in a given space to see and hear everything, having at the same time a proper level of proximity by which the people in an area can quickly know their neighbours and their nearby environment. This knowledge can be long-lasting for residents but can also be short-lasting for people in transit or that spend a small fraction of their time in the place.

Visibility is influenced by clarity, eyesight and level of lighting, but it is also dependent on human presence and social control.

Special attention, from a visibility and clarity point of view, must be paid to vegetation in the public space. Although it is important to include plants and trees in a public space, it is also important to keep them under control to avoid their volumes and their growth will not reduce visibility and clarity. Visibility can be reduced, for example, by volumes interfering with sight while clarity can be reduced by covering signals or paths or reference points that serve to clarify the structure. Vegetation must not interfere with "see and be seen" reducing visual clearance and obstructing sight, it must be designed and controlled to avoid hidden areas.

2.3.2.6 Sufficient lighting of the real public space

A well-enlightened area influences the perception of security of people. In particular, it helps in reducing crimes. Good street lighting, for example, reduces the number of road accidents, vandalism, burglary and bicycle, motorbike and car thefts. Street lighting is a key point in the process of making a place secure and safe, being an important deterrent for crimes. But also enlighting other kinds of public spaces is important, for the same reason. So, a well-lit public space is usually more secure than a dark one.

Another effect of lighting is improving visibility, resulting in the creation of a sense of ownership, a sense of control, among people attending into a public space, that eases natural surveillance and gives a positive image of the space.

Due to its importance from the security perspective (but also for safety) lighting must be designed to resist sabotage, to acts of vandalism, and its location must be chosen to avoid it being negatively influenced by vegetation, as already stated in visibility.

Lighting should only be installed where necessary to create a continuously enlightened area with a proper light level that must not be blinding. After sunset, the site lights should not be too strong because the human eye can adapt to darkness and too high intensity will blind. Typically, a low level of lighting smoothly distributed over the entire area will be adequate. The smoothness, in the sense of an area that has no sharp changes in lighting, is essential because switching through brightly lit and darker areas is not only unpleasant but also makes the surroundings less visible and defined. A typical minimal requirement is that people in a place must be able to recognise each other at a minimum distance of 5 metres.

Different types of public spaces can have different requirements for lighting but paths, especially those through parks or playgrounds, must always be illuminated.

In an open public space, the lighting must be well placed, pointing downwards and strongly fixed. In closed public spaces, the orientation of lighting can be different. In closed public spaces, illumination can be oriented to be indirect or can be diffused in various ways. Especially in open public spaces, lighting devices must be protected against vandalism with adequate materials and design.

Wrongly designed lighting can create a false sense of security and encourage people to move towards insecure places. For example, it is necessary to avoid the placement of lighting in an isolated area or along a path leading to a dark place. It is better to mark these paths (for example using fences) and avoid lighting them so as not to create a wrong sense of security.

Lighting, as any other device or element of the urban tissue, must be properly maintained. Removing or trimming vegetation that obstructs the light is mandatory but also put lights in a position (including height) where they can be easily maintained and replaced. To ensure quick replacement in the event of damage or failure, a specific sensor (able to communicate with maintaining company) or a telephone number to call in such cases should be provided.

2.3.2.7 The attractiveness of the real public space

The above-discussed qualities are key requirements for an area to be secure and, consequently, attractive, but other elements of urban design can strongly influence the feelings of security that fall in the attractiveness category.

Such elements are:

- **Aesthetics**. Citizens usually appreciate a mix of different shapes, sizes and patterns. Some universal elements often are applicable. For example, nature attracts, while wide areas are less attractive because they create a feeling of smallness and, consequently, insecurity. Special care for the aesthetics of the place should be provided to make the space more attractive.
- **Comfort**. People like to be in comfortable spaces. Climate considerations should be considered when planning public spaces. Noisy or “cold” places should be avoided.
- **Maintenance and management.** The maintenance state of an area largely determines the attractiveness of an area. Surely a clean place is more attractive than a ruined, fetid or abandoned place. Visible signs of destruction or damage, garbage and abandoned dwellings in an area will destroy its attractiveness. Even if the objective is not to create a perfectly maintained place, a cured and maintained space is essential for being attractive.
- **Readability and cleanliness.** These elements contribute to the citizens’ feelings of security. Public spaces where signage is partially or fully unreadable, due to dirt deposits or text erasure, seem abandoned and less secure. And it is also less safe because some of these unreadable signals could warn people about dangers and preserve their health. Public spaces blighted, broken pavements or sidewalks create a sense of lack of security among people. All these elements, together with others, suggest that the space is worn out or abandoned and influences its state of security and safety. It is necessary to quickly

repair damaged property, erase graffiti, remove illegal littering, and restore pavement coverings, sidewalks and plaster when damaged.

- **Frontage.** BoTryggt2030, for example, summarizes into nine qualities that are important to safety/security issues, already discussed before, such as lighting, urban form and mix of people. Which one of these nine characteristics is the most important is yet to be defined. Previous studies have suggested that light, open spaces, and access to protection, can be rated as the most important (Loewen et al., 1993). Also building façade has been demonstrated to be important for perceived safety/security because, for example, streets with a long continuity of a frontage have been perceived as less safe than streets with shorter continuity and many individual buildings (Harvey et al., 2015). However, there is still a lot to be researched on how such factors may contribute to perceived safety/security. Building frontages are believed to increase the sense of safety/security when there are frequent windows, doors and details, with visible internal uses on the ground floor level (Llewelyn Davies Yeang, 2007). Such frontage features are considered to add interest, life and vitality in a real public space. Today, proper frontage planning is considered one of the "best practices" and guidelines for both urban design and architecture, and local planning policies, require this kind of "active" frontage (Heffernan et al., 2014). Anyway, are missing large empirical studies on the effects of such active frontage on the safety and security perception of public space, as Heffernan et al. (2014) wrote. They are quite critical towards the positive benefits of active frontage, both theoretically and in practice, but their research is missing real evidence about it.
- **Technical sustainability**. All urban furniture (benches, street lights, garbage bins, etc.) must be sufficiently resistant to survive not only its intensive use but also to acts of vandalism. Urban furniture is often the main target of destruction, vandalism and graffiti. In a few words, street furniture must be selected according to its ergonomics, robustness and ease of maintenance.
- **Social sustainability**. Social stability and cohesion in a neighbourhood mostly determine the feelings of security of its inhabitants. If residents assist one another and get to know each other, the feeling of security will be increased. Although residents do not need to have particularly strong bonds, it is required that they should be able to rely on each other. For this reason, their involvement in managing and living in their neighbourhood should be encouraged.

2.3.3 Individual factors influencing perception and the real level of safety and security

An important aspect of real public space interaction is the experience it provides to people. The success of a real urban public space often implies, as stated above, a space composed of comfortable, connected, active and accessible places (Heffernan et al., 2014). Feeling safe and secure is a crucial part of the personal experience in these real public spaces.

As already introduced, people must not be focused only on the risk of an individual's risk of being a victim of a crime, but another important concern should also be how each citizen perceives his or her safety. Perceived safety/security refers to an individual's experience of "the risk of becoming a victim of crime and disturbance of public order" (Uittenbogaard et al., 2018). The risk of becoming a victim and the experience of it can be equivalent to the individual perspective (Halbur, 2010; Uittenbogaard et al., 2018).

Perceived safety/security has relevance in both large and small-scale cases. Some scholars have raised it to some sort of "spatial justice issue", introducing the individual's perception of safety in the discussions of what can be called a "just" public space (Haas & Mehaffy, 2018) arriving to define it as one of the universal rights of whom that live in a city (Harvey, 2008). This safety/security perception can be related to specific cases (e.g. "safe mobility" 2014, Ceccato) or general cases. And this is not only limited to the perception of safety/security but also to its real level of risk.

Many individual factors influence people's perception of security and safety. But these factors can also influence the real level of security. In this document, these factors will be analysed under two different perspectives: the citizen using the real public space (referenced as "users") and the citizen in charge of enforcing safety/security (referenced as "guardians").

First, it is important to remember that when making behavioural decisions (i.e. choosing the right behaviour to be implemented), individuals will very often decide based on their estimates of the risks associated with the various possible behaviours they perceive. Then, how citizens perceive threats will influence their responses to critical situations. Usually, it is not possible to analyse all the information that is needed to form a complete assessment of risk. Then, people take shortcuts in the decision-making process, by using less information, generating a processing model affected by biases and also using heuristics to simplify the task (Kahneman, Slovic & Tversky, 1982).

These biases and these heuristics can affect risk perception, evidencing that people generally have a wrong perception of risk (Lichtenstein, Slovic, Fischhoff, Layman & Combs, 1978). Since risk perception can have an impact on logical decision-making, understanding these factors is essential. In a few words, people who accurately perceive the risks are more likely to act appropriately. Therefore, it is mandatory to fully understand those factors that can alter accurate risk perception.

From a small-size perspective, perceived safety/security has immediate implications for the person. Most people try to minimise their perceived risk of becoming a victim of a crime or of an accident. Regarding the risk of being a victim of a crime, women very often, adapt their activities in a public space (for example avoiding unsafe places or rotating their ring to hide the diamond on it). Although these adaptations do not always imply a decrease in quality of life, such kinds of behavioural adjustments and restrictions, can cause emotional feedbacks that can degenerate into paranoia or fear, ending in negatively affecting life quality (Jackson and Gray, 2010). Some researchers have suggested that this phenomenon can decrease psychological well-being, reducing collective trust and cohesion (Jackson and Gray, 2010).

In the work of creating places with a high level of perceived safety/security in the urban environment, urban planners and designers are considered vital (Mehta and Bosson, 2018). The urban development concept of BoTryggt2030 is a Swedish contemporary initiative, which can be seen as a response to the call for urban planners and designers to get involved in perceived safety issues. BoTryggt2030 is currently developing guidelines for environmental design in new and existing built environments (BoTryggt2030, n.d.).

Because resources are limited and it is needed to plan for a wide range of citizens' needs (Mehta, 2014), it is mandatory to prioritise elements connected to perceived safety/security. To achieve this result is imperative to understand what aspects are important for the perception of safety/security to enable the right design to produce the desired high level of safety and security.

Although there is a lot of research on risk perception in general, empirical studies examining individuals' perceptions of risk regarding safety and security are missing.

Some authors have inferred perceptions of safety and security risks starting from research made in other areas. For example, Pattinson and Anderson (2007) have suggested that such perception is often influenced by a person's mood, recent media news, and an individual's experience. According to other authors, the same inferred approach resulted in stating that several psychological, social and cultural factors can also affect the way that people perceive risk (Bener, 2000).

In the following sections, the factors that influence the individual perception of risk will be discussed.

2.3.3.1 Availability heuristic factor

One of the most common biases in risk perception is called "the availability heuristic". This prejudice is based on the idea that people tend to estimate the frequency or likelihood of an event depending on how easily they can bring an example to their mind (Slovic, Fischhoff, & Lichtenstein, 1979; Tversky & Kahneman, 1973). This heuristic is also related to media news and the level of coverage given to some events because highly media-evidenced events are also more easily recallable to memory. It is important to underline that many studies have shown evidence that large media coverage of events where a risk has become a real case, has little or no correlation with the actual frequency of such risk, and this implies that the probability that people will have an inaccurate perception of the risk will increase (Lichtenstein, Slovic, Fischhoff, Layman and Combs, 1978).

On the other side, the frequency of very common but chronic risks, which generates over time (e.g., heart stroke, cancer, …), have a lower probability to be largely reported by media, and this causes, due to the availability heuristic, an underestimation. The same behaviour can be observed in common crimes, e.g. pickpockets, that are underestimated.

On the contrary, rare but acute risks, which usually appear suddenly and with large and dramatic coverage (e.g., murder, building collapse due to gas leakage, …) are overestimated as risks.

Recently, COVID-19's huge media coverage has led many people to continue to wear protection devices and ask for diagnostic tests even when the emergency was officially completed. This was another example of overestimation of risk due to massive media coverage and demonstrated that the availability heuristic can be long-lasting in individuals that have been "sensitized" about some risk, like a sort of post-traumatic stress.

The availability heuristic is most likely to lead to an underestimation of risk and this should be considered: to ensure security/safety the risk must be minimised with little or null confidence in the user's risk estimation and this means that real public spaces must be intrinsically safe and secure.

2.3.3.2 Optimistic Bias

Another kind of bias is the optimistic bias. In this case, people do not believe that they are at risk.

This bias is very frequent in information security. In this context most users consider as not valuable the information on their computers and, consequently, that they will never be attacked by a hacker. This bias does not even consider that, often, attackers aim at generic individuals to achieve access to the real target systems.

The optimistic bias is also present in conditions where people think that a warning message will be provided if they are vulnerable. In this case, people will often believe that if they do not see these warnings (e.g. the antivirus alert), they are not at risk. The optimistic bias results in usually an increment in the security risks due to underestimation of the risk made by users. This underestimation of the risk can cause missing procedures or patches because considered exaggerated. With optimistic bias, people underestimate the probability that their behaviour allows a security breach.

2.3.3.3 Personal Level of Control

Individuals have been found to also have idealistic confidence about risks if they perceive that suck risks are under their control. For example, if a person considers his or her actions on their smartphone as actions completely under his or her control, can be considered risks are improbable. In this case, the effect will be the same as the optimistic bias: underestimation that can lead to missing procedures or patches. A category that often falls into this level-of-control behaviour is that of car drivers: such individuals think that driving is completely under their control and have high confidence in their skills. This also happens to skilled people working and bypassing safety procedures.

2.3.3.4 Personal Level of Knowledge

A person’s lack of knowledge or training can cause excessive exposition to risk. Proper training, periodic recall and adequate practice are very important to avoid risks, to both safety and security. Without proper knowledge, it is hard to understand a risk. This is particularly true of some risks, where people may need specific knowledge to understand all the implications. Without such knowledge, risk perception, decision-making and risk management can be compromised. For example, reusing the same password on different systems is a typical case of a lack of knowledge.

2.3.3.5 Risk Homeostasis

In risk homeostasis, there is different behaviour from the person if the risk is known as being compensated. An example is that if a user knows that antivirus software is running on the system, then he or she will consider it less risky to open unknown files coming from e-mail (the user thinks “if the file is dangerous, the antivirus will block it and warn me”) and then gets infected if the malicious software is not yet in antivirus database. In a few words, people tend to lose prudence if they know that the risk is being managed by some device. And this is, again, an underestimation of risk.

2.3.3.6 Cumulative Risk

This risk derives from the fact that small risks if prolonged in time (or along another dimension), may become very risky. A simple procedure violation that introduces a very small vulnerability or hazard might have no practical impact on the risk but if this violation is repeated by many users and for enough time it can become a big risk. The cumulative risk bias is simply derived from probabilistic considerations: the probability that one event happens once can be very small but if we consider it as a set of repeated trials, the probability sums, accumulating up to an intolerable value.

2.3.3.7 Omission Bias

In people's minds, usually, an omission is considered more acceptable than a deliberate action. Thus, a person is more prone to omit some behaviour than to directly act. A famous Yahoo data breach happened because no one investigated small security anomalies (i.e. security incidents) that happened. Essentially, thanks to omission bias, inactions are considered (more) legitimate than deliberate actions, and this negatively influences risk.

2.3.3.8 Familiarity

Familiarity with risk can also influence its perception: exposure to a risk for a long time can introduce in the person that the risk is lower, causing an underestimation of it.

But also, the opposite is sometimes true. Some people are more likely to follow safety or security procedures when using products or brands with which they have familiarity. In this sense, this can be considered another case of level of knowledge.

2.3.3.9 Framing

The description of risk is called framing. It can be in the form of loss or form of gain. For example, saying that the probability to die after medical treatment is 25% or that the probability to survive is 75% is the same concept but it has been expressed with different framing. Exposing a risk in terms of loss will usually cause a repulsion to the risk while proposing it in terms of gain will cause an inclination to the risk. In the above example, conducted by Slovic (Slovic, 1986), medical treatment had the probability of dying at 32% and surviving at 62%. Proposing it in terms of gain (surviving) let it be accepted by 44% of participants. Proposing it in terms of loss (dying) while having an acceptance rate of only 18%. So this means that risk communication is very important to improve the behaviour of the involved persons.

2.3.3.10 Personal Variables

Many personal variables can affect the risk perception of an individual and, consequently, change the behaviour in deciding if follow a risk-taking or risk-avoiding approach. Personality and cognitive style are the two most important. Some scholars have categorised them (Lion & Meertens, 2005) and, consequently, individuals, according to their attitude toward risk. In the study made by Lion and Meertens (2005) they found that there were considerable differences in information analysis between risk takers and risk avoiders (they considered the risk related to the assumption of a drug).

A very critical category (Horvath & Zuckerman, 1993) is one of the so-called "Sensation Seekers", i.e. people who love the risk due to the emotions (sensations) generated by it. On the other side of the range, some people are more focused on risk avoidance and that prefer to follow the rules, These people have a higher probability to follow procedures and reduce the risk (Lion & Meertens, 2005).

2.3.3.11 Social Variables

Belonging to a social group can also influence individuals' behaviour. This influence is due to social variables like group rules or group psychological pressure. If a person has a predefined behaviour, for example, it follows rules and procedures and avoids risk, putting it into a group where, on the contrary, the risk is taken, will influence that person that will probably behave more as a risk-taker than a risk-avoider.

An example, (McIlwraith, 2021), is password sharing which can be considered to be a sign of trust in a colleague. In such a social environment, refusing password sharing could be seen as a lack of trust and subjected to psychological pressure.

Another social effect is that as the number of present people increases, they will move their responsibility onto the others with the effect that, in large groups, individuals may lose personal responsibility perception for safety or security.

2.3.3.12 Summary of Factors for real public space

In the following table the main factors influencing safety and security in normal conditions are evidenced:

Table 4 - Some of the main factors influencing safety and security in public space

Factor	Safety	Security	Further variables
Darkness	Influenced	Influenced	Time of day, season
Visible security	Low influence	Influenced	Can have an opposite effect
Crowded place	Low influence	Influenced	Reduces or removes the need for visible security
Cleanliness	Influenced	Influenced	
Maintenance	Influenced	Influenced	

As stated above, security and safety can be considered also in extraordinary situations like emergencies or critical situations. the difference between emergencies and critical situations is that in emergencies there is an urgency caused by the collapse of some vital system or by the happening of a natural disaster. In critical situations usually there we are the failure of some systems related to security and this increases the probability that a crime or an injury could happen.

For example, a collapse of a building will cause an emergency context while the failure of night lights in a street is a critical situation.

From this perspective, while the emergency cannot be managed in a short time, the criticality can (e.g. quickly detect light absence and activate a fast response maintenance team or increase police patrol in the area).

Some kinds of emergency can be caused by malicious people (e.g. terroristic acts) that create conditions for damaging people (e.g. a bomb in a mall) or as a diversion. The same scope can be realised using criticalities (e.g. false sudden sickness of a man). Sometimes these actions are created to inflict further damage to the responders and to curious people (e.g. a second explosive device that explodes ten minutes after the first and in the neighbouring).

In the following table, a quick resume of insecurity and unsafety is summarized:

Table 5 - Actions or events that generate an insecure or unsafe condition

Event	Description
Crime damaging values	Actions that, intentionally or not, cause damages to goods, properties or other tangible values without hurting people
Crime damaging persons	Actions that, intentionally or not, cause damage to people
Accidental emergency	An accident that, after having caused damages to people and/or values, can have further impact generating a high risk of serious damages to people of values
Natural disaster	A natural event that, after having caused damages to people and/or values, can have further impact generating a high risk of serious damages to people of values
Terroristic attack	Terroristic action (bomb, shooting, …) that, after having caused damages to people and/or values, can have further impact generating a high risk of serious damages to people of values
Criminal attack	An attack made for various reasons (usually money) that aims to steal or damage values or to injure or kill people
Emergency diversion	Emergency created as a diversion to distract law enforcement and other organisations from the protection of another target
Critical diversion	A diversion generated driving something to a high-risk state to cover operations towards another target,
Unforecastable criticality	Criticality that cannot be forecasted (e.g. asteroid hitting the city)
Forecastable criticality	Criticality that can be forecasted (e.g. risk of flooding from a river after long rain)

2.3.4 The virtual public space

All these results have been applied to the generic concept of the public space but it was implied that it was about public spaces in the real, physical world. In the next section, this concept will be opened to a completely different public space that is made in cyberspace, meaning that it is a virtual space where people can interact in a way that is similar to the physical, real space.

This kind of virtual public space exists in any kind of city but is ubiquitous and very advanced in smart cities.

Last but not least, is the ability of the Smart City to autonomously reconfigure the space, especially the public one. This ability will introduce a further degree of freedom in the RAFT framework and will be discussed in the next section about the public space framework.

2.3.4.1 Virtual places

In the last few years, an incredible set of evolutionary effects have happened and become reality: communication systems and simulation technologies have radically changed the common perception of public space. In environments where they succeeded in deeply integrating technology into daily life, the typical social behaviours related to space practices have defined new elements, and have defined a new generation of public space, that is a virtual public space.

Although this change can build new kinds of societies, that have no chance to be experimented in the real public space, it also has increased the fragmentation of the urban space (space in a wider sense, now). This fragmentation is more evident day by day, year by year, after the deeper penetration of digital technologies into people's behaviour and lifestyle.

This condition enquires urban planners and designers if such fragmentation is a real issue that must be adopted in new urban planning and design methodologies or not. Does it make sense to think of this space from a holistic perspective and then develop a new theoretical framework that integrates both virtual space and real space? Does it make sense to define a speculative theory about the relationship between the real public space and the virtual one? These questions can be put both in a generic city and in a smart city context. Even a normal, traditional, urban context can experience the presence and the impact of virtual spaces.

What is needed from this new, holistic theory, is not a technological approach but a social and anthropological perspective to ensure that future urban planning and urban design will consider, if needed, such new forms of public spaces.

At this stage of this document, is important to decide whether urban planners and designers should consider virtual public spaces in the context of a smart city, or not. So, the discourse will be limited to the public spaces and the smart city contexts, skipping all other cases (e.g. normal cities, other kinds of spaces, and more). So, for this section, the purpose is to investigate this need for virtual environments that can become (virtual) public spaces.

Metaverse, cyberspace, and e-agora are examples of terms that are very frequently today to be found in both popular and scientific literature. Unfortunately, most of the time, these terms are used in a way that does not allow a real understanding of what it is below the surface. This happens even in contexts (i.e. scientific or academic literature) where such kinds of concepts should be analysed in detail, with formal definitions. The reason for such a rough understanding is their interdisciplinarity and abstractness. Their relationship with space (and with time also) is deceptive. When handled by urban planners and designers, people used to working with real space and time, often see them as some kind of toys far away from reality and are considered as not having a part in the real, concrete world. To understand the impact of these elements on reality, we must shift to social sciences. Spatial disciplines like urban planning, architecture, geography and more are too focused on tangible elements in time and space that find it hard to connect such virtual worlds with the one, unique, real world. In a few words, they are very far from the acceptance that the information age is "real". This moves virtual public spaces behind the stage, in the background.

To drive change in this mind approach is important to understand how virtual space impacts their specific domain of analysis, especially in public places. These terms (public and space) have already been discussed but it is important to make now some recalls to let the discourse flow proceed smoothly, with no interruption or conceptual jumps.

Graham and Marvin (1996) in their paper about telecommunications and the city, define a first comparison of attributes of urban spaces and telematic spaces trying to better understand the elements of the virtual space. Their study can be summarized in the following table (Graham and Marvin, 1996) where electronic spaces and urban places are connected in a synoptic form:

Table 6- Synopsis between physical and virtual public space

Urban Places	Electronic Spaces
Territory	Network
Material	Immaterial
Visible	Invisible
Actual	Virtual/Abstract
Tangible	Intangible
Embedded	Disembedded
Fixity	Motion/Flux
Euclidian/Social Space	Logical Space

The first, immediate, difference between the two columns is the level of concreteness (in the sense of being made by tangible elements) of their elements. This tangibleness leads to the observation that the determination of an urban place is a physical process where, every component can be defined in physical, real-world, tangible and concrete terms. By this physical, concrete form, the requirement to describe, detect and identify a specific place is satisfied.

These features are reflected in the people's behaviour in their relationship with the real, physical place. Thanks to behavioural psychology, humans perceive different states if they are outside or inside a place. And this feeling is crucial in the perception of a place. Also, the depth of the space is another perception related to the place (i.e. the perception of being in an authentic space). In this sense, all physical thresholds are to be considered structural elements with the scope of varying spatial schema (Seamon and Sowers, 2008).

Now the question is if one should look for something like these physical structures in the virtual space is the question to be answered. The current structure of virtual spaces makes this possible. And also, gives a new sense to look for such elements in virtual space, letting this search logical. Why? Because the human perception of the virtual public space is similar to the one of the real public space. Let's consider, as an example, a modern meeting room (like those available on Microsoft Teams or Zoom) where users can meet in a simulated space and discuss anything, looking at them and even exchanging (virtual) items, like documents, images, audio and videos. In this case, the technological progress in virtual space has reached a level and a capability that architectural metaphors of the real world can be replicated.

The advent of digital twins, very common, pervasive and detailed in smart cities, has provided two-dimensional or three-dimensional architectural elements or metaphors. This implies that can be observed the accurate reproduction of the physical world but not only. Today is possible to conceive a new kind of spatial experience that implies a well-known sense of place but that cannot be repeated in reality. Some of these features are provided through the so-called augmented reality but, in any case, virtually built environments can be developed into forms with specific, often peculiar, spatial languages. The mimic provided by such virtual environments leads to the sensation of being in a place. These feelings are translated by technology, by a new form of understanding of such experience, and reach a level that allows the use of such architectural languages.

A Digital Twin is a virtual representation of an object or system, connected to it throughout its life cycle.

The Digital Twin is updated in real-time by data collected by sensors connected to the physical asset and uses simulation programs, machine learning and reasoning to provide actionable information about the asset and to develop predictive models of future performance and reactions of the subject to certain conditions.

In simpler terms, the digital twin is a highly complex virtual model, which is a replica of its physical counterpart. This can be anything from a car to industrial machinery, to an aeroplane, a bridge, a building, and so on.

Although the terminology, as we shall see, has evolved, the basic concept has remained the same. It is based on the idea that a digital information construct that pertains to a physical system can be created as an entity in its own right.

A product's digital twin is an invaluable source of information for engineers and operators. Information is obtained through the combination of several technologies, from the cloud to the Internet of Things, to Artificial Intelligence.

The Digital Twin is connected to the physical product through various sensors placed on areas vital to the functionality of the object. These sensors produce data on different aspects of the physical object's performance, from temperature, energy used/produced, weather conditions, and so on.

The analysis of this data, combined with other sources of information, allows us to understand not only the behaviour of the product but also to predict how the product will behave in the future.

This continuous flow of information allows the digital twin to run simulations, detect and analyze any product performance issues, and study possible improvements.

The data flow between the physical product and its virtual twin works in two directions: the Digital Twin receives data from the sensors with which the physical product is equipped, to then return insights.

Initially used for the management of single assets, Digital Twins are now also used for the management of complex systems, such as smart buildings or Smart Cities, for example.

Therefore, it is not a virtual replica of the building, but rather a complex model of how people and processes interact with environments.

Indeed, the digital twin of a smart building brings together systems made of different technologies, IoT sensors and third-party data. Information that is then contextualized with information on processes and people, obtaining a dynamic digital replica.

The benefits are numerous. The digital twin follows all changes in the real building and dynamically adjusts itself in case of recorded performance differences. Thus, for the entire building lifecycle, the performance predictions generated with the virtual twin represent an accurate basis for well-informed decisions.

This allows to efficiently manage various City systems (such as traffic or energy systems), as well as analyze the dynamic response of the City to changes in occupancy or energy supply.

Furthermore, data analysis makes it possible to plan predictive maintenance interventions and thus improve the City's performance and, consequently, of its Stakeholders.

But urban planners are not only concerned about space by itself: they are often concerned about social dynamics or, talking about a city, of its politics, in its original etymological sense of being concerned about solving the issues raised by the city. So, when the social context is considered, the concept of public space that is the focus of urban planners and designers has been described by Habermas (1991) as "a domain of our social life in which such a thing as public opinion can be formed". A necessary condition to this description is that people are free to meet and express their opinions. Thus, the formation of a public opinion is possible only if some conditions are met: there is a group of people and they handle a discussion somewhere (Habermas, 1994). Although Habermas states that such a discussion must be "rational", today it is clear that the discussion can also be based on irrational elements but, in any case, Habermas understands that people meet together to form such a public and use informative sources like newspapers, journals and others.

2.3.4.2 The socio-political impact of virtual space

In this context, the question of whether a virtual environment can provide a public space can receive the first answer. The virtual environment can enrich the socio-politics discourse like the Habermas concept? There is no doubt that the Internet, as an example, is capable of generating a series of relationships that create a new virtual social geography. There is no doubt that the Internet has already provided enough kinds of virtual social spaces through social networks, virtual communities, teleconferencing, and e-mail. And this is simply a new technical substructure that enables new modes of socialization. With the growth of telecommunications technologies, from the one-to-one telephone, through the one-to-many television, arriving at the current many-to-many available since the good, old, Web 2.0, the mapping of virtual structures over real-world structures has increased reaching a peak. Today, computer-mediated communications have generated an interactive process that flows through space and has enabled new social spaces where these technologies are used to leverage their power to overcome both spatial and cardinal limits. The cardinality of the relationships mediated by a computer is now many-to-many, and more effective and efficient even than the one of a real agora. Space limits are overcome through remote connections with high-quality audio and video real-time streaming.

But this power raises other questions. “From great power comes great responsibility” Spider-Man teaches. And the decentralized structure of virtual spaces implies the possibility to redefine democracy due to a change in the social power configuration of virtual communities. Is this real? Is there a risk that some communities can be excluded from such power? The generational digital divide (or even the geographical one) can impact democracy and sociality? Although the current development of ICT systems seems to be helpful to implement direct democracy at the local level, many elements related to presumed televoting frauds or fake news quickly spreading through social networks have raised the alarm that such technologies imply a real risk.

About this, two parties can be considered: those holding an optimistic attitude thinking that this can be an opportunity for a new, utopian, democratic community, and those criticizing such a possibility, mainly because there are economic and cultural inequities that can unbalance them. Another aspect against this sort of direct computer-mediated democracy is that, as social experience demonstrates, people will interact with a virtual voting environment with less seriousness, increasing the risk of a vote given on the pressure of the emotions instead that on rational discussion. Flamewars on social networks are very frequent and the interactions between users are evolving towards low-quality arguments.

Today, it is evident that is mandatory a qualitative analysis of ICT impact on social life rather than a quantitative one. The smartphone, for example, (but before it was the television) has been accused to be a cause of social decline, because it isolates individuals from one another, erodes social consciousness and leads to an a-politicisation process that makes individuals agnostic about society, politics and, as a consequence, democracy. Consequently, virtual environments can be an issue in such socio-political aspects.

Virtual (electronic and computer-mediated) spaces are seen as post-industrial space that has been designed to support consumption-oriented activities. They are seen as a big marketplace where, every instant, are provided consumption and provision of services. This perception exists since the beginning of the XXI century as the Internet spreading was evident and can be extended to all virtual places created through it or, in general, through ICT. But, over time, the impact on society and politics became evident generating a kind of transformation that appeared directly in the social structure. In such a context, virtual spaces have been accepted as the reproduction of social dynamics, and are perceived as a powerful tool for “losers”, in the sense of those that are oppressed or threatened by their opponents, as happened with the printing power of the press, that was an effective weapon for direct and even clandestine campaigns.

This concept of the Internet (ad the virtual spaces) as a new tool to improve democracy, speech freedom and sharing knowledge has been recently in the eye of the storm: recent COVID-19 pandemics has caused a strong debate about the so-called “fake news”, often carried by virtual spaces. But also Elon Musk’s Twitter files have demonstrated the influence of the FBI, Big Pharma and other centres of power to alter the virtual space content to change the narrative flows to pursue a specific scope.

If public virtual space is a place for political, social and informative discussions and not only a new form of marketplace, it is mandatory to take into account the profiles of its users, which should be the reflection of contemporary urban life. But this urban lifestyle is based on the existing communication culture and follows its evolution. So it should be evident the influence of such a cultural substructure in the dynamics of the virtual space.

The virtual communities of the Internet have the original electronic spaces into social spaces where the matter is the relationship based on the content of the message as a media (text, picture, video, …), but not on commercial relationships. In this sense, virtual communities fit with the definition of the public sphere due to their non-commercial context, defining a different kind of interaction that happens quite totally in the virtual sphere.

Although these communities have been born on the Web, for example, they sometimes move to the real world. An example can be the anti-globalist movement. This movement opposes globalisation another philosophy that is often called “glocalization”, a mix of both local and global. Other times, the same movement refers to local space only and they are often called “sovereignists” if their “local” is a specific country. These movements are created by different socio-cultural groups that construct their political movement in a virtual space (usually a social network) and then expand their activity including the physical space. This behaviour leads to the fact that they are performing their acts in a form that gives a social or political concreteness to space in both forms: virtual and physical.

Within the process of globalization, with the percentage increase of ICT in social life, the political context of locality has changed. The spaces of communication have spread all over the world, connecting borders that, in the past, were remote to each other. These new spaces are now contiguous, but they are virtual spaces. They are adjacent in the social sense and have allowed movements to become global when they started as local. The “glocation” term has been coined for this alternative way of globalisation: a compromise between local and global that goes beyond the two poles of localism and globalisation, arriving at the motto “think global, act local”.

2.3.4.3 Identity of virtual spaces

A place can be distinguished from a space based on its identity. Identity is provided by the users of the place. According to Tuan, a place is a kind of object where values are concentrated (Tuan, 1977).

The “meaning” of the place is built through a reciprocal and embedded process that involves both the single human being and the collective intelligence of the users of the place.

So, to evaluate virtual spaces by comparing them to the public place it is necessary to understand how, in virtual spaces, and whether, meaning is generated.

According to Tuan (1977), emotions and thoughts are determined through the individual experience of place. Experience can be considered a result of systems of sensations and perceptions. So, to have a complete experience, the optimum is to have a perception mediated by the five senses. In the virtual spaces, the perception is limited to view and hearing, because these are the two most diffused channels. Although today other forms of tactile interactions are emerging, taste and sense of smell are far away from being available. This limit can indicate that the virtual environment cannot be similar to physical urban space. Due to this limit, following the Tuan framework, the virtual space cannot be considered a meaningful place and, consequently, something like a physical place.

Other scholars consider that there is a close relationship between community and place. In this idea, the foundation is that collective action is the one that provides meaning. In a few words, the meeting of people and their actions creates a socio-spatial interaction. This causes that identity to be built among people sharing the same space, in the sense of the same portion of ground. This identity defines places that can be referenced as public places.

An important issue to be discussed is the stability of the place. According to Lefebvre (1996), place is something still, opposed to a movement, and it is different to what space offers. Lefebvre states that a place allows people to form an “oeuvre” which is the work provided by the collective identity. This oeuvre is realized within the rhythm of daily life, upon which all political projects impose their rhythm and practices (Lefebvre, 1996). Even if a virtual environment can be something very different from a political project, it is evident that it generates new practices, new habits, and new rites both on social, political and cultural sides. This means that a virtual community could be considered some sort of generator of oeuvre. But is this true? Even if the freedom and the power perceived by the members of a virtual community can be an illusion in many cases, they can change the individual’s behaviour in reality. In this sense, they can impact reality and provide a sort of stability, but in physical space only. Does this stability persist in the virtual space?

2.3.4.4 Is urban space evolving through virtual space?

At the end of the XX century, the process of globalization became evident. Developed countries decentralized their production functions to underdeveloped peripheral countries. In this process, a new kind of worker emerged, the so-called “white collars”. It was not a virtual process, but it showed many physical attributes and urban space in the city has been influenced and constrained to adapt to new dynamics generated by the fiancé capital mobilisation. A part of the ICT, usually infrastructures, became a key factor in the shaping of urban form. An example is that decisions about the location of new industries should have good accessibility to optic fibre connections. Although elements like 5G and Musk's Starlink will probably change this constraint (impacting again on urban planning and design), this is still a simple but good example of what we are looking for in our discourse.

The traditional definition of the city is gone. Today, a city needs to be smart and this requires the availability of an ICT physical infrastructure that allows both wide bandwidth communications and high-speed processing. It is also needed a significant number of tech-friendly workers which means technical schools of any grade, research infrastructures and development facilities like universities. But this is not enough. Such workers and entrepreneurs must be attracted by the place that should be suitable also for their families. And this means direct and easy access to broadband communications, and efficient surface and air travel services. Also, human resources management has gained importance. In this sense, smaller cities have become very important not for their extension or number of people but for the number of PhDs and universities, because they can provide support to such new communications craving industry.

This new trend of industry concentration planning, and its impact even on residential and service areas, has also altered the route of economics. When ICT changed the importance of some economies of grouping, immediately the planners altered the usual patterns at any detail level. Today's request is for good ICT facilities and small office spaces. With teleworking, the use of large permanent offices is dramatically reducing. Working teams in companies are often virtual teams. And team members are often far from the company, at their homes or offices, causing no parking, transportation, accommodation or food services to be needed. Consequently, no or smaller infrastructures for these services are needed. Companies that are based on intensive information processing, which were usually found in the city centres, now have moved to suburban or even, rural areas, wherever they have a good connection. The new patterns have caused, in some cases, city centre degradation. Some suburbs have become very developed while others are degraded, depending on their attractiveness for such new sorts of patterns.

So, a new form of competition between cities, both at the national and supranational levels, has arisen and governments had to improve the city image to attract these patterns. So, local governments are trying to provide good ICT infrastructure and overcome the fragmented structure of the city. Regeneration and redevelopment of city centres have become key factors and are based on two main strategies: local cultural level increase and new ways of interaction with the global system. Moving productive functions to the periphery has assigned to city centres leisure and art, reformulating urbanity towards city centres that have more publicness than in the past.

People clever in using ICT for their work will have more spare time for entertainment activities. More efficient transportation systems have decreased travelling time, leaving more time for recreational activities. So there is a deep change in behaviour. This means that the planning and design of space to support the increase in leisure time activities is becoming a new challenge.

In a few words, changes caused by ICT with the generation of virtual spaces where work is done or organised have led to a change in urban planning and design issues. But this topic will be discussed in the next section.

2.3.4.5 Is there a new mission in urban planning and design?

The participation issue has always been a key strategy in urban planning. The current crisis of representative democracy and other issues in terms of political participation has caused many concerns about it. Today an individual is more oriented to avoid participation or change it into violent forms (riots, rallies, …). The contrast between building and dwelling (Sennet, 2018) has led to a loss of participation. In this sense, the participation needs to be reinforced and even empowered. Virtual spaces, on the one side, increase participation but, on the other side, they accentuate individualism and poor results. It is, then, mandatory finding for new ways of planning making it part of the democratic life (and participation in general) of modern societies. This means that, without distinguishing the concepts from the methods, some guidelines on how to act must be sought out, redefining, if needed, some aspects of urban planning and design professions.

One guideline can be the one that Habermas defined as “communicative action”. Although his studies are not enough detailed, they identify such action as an important element of human action that involves participatory democracy.

Communicative action is a kind of action composed of the acts of the members of an inter-communicating community. He states that communicative action is the “island in the sea in human praxis” (Outhwaite, 1994).

This viewpoint has been hardly criticized because it seems to be based on a consensual position, meaning that it ignores conflicting forces (class, race, gender and culture) as drivers for participation in Marxism states (Healey, 1998). Healey considers planning as a form of action that can be done only after a conflict (discussion). Healey also states that this debate should be managed by discussing “moral dilemmas”. Anyway, Habermas’s claims of comprehensibility, integrity, legitimacy and truth (1991) remain mandatory for this process.

Participation in planning has emerged following criticisms. Traditional planning can be assumed to be a specialized scientific practice (where scientific is used in a looser form than Galileo's definition). In the '60s critics affirmed that planners were imposing their technocratic vision on a resistant society. These critics caused a change in the concept of planning from a top-down technocratic approach to one democratic bottom-up where participation is not an issue but the real focus of the process. Consequently, the planners' role has changed into a shaper of alternatives suitable for different social groups. The notion of public participation was formally clarified (through public organisation participation) in the 1968 Town and Country Planning Act (UK) whose aim was to understand the implications of strategic policies when applied at the local level. This meant that public participation in strategic planning can be considered a significant element of the planning approach. In this vision, local problems were identified in public meetings, questionnaires and study groups, but it missed to include participation in the decision-making phase.

Participation is a challenging issue to be dealt with in a political analysis framework. In the information age, public participation is made easier and the use of information tools (including virtual spaces) can be one of the searched guidelines to empower it.

Italian "Movimento Cinque Stelle" political party tried to implement this approach with its famous software platform named "Rousseau" but this experience demonstrated many issues that caused a heterogony of the goals: the platform was insecure, with a lot of security issues, often overloaded and missed the basics of traceability and certification. In a few words, it was a complete failure and many suspected that it was only a smokescreen to represent democratic decisions which in reality was an oligarchic decision.

A quick review of the social, cultural and political evolution of cities in our age, discloses the political content of urban planning and design. The Internet-based communication technology lets local identities evolve to be more political and global but, on the other side, it creates many fragmented localities in the urban space. The 3D reality is now overcome by the n-dimensional virtual space and, consequently, urban planning and design requires a review to be more politically focused (hopefully in the sense of democracy, but in many cases some oligarchic and technocratic forces try to harness them, like in the past regime architecture). But we can go further in this approach forcing us to consider social issues in the spatial context more than in the past, changing urban planning and design into a policy-making process.

Even if it is almost always considered that the virtual environment cannot be a real replacement for physical urban space and face-to-face relationships, we must remark near all technological changes with serious impacts on social, cultural and economic relationships are in the context of virtual environments, that impact on physical space reducing its importance. E-commerce, E-mail, social networks, and teleconferencing, just to give some examples, have led to the construction of a new interpretation of the public sphere. This public sphere on one side causes an involution of the individual over itself, increasing individualism, but on the other side causes the birth of new kinds of relationships, in many cases used as a child (e.g. maniacally publishing selfies on Facebook) but in other cases creating new experiences that were impossible before.

This new concept of the public sphere is ready to be deployed to combine social justice and cultural differences in the urban context. And also it is leading to new forms of virtual-real projects that can have an impact on public space and future planning and design of urbanity.

This evolution is leading to a new concept that has been proposed by some scholars that state that the protagonist of modern city building is not planners, but the "spaceless logic of networks" (Uçkan, 2000). This idea is surely applicable to the Smart City where networks are present since its foundations. But networks must not be considered only in the sense of real, concrete nets like streets, cables, wireless, or computer networks. The network concept is extended to virtual environments where the possible combinations are almost infinite.

This issue should be not considered only in a social and political analytical framework, but also in the sense of a more practical and pragmatic perspective, due to the evolution of the profession of urban planners and designers caused by new (types and shapes of) urban dynamics. The "fall of public man" (Sennet, 1992), impacts the public space, leading it into a crisis, but this crisis is not the consequence of formal or spatial issues, but mostly because a new type of activity has generated activity-based criticalities. It should now be evident that urban planners and designers must take into account ICT (continuous and fast) evolution to redefine activity patterns in urban public spaces. The present time is forcing all of us to merge physical and virtual spaces into a new concept. In this context, a relevant driver is an activity, whose design becomes a mandatory exercise especially, for example, for urban designers who are in charge to revitalize or recover urban space. This evidence implies that, while urban-architectural design can be even performed individually, an effective activity-based design needs public participation. But this, often, implies altering the behavioural patterns of different types of the space's users. Such change is a hard task, particularly today where immigration, urban culture fragmentation, family kernels collapse, and other social changes are increasing cultural diversities and, consequently, enhancing this problem.

Consequently, urban space design should promote real and effective negotiation among different types of user groups, because social diversity is yet considered an important element of urbanity (Butina, 1993).

In doing such user involvement, it should be underlined that it is expected that persons are interested in issues that impact their everyday lives and, consequently, in short-term planning decisions. Given this assumption, urban planners and designers should consider that trying to involve people in long-term macro planning decisions can be useless while staying close to their everyday life both disciplines (but urban design in particular) can not only result in being very effective but also in helping to establish public participation. But must be remembered that safety and security are sometimes far from the perception of the citizens (for factors listed in section 2.3- The RAFT Framework – part one – include safety and security) and planners should keep into account this criticality.

To allow democratic participation and also give room to security and safety improvements, the flexibility of the urban space design becomes a relevant aspect. Richard Sennett has identified such flexibility as "a narrative sense of place", interpreted as a "complexity of diverse activities and the possibility of surprise and discovery in space". According to his vision, to create a character in the urban space, a radical shift has to occur in the framework of urban design. The urbanist will have the mission to design borders between different urban uses in a weak and flexible form and free the cities from the ballast of rigorous zoning rules.

In this way, "spaces also come to life in the present tense" (Sennett, 1990). This new kind of design paradigm takes its origins from programmatic design, where a range of programmed activities are performed at the same time and where space is represented as a gap.

The urban transformation has demonstrated that the idea of "using computers for planning" has changed into "using planning for computers" since the end of the former century (Batty, 1995). With the aid of computers planners and designers understood and analyzed urban structure in more effective and complex ways. In a Smart City, this phenomenon has exponentially grown and, given that with computer-aided urban planning and design the urban space has become computable, including numerous social, economic, political and spatial variables and their relationships together, a Smart City this feature goes far beyond the design and planning phase and is extended to the entire city life-cycle. With the ability to read urban environment as a "datascape" and "infoscape", but especially through the immense data lake generated by a Smart City, it is now not only possible to avoid deterministic and static paradigms of urban planning and design and configure realistic and dynamic urban strategies, it is also possible to adapt to fast-changing requirements and technologies. By going beyond the traditional relational database paradigm, data has become easy to be stored and has been made available to a large public, enabling them even in a new form of the participatory process up to the decision-making stage and even further in change reaction steps.

2.3.4.6 Conclusions on the Impact of Virtuality on physical reality

The questions to be answered, at the end of this section, are:

- Does virtual space realize a form of the public sphere?
- Does it provide the notions of a collectively constructed place?
- Does it present the politically defined aura of publicness?

Answering “no” will mean that all ICT and other technological elements of modern society are just technicalities and have no impact on the socio-political components of our future.

If the answers are “yes”, then it is possible to infer that such technologies have a socio-political impact and must be considered in the future evolution of societies and communities.

But answering “yes” generates concern about the side effects of these social and political impacts, about lights and shadows that can arise from them.

To approach this question, two extreme positions are available: the pessimistic one and the optimistic one. The pessimistic view sees only the shadows (i.e. the risks and the dangers) and opposes change. The optimistic one sees only the lights and has total faith in the goodness of development.

The first results in the wide use of virtual spaces (social networks, the Web, virtual reality, …) have demonstrated that mankind is acting as a sorcerer’s apprentice and uses these technologies ignoring or not fully understanding the risks. Many advantages have been delivered by virtualization as many as new problems.

Even if in this phase both pessimistic and optimistic views have numerous supporters, what can be stated now is that there are no clear-cut answers about trends of the impact of ICT development on socio-political contexts. And this element is even more uncertain in Smart Cities where the obsessive use of ICT enhances reasons for extremely pessimistic and optimistic reasons.

An example is Amersfoot, a town of about 150 thousand citizens in the Netherlands.

Amersfoort will not become a smart city, because citizens concluded that the risks are too high.

Amersfoort wanted to be one of the smart cities in the Netherlands, but the Amersfoort Smart City program was stopped at the beginning of 2023. Citizens have been feared when thinking about smart streetlights, WiFi tracking, and algorithmic behaviour prediction. The municipality wanted to create an open "living laboratory" where to experiment with technologies, provided that no one could become a sort of guinea pig.

But suddenly Amersfoort cancelled the entire project because the costs and risks proved to be too high and too great.

The (former) project manager of the Smart City project, De Stadsbron, has gone beyond stating that, in his humble opinion, the smart city paradigm will not be applied in any other part of the country.

The first issue was the WiFi tracking of people. This technology has repeatedly been the subject of privacy concerns. Enschede, another 150 thousand citizens' town, had already introduced WiFi tracking with the result of a fine of hundreds of thousands of euros to the municipality. The reason for such a fine was that in the city centre of Enschede, passers-by were counted using sensors. According to the Municipality, these counts were carried out "anonymously". Nonetheless, the personal data authority fined the municipality €600,000. According to the authority, the citizens' privacy was not adequately protected, as they could be traced unnecessarily. In addition, the use of WiFi tracking is in itself a serious violation of the AVG (the Data Protection Regulation in the Netherlands), the authority said.

In the case of Amersfoort, the pessimistic perspective has prevailed but, on the other side, in the context of ICT, it seems reasonable to make optimistic projections about a sort of “new public man” concerning the social, political and spatial characteristics of virtual spaces. Such a perspective enables us to rethink the virtual sphere in a positive perspective considering the democratic vitality of the public way of life in real urban space as well.

The syntactic structure of the virtual environment has evolved and is moving away from the original conventional space conception. Today’s spatial metaphor is secondary in the virtual environment due to the birth of a new spatial language derived from ICT technologies.

Abandoning this physical syntax, the phenomenon of the virtual space has been increasingly tied with the activity patterns that it supports, initially ruled by commercial and entertainment spaces, but now related to other forms, sometimes not existing before, of social and political activities.

It is time, now, to reconsider planning and design, defining them as socio-political actions, that integrate virtual space into the process of planning and design, supporting a social transformation that integrates into the public sphere both real and virtual environments. Considering the tools of cyberspace in the planning and design process widens the impact area of planning, increases the flexibility of the results, and improves long-term participation, including the “new public man” (the XXI century’s citizen) into all phases of the feedback mechanisms, dynamically and continuously, in near real-time.

This will mean that not only the integration of both spaces must happen in technical terms, but also that is now possible the integration of the fragmented localities in urban space, which can now have a democratic voice in the decentralized virtual environment, in social and political terms.

2.3.4.7 Safety

Safety concepts start from day idea that individual health can be protected from risks caused by the environment and things where he or she lives. Usually, this is done through the prevention of risks. Some risks are intrinsic to things or spaces and some are related to persons.

2.3.4.8 Security

Security is about the protection of an individual's health and his or her properties from damage or from being killed. What impacts security are only man-made actions and these actions are intentionally targeted at the victim, even if, often, their level of impact is greater than planned (e.g. a theft can cause a homicide that was not originally planned).

2.3.4.9 The changes to Ramaprasad's framework

As stated above, Ramaprasad's framework is an ontology that can be used to generate all the illustrative elements that describe a Smart City. In the RAFT framework, the same structure will be maintained but some elements will be changed to include the safeness and secureness of a public space.

In this first step, changes will be done in both the generation formula and the single variables of the framework.

The original formulas have not been changed:

- Smart City = f(smart, city) (unchanged)
- City = f(Stakeholders, Values) (unchanged)
- Smart = f(Structure, Functions, Focus, Semiotics) (unchanged)

But the single components have been redesigned to add security and safety. In this first version of the RAFT framework, the values of the city have been adapted to include safety and security.

Table 7 - Changes to Ramaprasad's framework

Value	Initial definition	Updated definition
Sustainability	optimize current use of fossil fuels, eliminate waste, recycle, recover energy, save time, and reduce, or eliminate, pollution	No changes
Quality of Life	wealth, employment, the environment, physical and mental health, education, recreation and leisure time, social belonging, religious beliefs, safety, security and freedom	No changes

Value	Initial definition	Updated definition
Equity	Absence of unfair, avoidable or remediable differences among groups of people, The groups are defined socially, economically, demographically, geographically or among another dimension (sex, ethnicity, disability, …)	No changes
Livability	safety, mobility options, employment and educational opportunities, public space, and political stability	safety, security, mobility options, employment and educational opportunities, physical public space, virtual public space and political stability
Resilience	local knowledge, community networks and relationships, communication, health, governance and leadership, resources, economic investment, preparedness, mental outlook	No changes

2.3.5 The Public Space Framework

2.3.5.1 Types of real public spaces in smart cities

A smart city can manage flows of information, people, vehicles, goods, and services. And this can be done autonomously or be human-supervised. Before smart cities, urban planners and urban designers could already design conceiving multiple uses for public space (consider the medieval square, which had many uses ranging from meeting areas for business, for public decisions, for executions, for markets and more). In smart cities, public space usage can be "instantly" changed by "simply" reorganising how the smart city manages itself. For example, a road can be used as parking during normal traffic hours and as an arterial in peak hours, and this will be done automatically: smart vehicles simply will leave the road free when "The City" will ask and will park there when "The City" will allow. And this can be done better if vehicles are shared, re-allocating sharing requests on vehicles parked on such roads to move them without wasting energy and time, for example. In a few words, urban planners and designers can have a stronger degree of freedom in managing public space usage.

In urban design, how to resolve problems can quickly become outdated due to changes in circumstances, and requirements, due to unforeseen events or even consequences of the urban design itself. The same issue can arise about urban planning, i.e.: considering the city's layout from a higher perspective. One approach could be to design the city as a system that can adapt (or be adapted) to changing contexts. The Generator by Cedric Price not only could be reconfigured by its human inhabitants to support their different activities, but it also could rearrange itself in case it had been left in the same configuration for too long. The "too" should deserve a more formal definition and this could be done assuming that the project of the city (i.e.: the urban planning or the urban design) can be interpreted as a transposition of Pask's conversation theory (Pask 1975). In his theory, Pask considered social systems (which are dynamic by nature) as symbolic and language-oriented systems where the responses depend on the interpretation that a person does about another person's behaviour. So, this conversation theory describes the interaction between two or more cognitive systems, and how they engage in a dialogue over a given concept and identify differences in how they understand it. Pask's studies originated from his cybernetic research when he attempted to explain the learning mechanisms of both living organisms and machines.

To better explain the last sentences, a Smart City can temporarily reconfigure its public spaces to respond to inhabitants' explicit requests (e.g.: made by law enforcement agents or by the city major) or react to citizen's behaviour, learning from them through conversation in the Pask's sense (e.g.: reconfiguring a space in some way that leads to an improvement of some behavioural parameters of citizens in the space or its neighbouring). This last decisional process has not been configured by the city nor derived from simple statistical analysis or optimisation algorithms but has been learned by the City itself "conversating" with citizens.

In this sense we can consider having two different processes of decision-making: an explicit decisional mode where requests from some "privileged" citizens or organisations will be satisfied rearranging public space and a second one, the self-learning mode, where the City learns by itself how to reconfigure public space, conversating with citizens.

The second mode, the self-learning one, where a Smart City can decide autonomously to change after a learning process will not be considered in this paper and only the explicit mode will be discussed. The self-learning mode will be detailed in future work.

In this section, the main different types of public spaces will be enumerated and defined. Their extension into cyberspace will also be analysed in this and the next section.

Although the definition and the discussion of what is a Public Space and the differences between it and an Open Space is a very wide topic, this paper will be done a simple classification of typical Smart City types of public spaces starting from the taxonomy provided by Carmona (2010) in his "Contemporary Public Space, Part Two: Classification" paper and shaping them according to Smart

City capabilities, including their extension into cyberspace. The extension into cyberspace can be made by both digital twins and the provision of additional services.

The classification proposed by Carmona is summarized in the following table:

Table 8 - Public Spaces Classification

Space type	Distinguishing characteristics	Examples
Natural/semi-natural urban space	Natural and semi-natural features within urban areas, typically under state ownership	Rivers, natural features, seafronts, canals
Civic space	The traditional forms of urban space, are open and available to all and cater for a wide variety of functions	Streets, squares, promenades, pavements
Public open space	Managed open space, typically green and available and open to all, even if temporally controlled	Parks, gardens, commons, urban forests, cemeteries
Movement space	Space dominated by movement needs, largely for motorized transportation	Main roads, motorways, railways, underpasses
Service space	Space dominated by modern servicing requirements needs	Car parks, service yards
Leftover space	Space left over after development, often designed without function	'SLOAP' (space left over after planning), Modernist open space
Undefined space	Undeveloped space, either abandoned or awaiting redevelopment	Redevelopment space, abandoned space, transient space
Interchange space	Transport stops and interchanges, whether internal or external	Metros, bus interchanges, railway stations, bus/tram stops
Public 'private' space	Seemingly public external space, in fact privately owned and to greater or lesser degrees controlled	Privately owned 'civic' space, business parks, church grounds
Conspicuous spaces	Public spaces designed to make strangers feel conspicuous and, potentially, unwelcome	Cul-de-sacs, dummy gated enclaves
Internalized 'public' space	Formally public and external uses, internalized and, often, privatized	Shopping/leisure malls, introspective mega-structures

Space type	Distinguishing characteristics	Examples
Retail space	Privately owned but publicly accessible exchange spaces	Shops, covered markets, petrol stations
Third place spaces	Semi-public meetings and social places, public and private	Cafes, restaurants, libraries, town halls, religious buildings
Private 'public' space	Publicly owned, but functionally and user-determined spaces	Institutional grounds, housing estates, university campuses
Visible private space	Physically private, but visually public Space	Front gardens, allotments, gated squares
Interface spaces	Physically demarked but publicly accessible interfaces between public and private space	Street cafes, private pavement space
User selecting spaces	Spaces for selected groups, determined (and sometimes controlled) by age or activity	Skateparks, playgrounds, sports fields/grounds/ courses
Private open space	Physically private open space	Urban agricultural remnants, private woodlands
External private space	Physically private spaces, grounds and gardens	Gated streets/enclaves, private gardens, private sports clubs, parking courts
Internal private space	Private or business space	Offices, houses, etc.

2.3.5.2 Extension of real public spaces into cyberspace

All public spaces above depicted can have extensions into the cyberspace. This extension can lead to a sort of "augmented reality" that is the mixing of the real public space with its cyberspace extension and that will be called, to avoid misunderstandings, "augmented public space".

Augmenting the public space can be done in many ways, in the following table some of them will be described. The table aims to provide enough examples of how the augmentation of public space can be done. It is focused on the possibility to augment public spaces and will not consider most of the aspects of the smart city that are related to sustainability or security, although these concepts will remain valid. The use of these augmentations will be cleared in the next section.

Table 9 - Some types of augmentations for public space

Augmentation type	Description	Examples
Augmented reality	When virtual reality is superimposed over reality (e.g.: by impressing the virtual images over a real-time capture through the camera of a tablet or smart glasses).	Get tracing, dietetic and performance information about goods in a shop.
Autonomous things	Autonomous things include drones, robots, ships, and appliances, that lead AI to perform tasks usually done by humans. They operate ranging from semiautonomous to fully autonomous.	Vehicles can drive autonomously and be shared when needed. They will also swarm to improve the city's quality of life (e. g. reducing traffic).
Democratization (of technology)	The capability of technology to become easier to be used by citizens.	Citizens could develop their data analytics starting from available open data
Distributed ledgers	The use of technologies like blockchain will allow the creation of distributed ledgers where transactions of any kind are recorded and will allow a better data management	Vehicles can book parking places in an extremely easy way, even with large advance, and rearrange the booking with no human intervention and in a very quick way.
Edge computing	Edge computing means processing huge quantities of data near their sources, reducing latency time and improving response/reaction time. This is a typical layer in the Internet of Things systems.	Cars can directly dialogue with parking places and find the nearest free.
Geolocation	Geo-referencing any object means identifying its position in space. This can be done for items or humans and in many ways (e. g. GPS, several cameras triangulation).	Instantly knowing the position of any element of the city, including citizens, and, if possible, their destination, if moving.

Augmentation type	Description	Examples
Hyper-automation	Through this advanced form of automation, which mixes AI and robotics, humans can remotely control shared robots to act for them. Hyper-automation also includes the capability to remotely measure many parameters.	Shopping can be done remotely even for non-standardized goods like fresh goods, dresses and more that, currently, are bought by the customer directly trying them.
Multi-experience	Multi-experience replaces technology-literate people with people-literate technology. In this perspective, the traditional idea of a computer evolves from a single point of interaction to include multisensory and multi-touchpoint interfaces like wearables and advanced computer sensors.	Weekly food shopping can be easily done at home using an App to order what is needed, cooperative robotics to prepare and package it and autonomous vehicles to deliver it.
Virtual reality	2D or 3D virtual reality allows the creation of a virtual representation of any object (e.g.: park, street, touristic place) or concept (e.g.: traffic flow, available parking map) that can be displayed to a human being and with which the human can virtually interact.	Virtual tour of a tourist place or a restaurant. Virtual tour of shelves in a supermarket.

2.3.6 Safety and Security in virtual public space

The above definitions of virtual public space require the analysis of the safety and security of cyberspace. This topic will include many aspects of cybersecurity and, in general, information security, but will have a significantly different structure if referred to the one defined in the physical public space.

Considering many social conflicts rising (and often falling) in various areas of the world and analysing cyberspace crises, it is clear (Jiang, 2022) that people are facing an emotional impact and lack of security feelings, especially when responding to emergencies. In cyberspace, the most recent research shows the importance of focusing on discrete emotions. In virtual spaces, the most important risks are related to the psychological sphere of the person, with only derived impacts on his or her health (e.g. stroke by anxiety or stress). Up to now "emotional security" has not been a real concern but the awareness about it has been rising.

To qualify and measure this emotional security, a concept of social-emotional security has been developed by researchers, evolving it from the classical theories of social risk and psychological resilience. This social-emotional security has been integrated with some metrics like emotional bias, situational risk, and potential hazard. To control this social-emotional security, a regulation strategy will be analysed and defined to define some sort of "safety valve".

2.4 Reconfiguration mechanisms

The reconfiguration mechanism of the public space in a smart city will follow a general common process that starts from a trigger event that requires reconfiguration. This event can be a periodic event (e.g.: every Saturday the square becomes a market), which means that the event happens depending on time, a human-forced event (e.g.: due to an emergency, these streets must be closed to some kind of traffic), which means that some human has given the order to the City to act, or a business rule event (e.g.: the traffic is jamming the main roads and part of it must deviate to secondary roads to optimise vehicles flow), that means that some algorithmic rule (this is the real sense of "business" in this case) has been met and so proper action must be taken.

After the arrival of the trigger event, the City will react checking if the request can be satisfied or should be denied due to some constraints (e.g.: conflicting high-priority requests). If the request can be satisfied, the City will start defining the boundaries of its action, if needed developing different scenarios and choosing the best among them, then it will start applying the action(s) to overcome the request. Until the request will be satisfied, the City will monitor the evolution of involved parameters and check that things are going in the right way, otherwise, it will try to compensate for deviations or raise an alarm, if needed.

When the request is satisfied, The City will return to the space default configuration.

Although the term "The City" has been used up to now, it must not be considered as a central system that steers everything but as a distributed system of systems, mostly based on edge computing, that reacts to the request. The structure of this system will not be analysed in this paper, which focuses on the public space reconfiguration capability.

The following sub-sections will present four different examples of potential space reconfiguration in a smart city. Other cases will not be considered in this research for the sake of simplicity. These examples will not consider in detail why the change has been triggered but will only describe how this change can happen. Any reference to real places is a mere coincidence.

Table 10 - Summary of proposed reconfiguration examples

Title	Type	Needs
Parking, street, main traffic arteria	Basic	Autonomous things, hyper-automation
Mall by day, entertainment city by night	Mixed-use	Virtual reality, multi-experience, autonomous things
The Mini-Generator without cranes	Physical	Autonomous things, hyper-automation, nanotechnologies
Public Space and 3D printers	Large scale	Autonomous things, hyper-automation, nanotechnologies

2.4.1 Example 1: parking, street, main traffic arteria

2.4.1.1 Scenario

The City, at 8:00, orders all vehicles to not park in Baker Street and to those that are already parking there, to move to different places in the neighbours, already assigned them by The City. This is because, up to 9:00, Baker Street must become a main arteria in inbound traffic flow. Small streets that merge into Baker Street are assigned as temporary stops to let passengers leave their vehicles and go to work in the building near them, without hampering the main traffic flow. All vehicles are autonomous, so they obey this order with no human intervention. At 9:00, The City checks that the traffic has reduced its intensity and that Baker Street is not yet needed as the main arteria, so the Street Becomes a pedestrian-only road where shops are open, and people can move around to get some coffee or buy something. Many mobile shops made by autonomous vehicles can park in the zone. The pavement in the middle of the road automatically reverts and opens, showing a medium size children's playground allowing the neighbouring kindergarten to take children there to play. Around noon, The City decides that the mobile shops must move away (and they autonomously do this) and allows local restaurants to fill the road with tables and chairs. Weather report forecasts rain, so a covering is placed by an automated system all over the street and wind barrier are automatically put at the beginning and the ends of the street to repair the windchill that has also been forecasted.

At 14:30 the restaurant service closes and the road returns to a normal street where low-intensity traffic is allowed, closing coverage, lowering wind barriers and asking shops to remove tables and chairs, also hiding the children's playground. Now Baker Street is mainly used to gather people leaving their work. At 16:30 traffic in the city is increasing and The City requires again Baker Street as a main arteria, as in the morning, asking autonomous vehicles to leave it free of parking and diverting a portion of the traffic through it. When traffic flow reduces, around 20:00, Baker Street returns to being a normal, low-traffic street and it becomes a one-way street, with the central portion used for two-lane traffic, and both sides as areas to deposit and pick-up people that move to go to local pubs, bars, clubs and more. Then it cycles again from 8:00.

2.4.1.2 Comments about the scenario

In this simple example, the space that The City reallocates is an urban street. It has been made possible by the existence of autonomous vehicles (cars, mobile shops) that can easily respond to The City's requests. It is also based on the possibility of the children’s playground being hidden below the road floor. Also, the anti-rain covering and wind barriers have their role in this space reallocation. The use of the street as a normal road, pedestrian-only, high-traffic arteria, the one-way two-lane street is made possible by changing road signs, most of which are virtual, i.e.: visible only through virtual or augmented reality but readable by autonomous vehicles.

The scenario is quite easy and, for some aspects, naïve, but it is near to being practically realizable: only level 5 autonomous vehicles are missing it.

2.4.2 Example 2: Mall by day, entertainment city by night

2.4.2.1 Scenario

The Magic Wand Mall (or MWM) is a shopping mall where there are 208 “shops”. It has been designed to allow a set of mobile walls that can be controlled by The City. These mobile walls can be used to partition the shops into different subspaces. These walls can move (moved by someone or by themselves is not important). Each shop has a “default” area ranging from 60 square meters to 3,000 square meters.

To access each shop there are two ways: the first one is through the main halls and corridors, beautifully decorated that will be called “human access connections”. The second one is a normal set of corridors of standard width of 4 meters, with white walls, and connected to the mall warehouse. These corridors will be called “restock corridors”.

The mall, as usual, will have two different access types: the main entrance, which faces towards the human access connections, and the goods entrance, which faces towards the restock corridors.

At 19:00 The City analyses the inventory of all malls and shops that are in it and the forecasts for goods requested for the next day. This process ends around 23:00 and requests are sent by The City to all suppliers to provide differences to what is already planned and not yet under shipment. In this way, The City has planned the entire logistic supply chain from peripheral logistic areas, just outside the city, that have been refilled during the day, up to a single shop in a single mall.

At the same time, the MWM spaces are returned to their default configuration of pubs, clubs, and other entertainment places by robotic teams. Warehouse spaces (which will be explained later) used as shops during the day are now hidden by mobile walls. Everything has been cleaned before 20:00.

Starting from 20:00, the shops in the MWM are open to the real public (i.e.: humans) as restaurants, pubs, clubs, cinemas and other aggregational and entertainment places. This configuration is the default configuration of the public space. Up to 2:00 of the next day, people lives the MWM as an entertainment and meeting area. After the last human has left the area, the cleanings are done by automated systems (i.e.: cleaning robots).

At 3:00, The Mall reorganizes its space to receive goods to be sold by remotely accessed shops: mobile walls are removed to use all the available space as storage. So, until 5:30, the MWM will be filled with robots that are refilling the warehouses which were hidden by mobile walls and also the space used by people as pubs or restaurants just a few hours ago.

In this case, customers, from their homes or using mobile apps from anywhere, virtually visit the shops in the mall and choose goods to be bought. In some cases, shopping AIs (i.e.: Artificial Intelligence programmed to buy daily products basing their choices on customers' tastes) will make the order. In both cases, humans and AI, using hyper-automation and multi-experience, can virtually try dresses, smell scents of food, try fruit consistency and do other sensorial activities remotely. For all day, until 19:00, the MWM is closed to the public (or only a portion of it can be open), while most of it is used as storage space for virtual shops.

At 19:00 the loop begins again.

2.4.2.2 Comments about the scenario

In this scenario, the same space, which has been designed as an entertainment or meeting place, is used for half of the day as storage from where buy goods acting from remote. Using citizens' behaviour prediction and other kinds of statistics, The City can rearrange this space to both support the need for meeting and the need for shopping.

This scenario requires a bit more technology than what is currently available, but the trend ensures that in a few years, it will be possible to be realized.

Using a mall in this way will improve sustainability: the supply chain will use spaces that, after being freed by customers that buy goods, will be reused during the night for different purposes.

This scenario can be evolved into the next one.

2.4.3 Example 3: The Mini-Generator without cranes

2.4.3.1 Scenario

In this scenario a space is a building with many floors but no walls (or only a few walls). Provided that it has various goods hoists that can move large loads from one floor to another, it is possible to reconfigure the space dynamically (as dreamed in The Generator). The only issue is about the interior design. And this is the main issue that will be faced in this sub-section.

Changing the space configuration is not difficult: even today's automation level, using already existing forms of cooperative robotics, can provide mobile walls that can be put practically anywhere. Also, electrical connections should not be a problem: connecting from the ceiling and distributing through mobile walls specialised connections. Hydraulic connections can be provided through the floor or ceiling, directly to furniture, even in the case of gas furniture (for cooking). Climatization can be provided, again, by hiding pipelines in floors or ceilings. The problem is that spaces to be used by humans, need specific furniture to be provided and decorations and designs that must be changed in the blink of an eye. So, we will assume that the mobile walls are not a problem, and we will focus on furniture change.

There are at least three different ways we can arrange different furniture. The first one is using furniture which moves autonomously, i.e.: that are mobile devices that know where to go and how to connect. It's easy and the only issue is where to put them when they are not used. The second one is to use furniture moved by someone else (e.g.: a robot which carries them and robots which position and connect them). Also, in this case, there is again the problem of where to put them when not used. In both cases, there is also the issue of damages during transportation. The third one is using furniture that is assembled starting from a common set of reusable components (e.g.: panels, small doors, glass windows, taps, sinks, …). In this case, the needed storage space will be lower but there is the problem of decoration: all elements are raw and need specific decoration to be used.

The solution to the decoration issue, and probably, but with the need to further develop the technology, for the elements or furniture storage, is the use of nanotechnologies.

Using nanotechnologies will be soon possible to paint surfaces create changing patterns (remotely controlled) and also to create sensorial and interactive walls. In this way it will be possible to change the aspect of raw elements, giving them the desired aesthetics and also specific surface performance (e.g.: waterproof, smooth, cold, hot, lighting, …). Such nanotechnologies promise that using nanorobots, simple structures can even be built. Structures interesting in this scenario range from intelligent seals for gas or hydraulic connections (for safety reasons but not only), passing through the creation of simple small elements like glasses, lamps and more, up to complex elements like furniture and even walls. For these last two, the technology is rather far to be ready, but for small-scale applications it is promising.

If we assume that nanotechnologies or even swarms of small robotics components can be used to realize and decorate furniture, in cooperation with the assembly of standard elements, we can entirely reshape a building acting on all non-structural elements.

Assuming this last statement, this will mean that The City will be able to reconfigure public space for periods longer than one day or a few hours through mobile walls, modular furniture, and smart decoration. So, the building considered in the scenario will be able to be reconfigured by The City according to its needs. For example, it could start as a business building where there are offices and food services and then, after a few months, when the request for apartments near it has grown, be partially readapted by The City as residential. When a convention is needed, part of the offices will be arranged as a conference room. With the arrival of inhabitants in the building apartments, also some schools will be needed and, for nine months each year, some space will be used for educational purposes.

2.4.3.2 Comments about the scenario

Although based on technologies that have to be further developed, this scenario gives reality to Price's Generator project and considers space (not public only but also private, like an office or an apartment) as something that can be shaped by The City (autonomously or under human control) to fill specific needs. In this perspective, the (public) space becomes a place where meet other people to socialise and maintain the human contact that has been revealed to be important during the COVID-19 lockdowns: people have discovered how good is working at home but also the need to meet colleagues and other people. In a few words, people have discovered that they need a balance between smart working (or studying) and physical contact at the office (or school). This scenario is remarkably interesting because allows us to find these balance points even considering change drivers like the growth of the average age of people. A city should support social changes reshaping its space and this can be done if the technologies depicted above are used.

Last, but not least, with the above approach, extended to any existing building, The City will be able to plan its whole reshaping to improve the overall quality of life, compensating for some urban planning/design errors or requirements changes.

2.4.4 Example 4: Public Space and 3D printers

2.4.4.1 Scenario

Large-scale 3D printers are today able to build an A-class house from scratch in a few hours. Anti-seismic, cheaper, sustainable houses can be quickly created directly on-site with this technology.

Soon, even large buildings could be created using the same technology. In this way we can imagine that The City will be able to rule an army of such 3D printers, equipped with AI and with an adequate degree of autonomy and will be capable to expand itself, creating new buildings, new roads, and even new districts.

In this way, The City can permanently change its (public) space. But the scope of this paper was a temporary reconfiguration and 3D printing does not allow this. Mixing 3D printing with nanotechnologies can lead to an interesting result: buildings will have very special features thanks to the nanotechnologies and can be demolished with up to 100% recycling due to the capability of nanomaterials to be easily separated and reused. Although this technology must be further developed, the trend is clear and remarkably interesting opportunities are on the horizon.

Using such kind of approach, The City will be able not only to change its space (public or private can be considered the same) but also do this "temporarily", which does not mean hours or days but surely can be done for periods of many months or years. In this way, The City will support urban planners and designers to realize their ideas, giving both the data analytics to take decisions and the manpower to physically realize them.

2.4.4.2 Comments about the scenario

This last scenario requires a lot of technology that is not yet available and puts some questions about the energy efficiency of a process of creation and destruction, but the answer depends on a deep analysis of the advantages and disadvantages. In this case, the Urban Planner and the Urban Designer will find in data analytics gathered from The City an important source of information to support decisions and can create not only simple renderings of the future urban forms but also very detailed simulations that will increase the effectiveness of their work.

2.5 Challenges for urban planners and urban designers

Considering all the above considerations, the Urban Planner and the Urban Designer have to take into account the capability of the smart city to reconfigure public (but not only) space. The Generator, in the end, has arrived, to use a metaphor, and it is time, as in Generator, to put together Architects (i.e.: Urban Planners/Designers) and engineers (i.e.: ICT and Robotic engineers) to work together. This is the first challenge that has to be faced. But Price and his consultants did it in the past, so it should be possible now. But there is a fundamental difference: the level. The Generator was a utopistic project, never realized, and did not have to face reality (i.e.: time, maintenance, errors, failures, …) while a Smart City is something that must live for a very long time and adapt to very quickly changing technologies and less-quickly changing social needs. What is needed is something that can be improved in time and that will allow us to reproduce successes and learn from failures to avoid repeating them. This is a methodology. A methodology, in this paper, is defined as made by two fundamental elements: descriptive language and a creative process.

Descriptive language has the scope to describe what people are talking about. The language should be mainly graphical because drawings are concise and expressive. It should also have the ability to define something to be measured because we cannot improve what we don't measure. Just to cite Edward W. Deming, an engineer who was one of the founders of the Quality concept, "You can't manage what you don't measure".

A creative process has the scope to define the steps to reach the desired goals starting from some initial state. The creative process describes how things must be done to achieve success.

Putting together the language and the process, it will be possible to create these interdisciplinary teams and get the maximum from them. This interdisciplinarity is physiological in computing and has already been developed in other contexts: bio-informatics (for ICT application to medicine and healthcare), info-logistics (for ICT application to logistics) and more are, by now, well-established disciplines, where interdisciplinary teams work in a very efficient and effective way. But in these fields, the solution was affordable: medicine, healthcare, logistics, chemistry and more are disciplines where there are already very rigorous procedures and, except for advanced and theoretical research, creativity is not the first quality people should have. In Urban Planning and Urban Design (and, in general, in Architecture) we have a very creative, soft-skilled, emotional, human-sciences-oriented approach that must be met with the aseptic, cold and schematic mind thinking of ICT and Robotics engineers. In this case, the lack of a common methodology that preserves both approaches leaves the two parts of the team to work separately. To use a metaphor, the architectural portion is the left hemisphere of the brain while the engineering one is the right hemisphere. If we want that our brains will work, we have to let them strictly cooperate while preserving the identity and peculiarities of each one. Today such bridging is missing, and architects and engineers work separately on these topics. And no methodology is yet available and no research in such a sense are reported. And this is a serious issue that should be deeper analysed and, if found a real issue, solved.

2.6 A set of methodology definition requirements

The above-cited methodology should comply with the following requirements that can be considered an initial set of guidelines for its implementation. In the table below, UP and UD refer to Urban Planners and Urban Designers while ICT refers to ICT & Robotics Engineers:

Table 11 - Methodology requirements

Title	Description
Methodology goal	The scope of the methodology is to transfer requirements and specifications from UP/UD to ICT
Expressive capability	The methodology will be able to describe requirements and specifications for both UP/UD and ICT
Initial state	The methodology will start from UP/UD requirements and/or specifications
Final state	The methodology will end with ICT requirements
Bottom-up change management	The methodology will be able to transfer changes on the ICT side (in technologies or requirements) towards the UP/UD side, tracing up to impacted UP/UD requirements and specifications
Top-down change management	The methodology will be able to transfer changes on UP/UD side requirements and/or specifications towards the ICT side, tracing up to impacted ICT requirements
Risk analysis support	The methodology will be able to define all elements needed for a risk assessment or a risk analysis.
Measurability of kernel entities	The methodology will define some core entities that will have applicable measures and that can be used to evaluate in a quantitative where the methodology is arrived, from where it has started and where it has to go
Expandability	The methodology will define a mechanism to extend it and to adapt it when needed without the need to alter its kernel
Structure	The methodology will be composed of both descriptive language and a creative process

2.6.1 The RAFT Framework – part two

2.6.1.1 The physical public space

The factors influencing safety and security identified above were:

Table 12 -Some of the factors influencing safety and security in public space

Factor	Safety	Security	Further variables
Darkness	Influenced	Influenced	Time of day, season
Visible security	Low influence	Influenced	Can have an opposite effect

Factor	Safety	Security	Further variables
Crowded place	Low influence	Influenced	Reduces or removes the need for visible security
Cleanliness	Influenced	Influenced	
Maintenance	Influenced	Influenced	

Customisation with public spaces, both physical and virtual, requires that the framework takes into account the different safety and security properties of each public space, with the factors that are related to it.

Table 13 -Some kinds of public space and examples of related factors

Type	Influencing factors
Natural/semi-natural urban space	Darkness, visible security, crowded place
Civic space	Darkness, visible security, crowded place, cleanliness, maintenance
Public open space	Darkness, crowded place, cleanliness, maintenance
Movement space	Darkness, cleanliness, maintenance
Service space	Darkness, cleanliness, maintenance
Leftover space	Cleanliness, maintenance
Undefined space	Darkness
Public ‘private’ space	Darkness, cleanliness, maintenance
Internalized ‘public’ space	Darkness, cleanliness, maintenance
Retail space	Darkness, cleanliness, maintenance
Private ‘public’ space	Darkness, crowded place, cleanliness, maintenance
Visible private space	Darkness, crowded place, cleanliness, maintenance
Interface spaces	Darkness, cleanliness, maintenance
Private open space	Darkness, cleanliness, maintenance
External private space	Darkness, cleanliness, maintenance

3 The Essence Standard

3.1 The Essence Language

3.1.1 Requirements

The Language high-level requirements are:

- Define an integrated UP/UD/ICT development process.
- Define checkpoints as milestones.
- Evaluate the project’s health/state.
- Maintain traceability from UP/UD and ICT.
- Support risk management.
- Support “quantitative” evaluation of “unquantifiable” elements

3.1.2 The Essence 1.2 language structure

The Essence language in its version 1.2 is composed of the following elements:

- **Alpha**: entity to be measured by state
- **Alpha State**: a measure of the Alpha
- **Work Product**: the desired result
- **Activity**: how to get a result or progress a state
- **Activity Space**: a way to organize activities
- **CheckPoint / Milestone**: a step in the whole process to check overall project health
- **Phase**: a way to order and filter activities
- **Resource**: something needed
- **Pattern**: a repeatable schema
- **Competency**: a skill
- **Team Role**: a role
- **Relationships**: connections between elements of the language

These elements, and their relationships, are depicted in the diagram below:

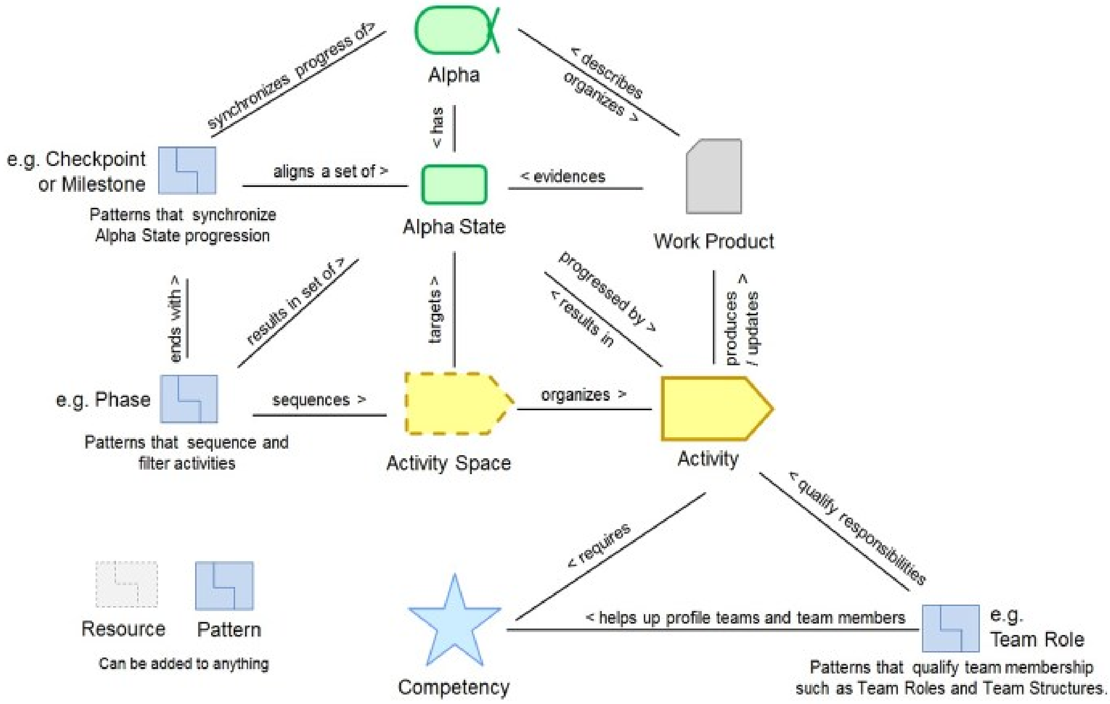

Figure 10 - Essence language 1.2 structure (Source: Essence Specification 1.2)

The Alphas (i.e., the entities that have to be measured) are, in the original version of Essence, organised in three main areas of concern: Customer, Solution and Endeavour.

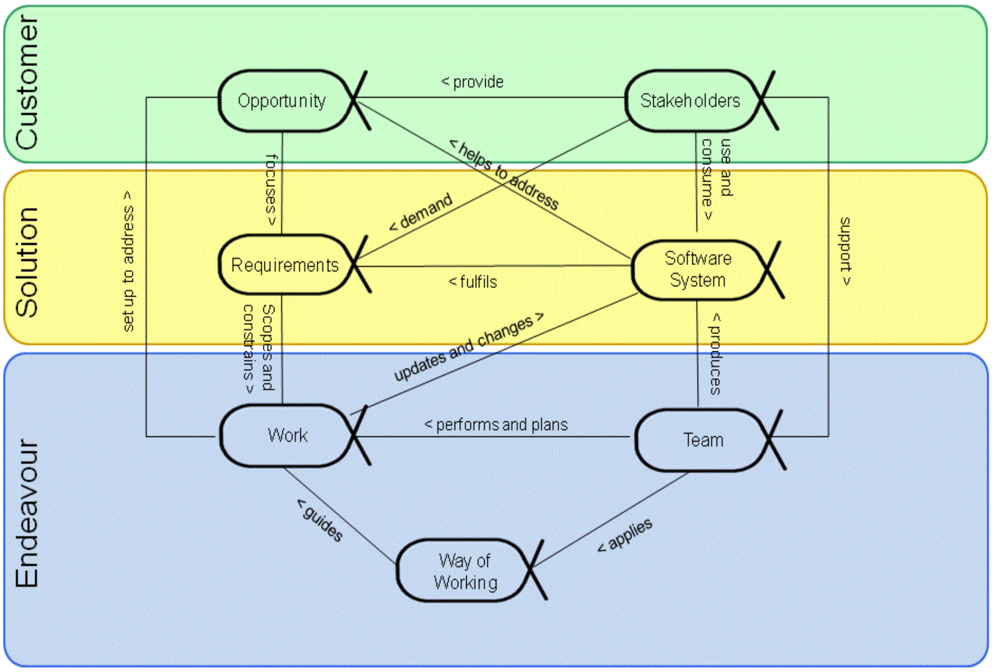

Figure 11 - Areas of Concern of Essence 1.2 (Source: Essence Specification 1.2)

The Alphas are measured through their “state” using Alpha State Cards, which are checklists that allow to see if a state has been reached or not. In the diagram below there is an example of some alpha state cards:

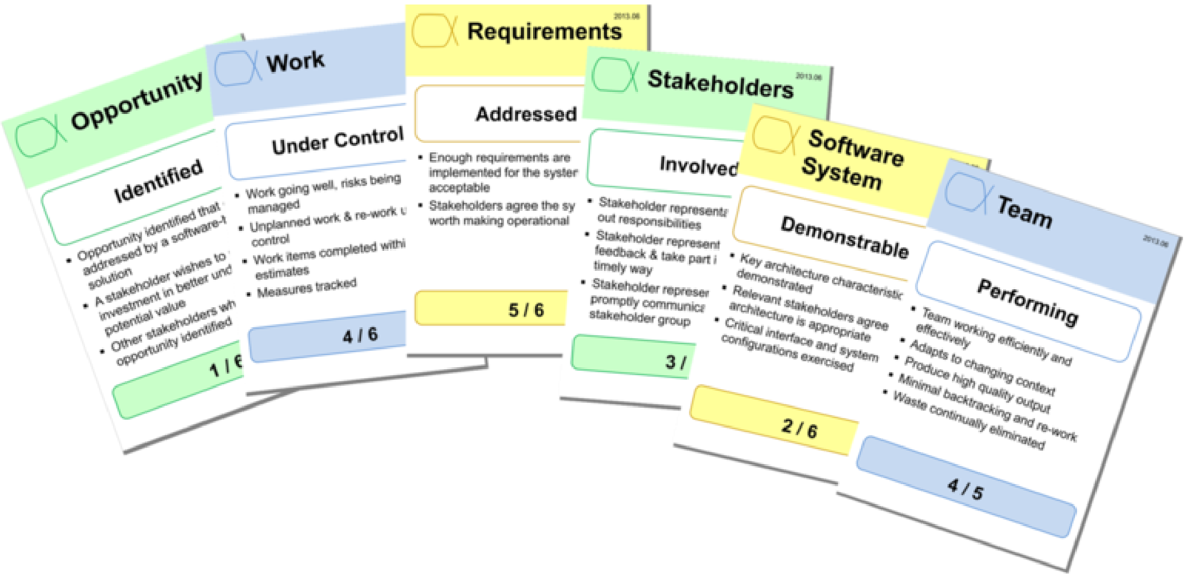

Figure 12 - Some alpha state cards (Source: Essence Specification 1.2)

Last, the activities to develop something are organised in a way similar to alphas' activity spaces:

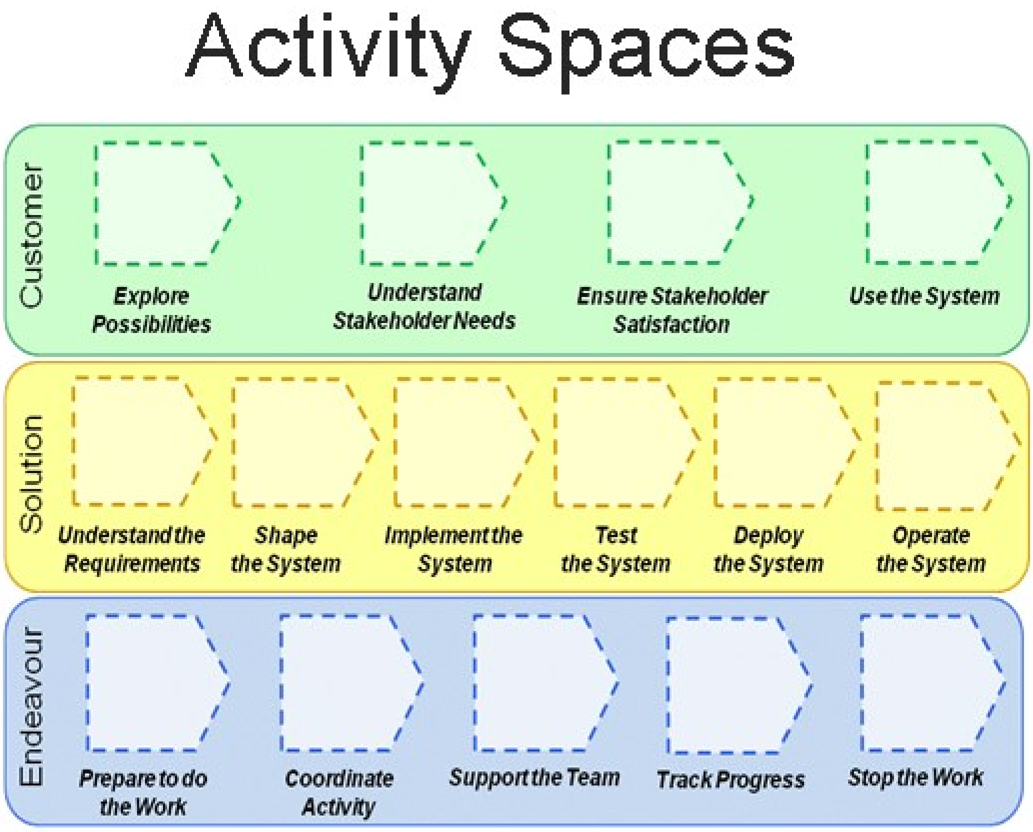

Figure 13 - Activity spaces in Essence 1.2 (Source: Essence Specification 1.2)

3.2 Essentialisation

3.2.1 Definition

3.3 The application of Essence 1.2 to the Smart City Framework

To apply a customised form of Essence 1.2 to the smart city, a new organisation of areas of concern has been done. For the sake of simplicity, in this document, the endeavour area of concern has been omitted, because it goes beyond the scope of the paper. In the following picture, the new organisation of areas of concern is shown.

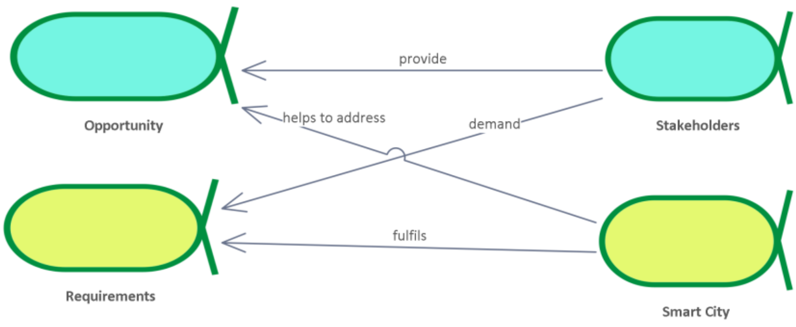

Figure 14 - Essence 1.2 Areas of concern adapted to a Smart City (image of the author)

The change to be evidenced is in the Software System alpha which has been replaced by the Smart City alpha. The other alphas have remained unchanged. This change, according to Essence 1.2 specifications, was not needed because its extension mechanism allows the creation of sub-alphas but, in this case, it seemed to be more opportune to define a new alpha to make the diagram more understandable.

In this customisation, some sub-alphas have been added to implement the chosen Ramaprasad framework. The first sub-alpha set is about Stakeholders' alpha.

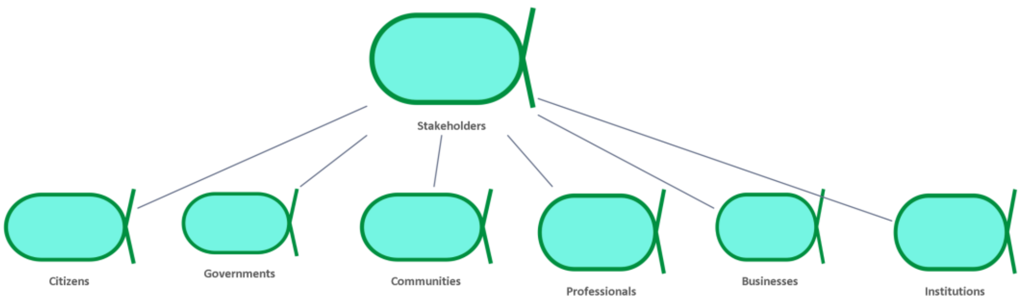

Figure 15 - Sub-alphas for Smart City's Stakeholders (image of the author)

The second sub-alpha set is about the Opportunity alpha: the outcomes (values) proposed in Ramaprasad's framework have been mapped as sub-alpha.

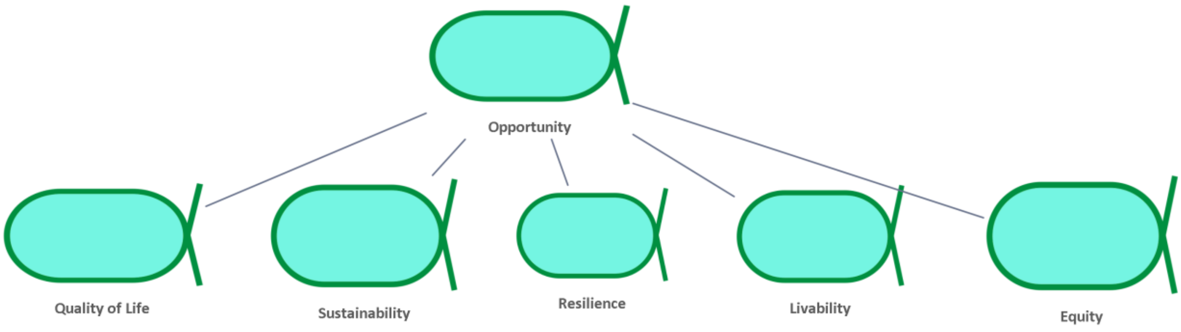

Figure 16 - Sub-alphas for Smart City's Opportunity (image of the author)

The third sub-alphas set is about Requirements. In this set the Green Urbanism principles have been arranged because they are the "requirements" to be satisfied (after their gathering and discovery) by the Smart City alpha, to provide Opportunity (outcomes) needed by the Stakeholders.

The model used in this research is the fifteen principles of Green Urbanism according to Lehmann, in its 2010 formulation, depicted in the diagram below:

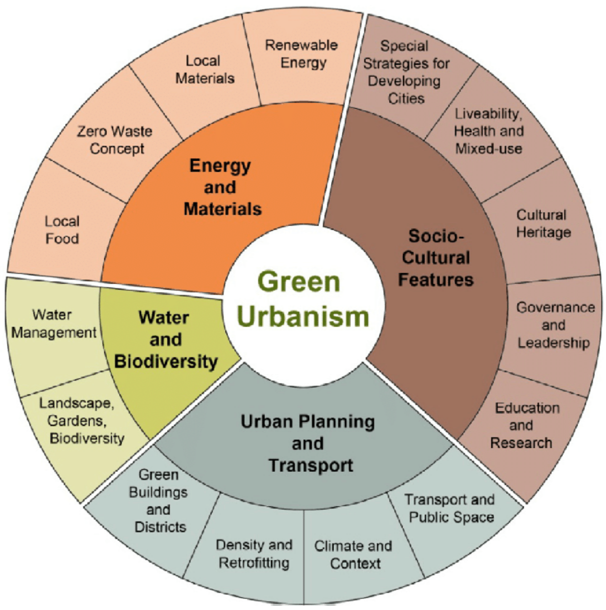

Figure 17 - Principles of Green Urbanism according to Lehmann (image from Lehmann, 2010)

Lehmann divides his Green Urbanism model into four sections: sociocultural features, urban planning and transport, water and biodiversity, energy and materials. He defines a holistic vision where these four areas (and their fifteen subsections, The Principles) are interconnected and they influence each other. In his formulation, Lehmann also considers some actions to be taken for each principle.

An example of these actions is shown below:

Principle	Recommendations
Principle 6: Transport and space The city of eco-mobility would have a good public space network and an efficient low-impact public transport system for post-fossil-fuel mobility	Invest over 6 per cent of GDP in public transport, expand tramlines and introduce free hybrid buses. Offer multi-modal public transport systems: a high number of connections and choices, frequent trams and buses, and safe pedestrian and cycle networks. Improve streets by giving greater priority to pedestrians and cyclists
Principle 12: Cultural heritage The city should promote public health and cultural identity, becoming a safe and healthy city, which is secure and just	Protect existing structures; demand and facilitate more adaptive reuse by relaxing the building code. Consult and involve communities to ensure genuine commitment
Principle 14: Education, research and knowledge-sharing The city should provide education and training for all in sustainable urban development	Invest 3 per cent of GDP in research and innovation; strengthen university education programs to include climate change impact. Facilitate sustainable behaviours and provide incentives for long-term behaviour change by positively influencing values and attitudes to reduced consumption. Remove policies that encourage wasteful consumption (e.g. fuel subsidies)

Figure 18 - Examples of GU principles according to Lehmann

From our perspective, these principles are the requirements, according to Essence's vision, to be satisfied to ensure that the opportunities are met, i.e. the Stakeholders' values are provided.

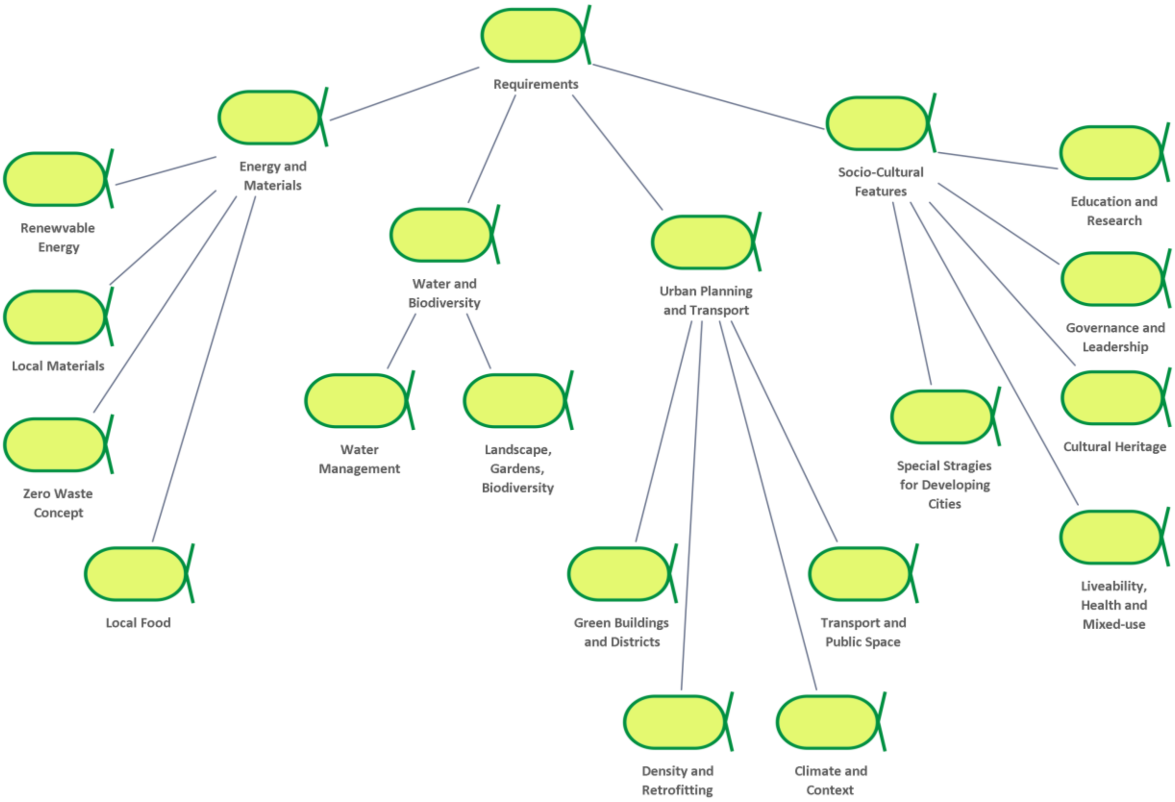

Figure 19 - Sub-alphas for Smart City's Requirements (image of the author)

The last sub-alphas set is about the Smart City alpha. In this alpha have been put all the elements of the framework "smartness" element, according to Ramaprasad framework.

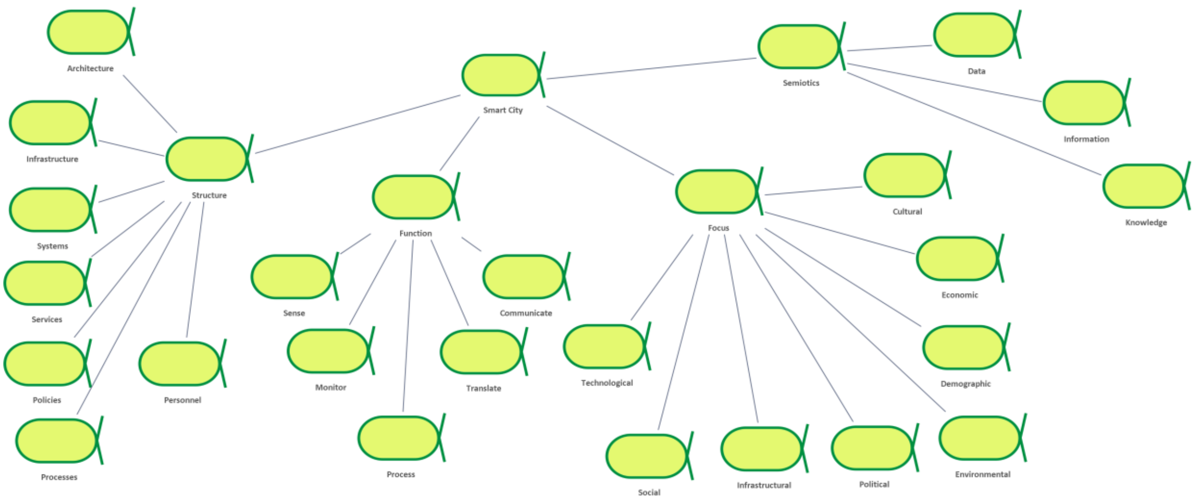

Figure 20 - Sub-alphas for Smart City alpha in Ramaprasad's framework (image of the author)

This last sub-alpha set is one that directly controls and measures the smart city development stage. In this paper this last sub-alpha definition, coming from the Ramaprasad framework, has not been considered useful and the research has moved into using it as an ontology (as Ramaprasad idea was) to describe all the illustrative elements. Anyway, this representation has been reported because further investigation will be done in future research about a formal descriptive theory of Green Urbanism.

To effectively apply Essence, for each alpha, a lifecycle composed of some alpha states must be defined. The alpha states are evidenced by checking the evolution of some Work Products, that are used to organise the Alphas and give visibility to their progress. To progress the Alpha States, some activities are performed and their outcomes (changes in Work Products) provide the Alpha States evolution.

In this article, not all the elements will be reported because they are too many for the scope of the paper but the methodology should be clear. Considering only Ramaprasad's elements they are 25,200 possible "illustrative components", but each of them can exist in different forms so the possible number of cases is even higher.

There are some other elements, according to Essence, that must be designed. They are:

- Activities, the task to be accomplished to progress with the smart city development.
- Competencies, to explicitly declare needed skills
- Patterns, to provide qualified solutions to common problems

Also, these elements will not be detailed to keep the article focused on methodology demonstration.

4 Risk Analysis

4.1 Definitions

From FAO & WHO definitions, risk analysis can be defined as follows:

risk analysis = risk assessment + risk management + risk communication

Risk assessment is defined as 'the process of hazard identification and risk estimation (likelihood and consequence)'. The risk assessment process aims to identify and assess all risks that could result in requirements coverage loss. This is a generic definition. In this document we are interested in defining a specific violation of safety and security requirements so, for risk assessment, it will be needed to state which are these requirements. This can be considered step zero of the risk assessment.

The three main steps of risk assessment are:

- hazard identification, which is the analysis of what, how, where and when something could go wrong (impacting one or more requirements) and the causal path that leads to it;
- consideration of the likelihood of the above adverse outcome and its severity (severity of the consequences)
- risk estimation to determine the weighted impact. The risk estimate combines the likelihood and consequences giving a final, summarized, impact level (usually a discrete value like low, medium, or high).

Risk management is defined as the overall process of risk evaluation, risk treatment and decision-making to manage potential adverse events that will impact.

4.2 Unified Risk analysis frameworks

4.2.1 Comparing security and safety risk analysis frameworks

In the city planning, design and construction, security was only physical security and information security played a secondary role because elements of the city were not connected to the Internet. With the introduction of smart cities, the advent of Internet-of-Things distributed ledgers (e.g. blockchains), cyber-physical systems (CPS), digital twins, virtual communities and virtual spaces/places, there is the need to include such kind of security into the risk analysis. A smart city is a highly interconnected, hugely distributed system of systems, full of automation and control systems. These systems often belong to different areas, spreading from energy and water management systems to intelligent transportation systems, industrial systems, virtual societies, smart homes, cooperative robotics and more and more. In this context, information security systems are mandatory to protect all these elements from attacks, whatever an attack could mean. In a smart city, many systems can be seen as mission-critical and, consequently, system security is an essential factor that will affect also the safety of such systems. Consequently, it is needed a holistic approach integrating both, security (information and physical) and safety, considering normal conditions and emergency conditions.

In systems engineering, a specific jargon term exists, and it is called dependability. Dependability is defined by its attributes. These attributes are, usually six and are:

- Availability, that is the capability of the system to provide its function under nominal conditions;
- Confidentiality is the ability of the system to avoid unauthorized people can access information;
- Integrity is the capability of the system to not allow unauthorised data changes or to detect when undesired change happens;

- Maintainability, that is the quality of a system to maintained at a desired level of efficiency and an acceptable cost;
- Reliability is the measure of the probability of the system working under the specified operating conditions and in the desired time;
- Safety is the ability of the system to preserve human health during operation and maintenance

All the elements of dependability depend on both the intrinsic properties of the system and respect for specific procedures and almost always they are designed to consider human errors or intentional misuse or attack.

Dependability means, for engineers, the “reliability” of the system, and quantifies the ability of the system to satisfy the requirements from which it has been designed. This feature must be ensured at a sufficient level. In the context of our research, these requirements should backtrack up to the original urban planning and design requirements and not be limited to typical systems engineering specifications but also include other elements like democracy, green principles or participation that are typical of these domains.

To evaluate the dependability level, it is very common to consider the risk of potential problems that can arise during system operation. These problems can be of various types and must be identified. For each of them is necessary to apply specific countermeasures that act as risk reduction or prevention mechanisms. For example: for a fault, we can define a strategy to forecast it or redundancy to let the system continue to operate even if one component has failed. Another strategy can be the elimination of the possibility of fail to add some preventive elements of removing the risky component.

The term fault is a generic word that can vary from software to hardware failures, from process to accident malfunctions, and that can be systematic or random. A failure can be related to wear for things that can experience a damage after long use or can be completely independent of it (e.g. many software issues do not depend on the “wear” of the software).

In this section, we will call risk reduction which often includes also its prevention. In successive sections, the two elements will be distinguished.

Risk reduction is considered as the set of strategies, actions and measures aimed to reduce risks. This reduction must be both cost-efficient and able to keep it below a threshold that is an acceptable value. Thinking to reduce the risk to zero is practically unfeasible, very often expensive and rather seldom possible. So, it is essential to define a ranking of the risks and prioritize prioritising them, considering both the current risk level (i.e. with no countermeasures) and the acceptable risk level (i.e. after the adoption of specific countermeasures). Following such a priorities list, starting from the most important, specific risk “approaches” must be defined to manage and reduce the risk, for each intolerable case.

Risk management is the process to identify a good approach to reduce risk to a tolerable level. It is an iterative process of four steps. In the first step, existing risk treatments are assessed, In the second step, the residual risks are evaluated. In the third step, these risk levels are checked against the tolerance level (i.e. the acceptable residual risk level). If the risk is not acceptable, the third step looks for new risk treatments, assesses their risk level and goes back to step three. If the level is tolerable or there are no new possible risk treatments, the process ends. Usually, there are many different risk treatments approaches available and, consequently, decisions about risk treatments usually influence system design, demanding a review of engineering resources allocation. In the case of a smart city, which is a system of systems, this approach from a holistic perspective is very hard to be accomplished. In addition, it is mandatory to map urban planning and design requirements onto the dependability. But let us further detail how this can be done better defining what is a risk.

Risk is generally defined as the product of two factors. The first one is the likelihood (i.e. the probability) of the occurrence of the risk. The second is the impact (i.e. the severity in case of occurrence) of a risky event. Risks are not of the same type and can be classified under different categories. Then, it is possible that, in one case, we can consider financial risks, while in others we consider safety risks and in other cases, we consider both. Some risk categories impact operability (i.e. the ability of the system to work) while others impact the loose of more general requirements, like democracy or participation. These categories will have to include all the elements (coming from our smart city framework) that we want to include as requirements to be protected from risk. For example, some events can reduce the livability below a desired level and this is a risk. But not all the categories have the same weight. Some categories can be heavier than others. For example, a financial loss has not the same importance of human life. To solve this issue, different categories should be considered independently.

As already stated above, the Smart City is a tightly connected and critical system of systems. Starting from this consideration, it is essential to go beyond the traditional engineering approach that limits most of the risk analysis to functions (i.e. operational risks), safety and security risks, including also the risk of loose original requirements requested by the Urban Planners and Designers. Before proceeding with this further analysis, information security risks must be further detailed. These risks originate from undesired events on information or their processing. These manipulations can be made both by internal or external actors and, usually, protecting from internal factors reveals to be more difficult than protecting from external, especially when these factors are human factors. These manipulations, due to the strong integration between ICT and the Smart City, can impact dependability, hitting one or more of its attributes, and generating failure effects that can be categorized in different ways, increasing the difficulty to prioritize risk treatments.

For example, a failure in some data processing pipelines could create a danger that impacts human health (safety) and the ability to maintain some technological systems (maintainability). This failure of ICT systems will cause other failure modes that will impact human health or even human life, and reduce maintenance effectiveness and efficiency, leading to operational failure risks and life cycle cost increase. Consequently, it is mandatory the coordination between construction and ICT engineering, which have different focuses. For example, construction engineers are very concerned about safety and maintainability while ICT engineers are mostly focused on confidentiality and integrity. Putting attention on different attributes is even more evident when comparing with urban planners' or urban designers' perspectives. Urban Planners and Designers consider elements like Democracy or Livability that are light-years far from the engineers’ perspective. And this happens, mainly, for two reasons. The first one is that Urban Planners, Architects and Urban Designers operate at a level that focuses on the whole Smart City or a large portion of it while engineers focus on single systems of single infrastructures. And this is a change of scale that fragments and dissolves the Urban Planning, Architectural and Urban Design requirements into smaller elements that are observed by engineers. The second aspect is that they have almost always, completely different qualities to be observed and this leads to a partitioned, siloed, approach in risk management that can save the detail and lose the big picture. As far as Smart Cities spread all over the world, this problem will become more and more evident and needs a new coordinating approach. This coordination, as already stated since the beginning of this research, requires an agreed combined creative process and a common language for communicating, comparing and treating risks.

In safety risk analysis most of the risks come from a statistical failure probability. In the security domain, risk analysis depends on the statistical estimation of vulnerabilities, weaknesses and the interaction of an attacker (that can be human or a machine) with the system. And this interaction is the one that will drive the design of the system’s resistance to the attack. Including such human factors (like emotions, revenge, avidity, and personal advantage) into a likelihood for risk can be difficult. In Urban Planning risk analysis it depends on completely different elements that are diluted during the implementation and very hard to be managed.

For example, Songdo, the Korean Smart City designed from scratch, can be considered a failed smart city project (Yoo, 2017). According to Yoo, many reasons have led to this failure and, reading these reasons in the light of this research, many of them can be considered as giving too much focus on ICT than on regional policies, i.e. building using technology, "forgetting" the original Urban Planners perspective. For example, according to Yoo "A call for readdressing U-City policies is required in the circle of urban regeneration and regional planning rather than building a new town with ICTs" which means that ICT has been the driver in Songdo's implementation rather than the continuous focus on the big picture.

Before proceeding with the proposed integrated risk analysis framework, a state-of-the-art analysis of existing methods will be provided with the explicit aim of integrating safety and security in a single methodology. So, in the next sections, we will examine existing frameworks for risk analysis, integrate safety and security and then add any other requirement risk analysis, arriving to fully cover both dependability and Urban Planning, Urban Design and Architecture risk analysis.

4.2.1.1 The need to integrate safety and security

The idea that risk analysis for safety and security can be unified in a single methodology has been widely accepted and it is a relevant trend in scientific research. Many reasons are increasing this trend, from the need to co-design systems to the evidence that, in many critical systems, both aspects are influencing each other, and many authorities have started designing security standards for safety-critical systems. In addition, in many cases is mandatory that strong and efficient communication and coordination are ensured between safety and security domains. But there are some challenges to achieving this unification. The first challenge is that most safety risks are tied to device failure or human errors then they are managed on a statistical basis, while security is often threatened by deliberate attacks and should be managed on vulnerability assessment and countermeasures definitions. Another important challenge of this unified approach to safety and security risk management is that the disciplines have standards that are at different levels of development. Also, the available knowledge used to define such standards follows different dynamics: safety follows a technology that changes slowly if compared with the evolution of information security. In addition, safety is related to complex systems that are not complex as modern ICT systems and that do not evolve continuously as the software does. For example, an HVAC system or a building can have different grades of complexity but they change very slowly. Software used to manage a building or an HVAC system can have many changes in one year and if the software has to manage something complex, like a building or a wide community, it can be changed even many times each day.

In any case, safety and security engineering must be focused on system-wide features and adequately integrated because both have a major impact on the development and operation of the “product”, and even on the company's reputation.

The main difference (and also the main obstacle) between security and safety is the already evidenced different point-of-view that results in a very different engineering approach. This different approach also results in naming and definitions.

As already introduced above, safety engineering focuses on the analysis of the effects of defects (production, maintenance, operation, …), failures (direct, induced, caused by wear, detectable and not detectable, …), and errors (software errors, procedural errors, human errors, …). These risk elements can be mostly predicted at design and development time using techniques like FMEA, FMECA, and Fault Tree Analysis (S3000L, 2023) and also can have quantitative approaches, for example for reliability, if supported by statistical models founded on wear curves, failure and failure modes distributions, clustering to define system models classes and return-from-field data. Consequently, safety risk analysis methods define processes that have been designed for each specific domain and methods conceived mainly to develop safety-critical systems or to avoid hazards during work (i.e. the so-called occupational health). These methods aim to minimize the systematic failures risk during development as well as to control random failures during operation. These standards mostly depend on effective quality management and systematic processes for risk identification and management. This approach must be kept for the entire lifecycle, starting from the pre-acquisition phase, and passing from design, development, early service, in-service and disposal phases.

Another kind of safety, occupational safety, first depends on these methods because the first step is to use “safe things”. But this kind of safety also considers environmental and biological elements that can cause damage to workers’ health. So, in this safety, the approach is based on production process design to avoid these hazards. Then, the safety relies on typical patterns that must be considered and that are usually analysed with a top-down approach.

On the other side, security standards not only consider the risk analysis process to assess and manage risks, but often provides best practices and guidelines principles for the entire life cycle, or identify basic principles, especially for cyber-security. Sometimes they also are limited to a portion of the complete design, development, production, operation and dismission system life. When approaching security, these standards, almost always, have no practices and no methodologies shared with the safety domain. In addition, often there is no sharing or overlapping between security standards and engineering standards. An example could be the Common Criteria (CC), a robust and well-known standard for information security evaluation, able to certify something by ranking it according to the security level scale, but not applicable to security engineering.

It is evident that, anyway, security and safety have a reciprocal impact, many similarities in principles, and a set of interdisciplinary commonalities. Nevertheless, their different structures often lead to considering them as having different targets and effects, while real interferences between them exist. This causes the (undesired) effects of these interferences are not completely considered at the design level and, consequently, not handled. But this can be even worse because safety and security often have contrasting behaviour if considered in their relationships with system functions, costs and performances and often are even in contrast between them. A straightforward example of this last considered contrast can be shown by an electrical steering wheel lock system. For security, it is needed to lock to prevent or resist an attack (for example a trial to steal the vehicle) but, it is dangerous because introduces a new failure mode that can lock the steering wheel during driving causing the driver to lose the control of the steering wheel and going in the wrong direction.

What happens too often is also that the incoherent approach deriving from non-integrated methodologies to manage risk could lead to inconsistent (and potentially dangerous) design, which will be (probably) identified in a late development step, with an increase in cost and the need of more expensive compromises or huge refactorings. In conclusion, a common approach for both safety and security risk management handled by cross-domain expert teams is required.

A final consideration is that, in the specific case of a smart city public space, the safety and security risks should be analysed keeping into account the original requirements coming from Urban Planning and Urban Design. Many elements provided in the first part of this research are aimed at traceability. Having evidenced Essence 1.2 role or classified public spaces are needed to support this unified risk analysis approach in keeping original requirements valid. But this kind of discourse will be further detailed later.

4.2.1.2 Qualitative and quantitative approaches

Most used methods of risk analysis are based on qualitative assessments through a discrete ordinal scale. For example, some safety standards have an integer risk scale ranging from 0 to 3, while some security methods consider the threat level on a scale that has been discretized in 3 values like “no risk” to “moderate risk” and “high risk”. The same for the impact. These scales are also of two or three types (i.e. the different elements that compose the risk) and then their values are added, multiplied or put together with some formulas (the most common approach is multiplying the discrete number associated with each possible class). After having computed such a formula, a total risk rating is obtained and it is compared with some thresholds that decide the final risk level.

For example, a probability of 1 (low probability) multiplied by an impact of 2 (medium impact) gives a risk of 2 that is considered moderate. These qualitative standards have many weaknesses like poor resolution, range compression, risk inversion, ambiguity, and neglecting correlations.

To solve these issues, some methods have been proposed that are based on a quantitative assessment. In this case, values range in a given interval but continuously. In the case of security, the FAIR (Factor Analysis of Information Risk) methodology is an example. The FAIR model is based on quantitative analysis of the events' likelihoods and impacts, for each system vulnerability using a probability distributions-based approach that also considers the uncertainty (called confidence) of an estimation into account. Thanks to this approach, it will be possible not only to estimate risks but also to understand the quality, precision, "confidence" of such analysis and then pay more attention to low-confidence elements where the analysis has a lower quality.

4.2.1.3 Already Existing Integrated Risk Assessment Methods Comparison

A good, well-founded, risk management approach is defined by ISO 31000. It is a domain-independent approach that can be used to define a system to manage risk. It is required by ISO and IEC standards for their development (as explicitly required in ISO/IEC Directives, Part 1). These Directives define the rules to be followed in the development of International Standards. This means that any risk management standard that can be applied (directly or indirectly) to products, economics, industry, or services, has to explicitly reference or (explicitly) comply with ISO 31000.

ISO 31000 considers risk analysis from both quantitative and qualitative points of view. It also requires that all the results of the analysis must be consistent and allow comparison between different elements to ensure effective risk management. In this sense, the ISO 31000 standard does not allow mixed qualitative and quantitative approaches that lead to inconsistent results but it allows to use of one or both methods and, in the end, computes risk in a coherent approach that allows comparison, because the key of risk reduction is the ability to evaluate an improvement (reduction) of the risk value.

Moving far standards from IEC and ISO, also other authorities have developed their risk management models. For example, another important organisation like NIST (National Institute of Standards and Technology) has defined its framework for risk management. Its SP800-30 standard is a guideline for risk assessment in the domain of information security. NIST has also provided another risk management framework identified by the acronym RMF (Risk Management Framework) that considers some best practices to conduct a risk assessment in information and privacy management. In SP800-30, quantitative, qualitative and mixed (i.e. semi-quantitative) approaches are discussed. It also presents an approach that could be considered similar to FAIR because the probability of an undesired security event is split into two elements. The first one is the probability that an attacker starts a threat activity. The second one is the probability that such threat activity results in an undesired effect.

In semi-quantitative approaches the SP800-30 states that can be a hard task assigning a probability to a particular class (classes are bins obtained grouping elements in a range, for example, 10-20).

Macher et al. has proposed a framework that combines many different methodologies used automotive industry. Their risk management approach is founded on different approaches:

- Risk management for security (SAHARA - Security Aware Hazard and Risk Analysis)
- Risk management against failures during design and development (but also possible during early service and in-service phases) through Failure Modes Effects and Criticality Analysis (FMECA/FMEA)
- Security Framework for an FMEA (FMVEA), that extends FMEA with the analysis of the effects on security.
- Attack tree analysis (ATA), includes, in security risk assessment, a graph describing the successive actions done by an attacker, because the attack is often done using a multi-step strategy.

This risk management methodology proposed by Macher can be considered a good example of an integrated approach that allows the robust design of both safety and security on systems in automotive. Its most general concepts can be also applied to many other areas. In this research, this approach is used as a starting point to produce our RAFT framework.

The limit of the Macher approach is that it starts and ends in the automotive sector. What is needed in this research is something applicable to an interdisciplinary world that ranges from Architecture, Urban Planning, Urban Design, ICT Engineering, Robotics, Organisational Engineering and Construction Engineering. In this context, if the risk is considered, in its most common general sense, as the loss of a requirement, our integrated risk management approach should challenge the fact that an issue in some system (e.g. a database server) can impact a requirement defined at architecture or urban planning level, that is far from that system. Another important aspect of RAFT is that it must support ISO 31000. It has also to allow the management of uncertainty, also because of missing information (that will lead to the need to estimate them) in the risk management process. This requirement is needed because in the smart city context, day by day, this information and these likelihoods can be measured and estimated due to the enormous quantity of data managed by the city itself.

The SAHARA method defines a well-constructed process to quantify the impact of security on systems that are safety-related. It allows the identification, qualification and quantification of interference of security events with the system's safety. This evaluation is done at the system level. SAHARA arises from the combination of two methods:

- HARA (Automotive Hazard Analysis and Risk Assessment) is used for safety (and more in general other risk assessments)
- STRIDE, used in security for threat modelling. Stride is focused on analysing risks for the most common forms of attack which are Spoofing (confusing the system and leading it to consider an unknown source as a trusted source), Tampering (making undesired changes), Repudiation (capability of denying that a message is sent by a source was not sent by it), Information Disclosure (violating confidentiality) and Denial of Service (making a system unavailable, typically flooding it of request). These words are used to form the acronym STRIDE.

SAHARA focuses on the system level.

The FMVEA method is a derivation from FMEA/FMECA but with the addition, to the risk analysis, of a security risk management approach based, again, on STRIDE. FMVEA methodology combines the threat model and the failure-mode-effect models ensuring both safety and security risk analysis not at the system level only (as SAHARA) but detailing it up to the item level.

Both methods (SAHARA and FMVEA), are an example of combined safety-security methods. Both start from well-established safety approaches for risk management and extend them to integrate with risks about security.

For the information security risk classification, both methods (SAHARA and FMVEA) use an approach similar to the one used in safety engineering but integrating it with security. While traditional cybersecurity risk assessment is focused only on the identification (and evaluation) of (potential) vulnerabilities and threats, they also consider the interferences (i.e. the interactions) that both (safety and security) can have following the actions of potential (identified) attackers. Due to this approach, both methods provide evaluation frameworks to calculate important metrics to be used in a more detailed risk evaluation. The attacker's strength is one metric that can be defined by the combination of the attacker's capabilities (the ability to access a set of resources to perform the attack), intentions (the reasons, motivations and objectives of the attacker), and know-how (how expert and how much knowledge the attacker has to perform the attack). (Othmane, L. Ranchal, R. et al., 2015)

System resistance is defined by two elements: static security measures and impact.

Static security measures are countermeasures that are statically defined in the system like, for example, the system reachability (how easy is to connect with the target system to attack it), the system structure (that is the organisation of the system), and the tools that are necessary to execute the attack (attack tools). The impact on the system after a successful attack, considering such impact as the "sum" of the effects on the system and the related environment, is another element of system resistance.

These two metrics are intended to measure the capability of the attacker to make its attack successful and the second the capability of the system to resist an attack. The combination of these two metrics is used to calculate the likelihood of a successful attack in terms of the probability of the event.

Having the probability only, as already explained, is not enough. It is important, from the risk perspective, to estimate the "magnitude" of the event. So, for this estimation, the attack probability is used, in combination with the related impact, to define the "criticality level" (in a more general sense not limited to security only) of a "menace". The same criticality level is, in fact, also used to identify the safety importance, i.e. the interference with safety, of the security threat. In this way, the security risk is extended into the safety zone.

In addition to this criticality level, SAHARA defines the "security level" (SecL), a metric that can be used to select the countermeasures that should be considered.

The FMVEA, also uses an RPN (Resulting Risk Priority Number) as an indicator that allows risk ranking, defining a priority in risk evaluation during design and development (but also at any design review during the life cycle of the system) focusing engineering activities first on the most critical elements.

To calculate both SecL and RPN, the above methods use qualitative measures.

Qualitative measuring can be considered (almost always) an issue because it cannot be used directly in mathematical models to calculate a value for the system's vulnerability. In addition, these qualitative measures have poor calibration with the failure probability and are often not sufficient to develop an adequate integration between safety and security from the perspective of risk assessment, first, and risk management, then. Last, but not least, the discretization induced by the qualitative approach causes a quantization error that can easily spread through the entire analysis and lead to instability.

Another issue is that both methods are limited to analysing single causes and not multiple combinations of causes. While this multiplicity is very rare in safety (it is the combination of probabilities and multiplies values that are, usually, very lower than 1) it is common in security, where attackers use an attack path (i.e. a sequence of actions, that is a sequence of causes) to perform an attack. Consequently, multi-stage attacks could be neglected, and this is not acceptable from a security perspective.

Another methodology, that considers the attack path, is based on the so-called diamond model. It models an intrusion and allows its analysis. It is a very good and formal method for an a posteriori analysis of cyber incidents. The diamond is the main atomic element of an intrusion attack. The basic assumption of this model is that “for every intrusion event there exists an adversary taking a step towards an intended goal by using a capability over infrastructure against a victim to produce a result” (Caltagirone et al., 2013). According to such a definition, a security event like an intrusion is made of four elements: adversary, capability, infrastructure, and victim. These elements will be described later in detail but are represented as a diamond picture. In this diamond, as usual, there are four vertices, one for each element. One vertex is for the adversary, one for the capability, another for the infrastructure and another for the victim. The edges of the diamond are five and represent the relationships between these elements: adversary-capability, capability-target, and more. An advantage of this representation is that it also defines some meta-features that can be used to create more complex elements like, for example, activity threads or attack graphs.

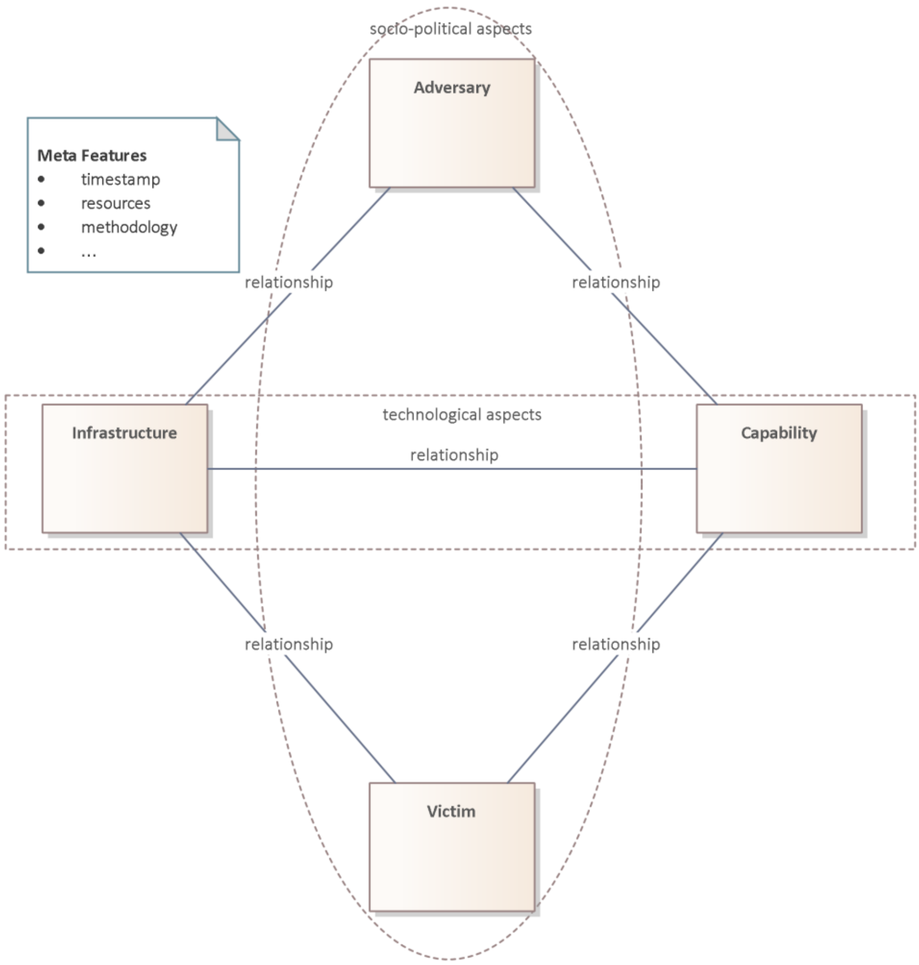

Figure 21 - Diamond basic model with core features and meta-features

Activity threads of the diamond model, as far as the attack graphs, have been conceived for intrusion analysis and are conceptually similar to attack trees because, if we consider a group of connected diamonds, the so-called "activity thread", it represents an attack path. An attack graph is defined as the composition of all the possible paths to perform the attack. Consequently, it is an effective way, often used in a posteriori analysis of an attack, to consider all the possible paths that an adversary could have taken in the attack. The activity thread is, then, an attack path that has been completely identified (if used in an a-posteriori analysis).

After that a security incident has been detected, usually, there is not enough information to immediately understand what has happened (we are yet considering the posterior case). Then, what the diamond model provides for a posteriori analysis, is that the events, the threads, and the graphs facilitate the analysis of the incident. In this way, security analysts will be helped in gathering missing information. This analysis is done by assigning confidence values to elements (features), so it is done using a quantitative approach.

The FAIR method, cited above, is another approach and can be used in an apriori analysis to estimate the risk of a security attack. FAIR works by splitting the risk into sub-factors that are used to build a PERT (Project Evaluation Review Technique or three-point estimation) diagram. Using FAIR, three sub-factors (the three points for estimation) are quantified giving the minimum, maximum, and most probable value of the risk (with a confidence rating). These evaluations (judgements) are modelled in analogy as PERT probability distributions.

4.2.1.4 Moving towards RAFT integrated risk methodology

Now it is time to integrate the safety and security risk analysis frameworks into a common methodology. The process we will follow will start from the quantitative security approach and extend to safety. This approach will lead to a common risk analysis framework (common in the sense of integration) for both safety and security that will allow the analysis of both security and failure events chains and coordinated safety-security risk management.

Let's start with the diamond model which is suitable for cyber incidents analysis and extend it to include safety and security.

A security-relevant event is represented, in the diamond model, by the above-described four elements (often called "core features". The diamond model also allows the definition of additional "meta-features" in addition to these four. The strategy that we will follow is to use these meta-features to represent the SAHARA and FMVEA elements in the diamond model. This approach is shown in the figure below. The two side boxes represent SAHARA and FMVEA attributes and classes, while the squares at the vertices are the four elements of the model.

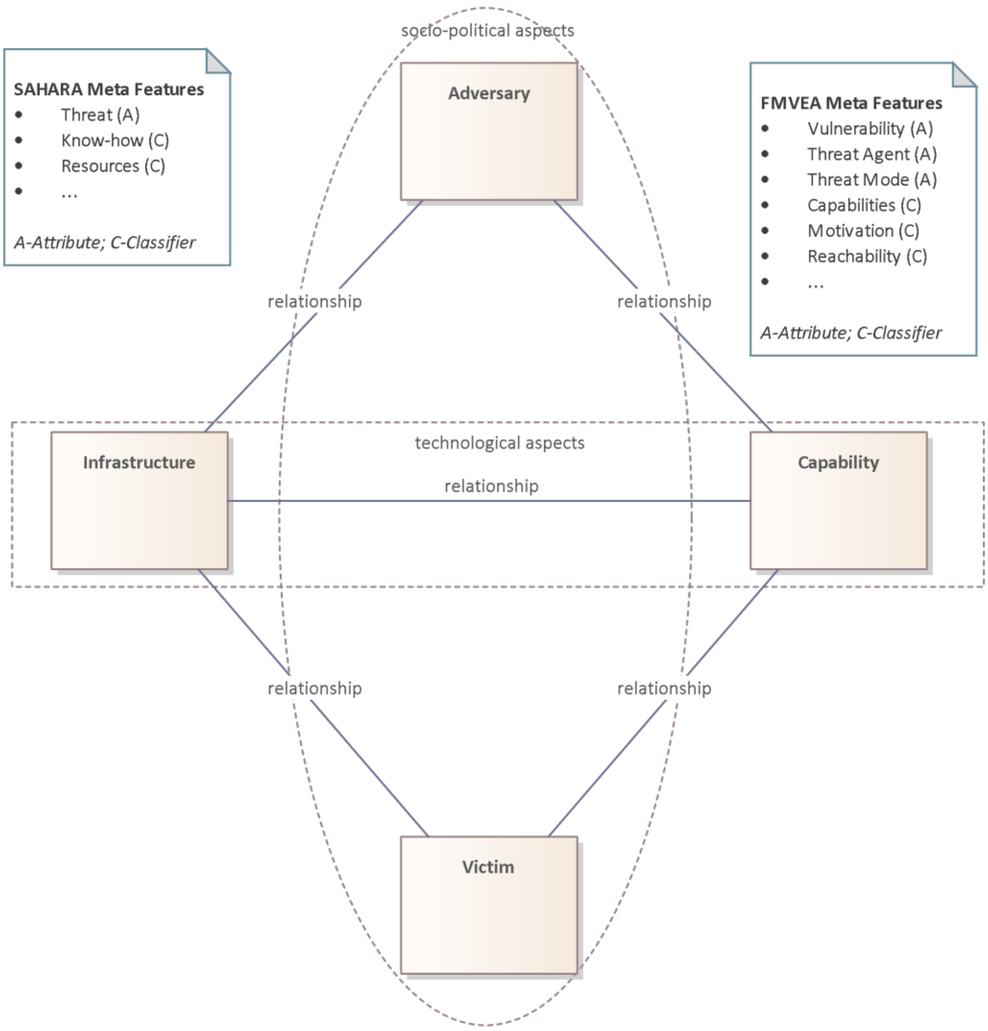

Figure 22 - Extended Diamond Model

4.2.1.4.1 The mapping of the adversary

Now a first specification about the mapping is done starting from the features and meta-features of the diamond model. Let's start with the adversary concept.

The adversary feature represents a set of adversaries that aim to violate a system. But an adversary is a too general term because it is missing the motivation, i.e. the reasons to try to attack the system. Let's call these reasons the "objectives" of an adversary. These objectives imply that an adversary could be split into two components: the operator, who is conducting the attack, and the customer, who will benefit from the attack, which could even be the operator itself.

The SAHARA method does not define the "adversary", while FMVEA does (because the "threat agent" defined by ISO 27005 is conceptually identical). The reason for this difference resides in the fact that SAHARA is about safety while the adversary is a term about security. For the same reason, FMVEA, which includes security, considers it. We can solve this issue by understanding that an adversary can be defined in terms of two SAHARA classifiers, the "know-how" and the "resources".

The know-how measures the skills and comprehension that are needed to attack the target system. Consequently, know-how is mapped along two edges that determine the relationship between the adversary and the infrastructure and the adversary and the capability. This is shown in the picture below where the classifiers from SAHARA are shown as circles and are connected as already explained.

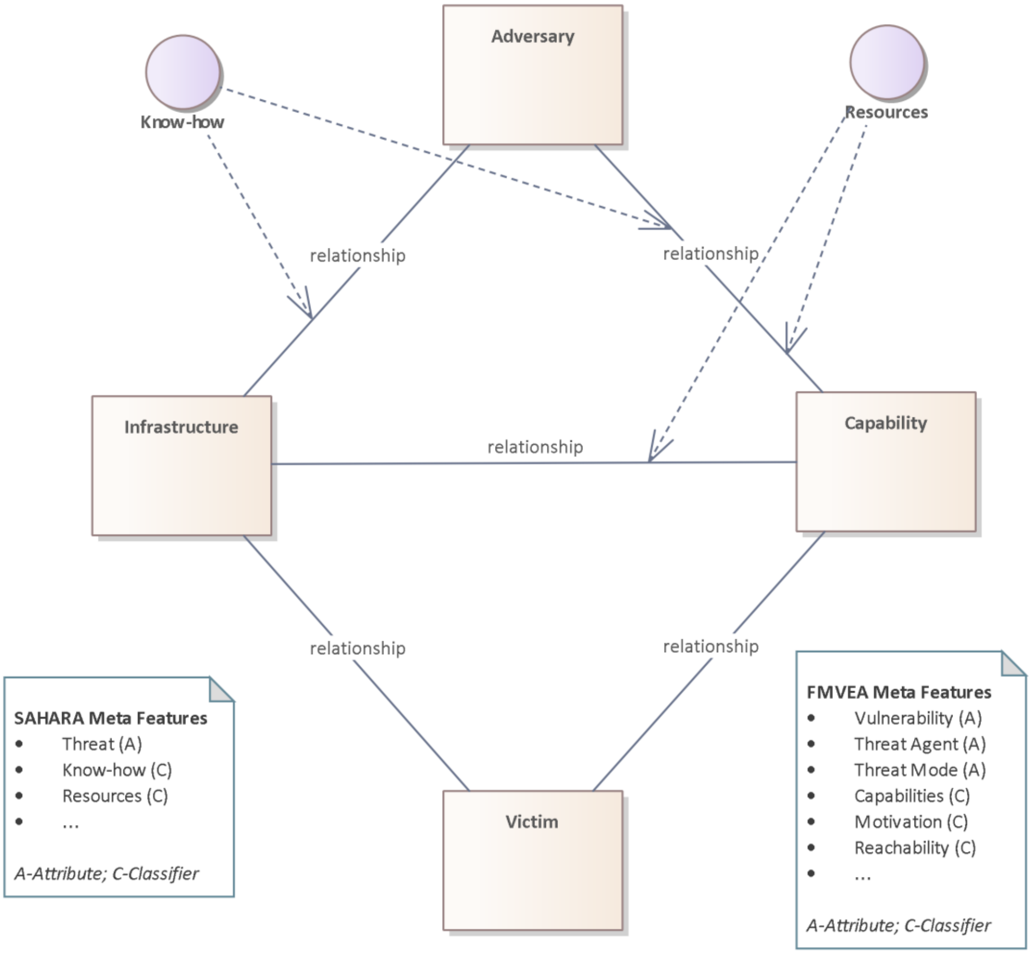

Figure 23 - Extended Diamond Model with an example of mappings from SAHARA

To complete the attacker representation using SAHARA, we consider the resource classifier, again from SAHARA, which qualifies which resources are needed by an adversary to attack the target. This classifier is then mapped onto the relationship between adversary and capability and the relationship between the capability and the infrastructure.

Both the mappings onto the adversary-capability and the infrastructure-capability edges represent the “gadgets”, the “money” and all other elements that an attacker needs to use to complete an attack on the target system.

The process can be repeated with other SAHARA elements (Dobaj et al., 2019).

With FMVEA the process is easier because it explicitly states the adversary as a threat agent and so the mapping is trivial. Because FMVEA is based on ISO 27005 classification, it also defines the adversary's capabilities as composed of two elements. The first one is the knowledge that the attacker must have of the attacked system and it is identified as "knowledge". The second one is its financial capability, that is the monetary budget that the attacker can use to deploy the attack. In addition, FMVEA improves this representation with a specific classifier, which considers both technical and socio-political aspects, which is called "motivation". As depicted in the diagram below, it impacts the adversary-infrastructure relationship and adversary-victim edges.

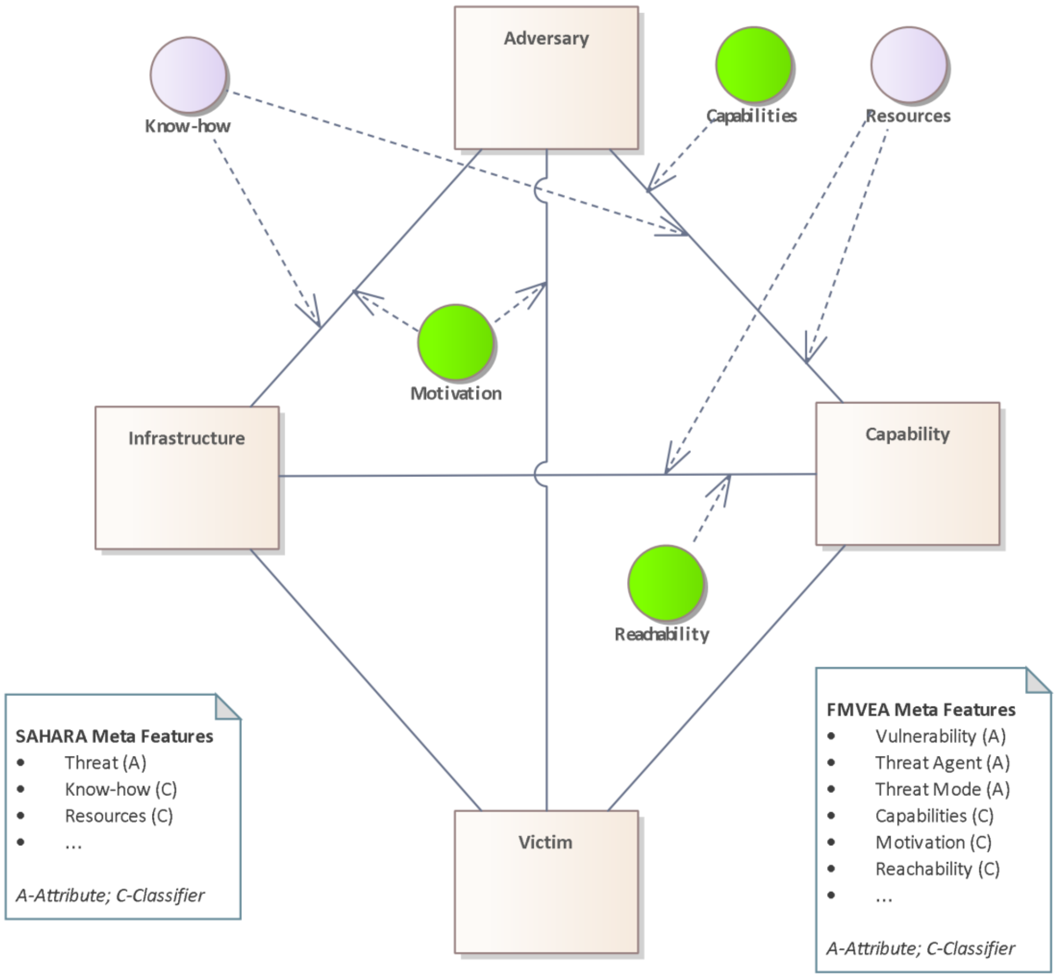

Figure 24 - Diamond Extension with meta-features from FMVEA

4.2.1.4.2 The mapping of the capability

The second concept to be mapped is capability.

The capability feature, in the diamond model, describes the tools and techniques used in an attack.

Capability can also be considered as an opportunity because it is the set of all vulnerabilities of the target system that can be used by the attacker. In addition to the vulnerabilities, the capability also considers the adversary's skills (in terms of tools, techniques, knowledge, ...).

Capability can be used to document non-exploited vulnerabilities driving the system's risk reduction activities.

The capabilities classifier from SAHARA and the know-how and resources classifier from FMVEA are easily mapped as already explained before.

4.2.1.4.3 The mapping of the infrastructure

A third concept is the infrastructure. It describes all the communication elements used by the attacker.

Infrastructure, in a diamond, can be classified into three types.

The first type is when the infrastructure is completely under the control of the attacker.

The second type is when it is controlled by an intermediary (that can be aware or not of this control). This second type is, typically, another infrastructure that (like *zombie nets*) is used by the attacker to hide.

The third, and last type, is composed of organizations that provide services needed for the other two types. (Caltagirone et al., 2013).

SAHARA and FMVEA, are both based on the STRIDE approach that is easily mapped using its ways of identification and categorization (Dobaj et al., 2019).

4.2.1.4.4 The mapping of the victim

The last concept is the victim. It can be partitioned into two elements.

The first one is the "persona", which is the people (in both physical and legal meaning, then also including organisations as personas) targeted whose assets are exploited and attacked.

The second one is an asset, considered as one in the set of ICT assets, which is the "attack surface" used by the attacker and towards which it targets its capabilities.

It is important to remember that many attacks are composed of many steps. In these attacks, the target could be, for example, an asset, that, after a successful attack, can become the infrastructure used in successive steps. Consequently, is important to understand that the victim of an attack could be different from the "final" victim, which is the real target of the whole multi-step attack.

Considering SAHARA and FMVEA, the victim is the target system, equipment or component that is subjected to failure modes or threat modes. If talking about safety, it is an element in the configuration tree, if talking of security the definition is easily taken from STRIDE and ISO 27005.

4.2.1.4.5 Mapping results and FAIR extension

After having mapped into the Diamond model the attributes from SAHARA and FMVEA, we are ready to estimate the risk of a diamond event (that will become not only a security one but also a safety one). The next step is applying FAIR and extending it. The use of FAIR will let us rely on a consolidated method with a strong mathematical basis.

The idea of the FAIR extension is based on the fact that using many different inputs coming from different experts allows a better distribution of probability. Mixing these inputs (i.e. the probability distribution according to each expert) the new, combined, distribution, will average the error of each expert and will result in a more realistic probability distribution. This approach will also have to consider the confidence levels and calculate the mixed level. All these analyses have to be conducted after normalization of the original experts' distributions.

The FAIR method does not limit the type of used distributions so, it is possible to combine different distribution types. As a consequence, RAFT will not be limited to PERT distributions only, as said before.

In this document, the proposed approach will be based on FMVEA but with an extension to support urban planning and design in smart cities.

4.2.2 The FMVEA-based approach in RAFT

FMVEA considers the combination of safety risks and security risks and has been developed in the context of product or system engineering. This genesis focuses on the avoidance of failures (that can have an impact on both safety and security) and on threats and vulnerabilities (that can have an impact, again, on both safety and security) but considers them separately and does not keep into account, as already explained, a possible sequence of events. In addition, it does not consider a third kind of danger which is those that derive from the environment. If we consider occupational safety standards (e.g. ISO 45001), we can see that each work process is analysed to detect dangers but some of these dangers are not related to malfunctions but are intrinsic in the process. For example, selling fuels like gasoline exposes the seller to chemical substances that can be dangerous. In this case, the exposition is not due to a failure but only to the intrinsic imperfection of the process. This consideration can be extended to any human activity in any context.

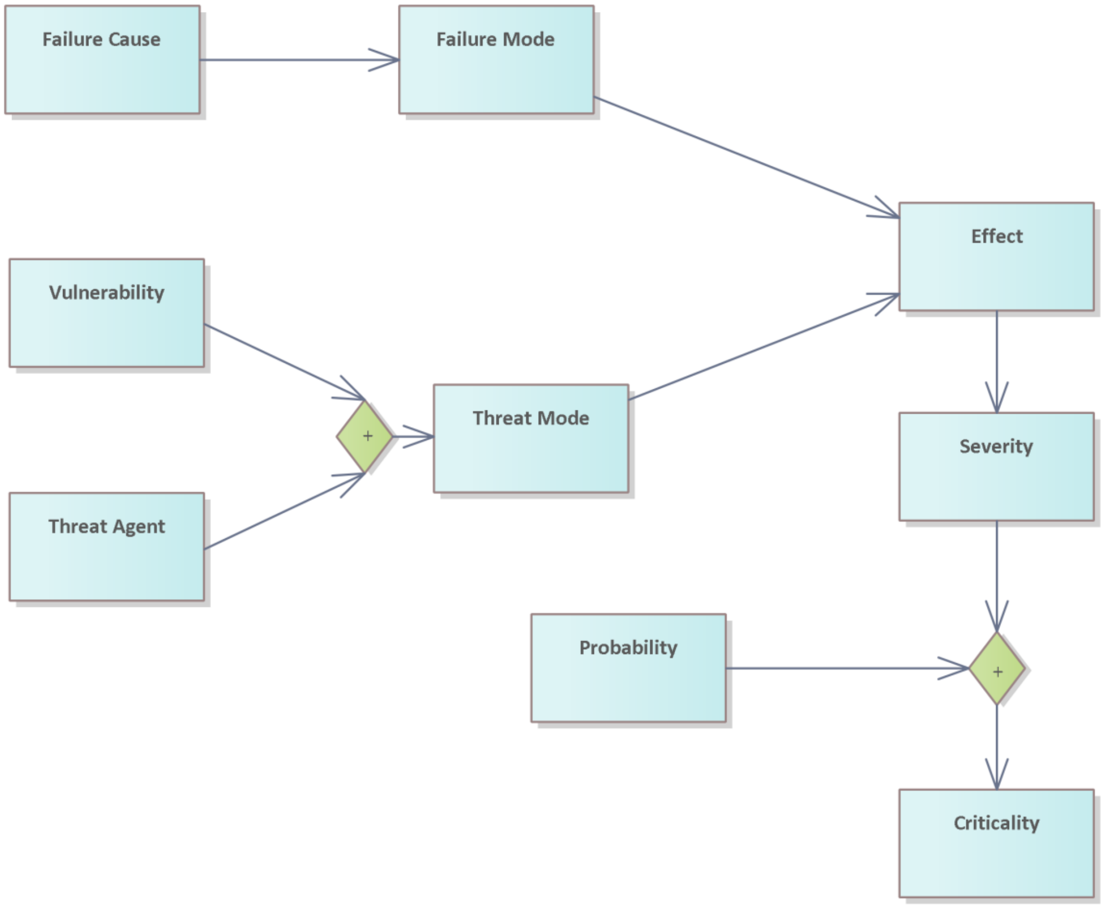

Figure 25 - FMVEA process

To unify the risk management considering all these elements, in RAFT we consider that risk can be of three types:

- Risk caused by malfunction
- Risk caused by deliberate attack
- Intrinsic risk present in the context

In the RAFT framework, the risks are then classified in terms of originating sources (i.e. hazards) and are of three types, depicted in the diagram below:

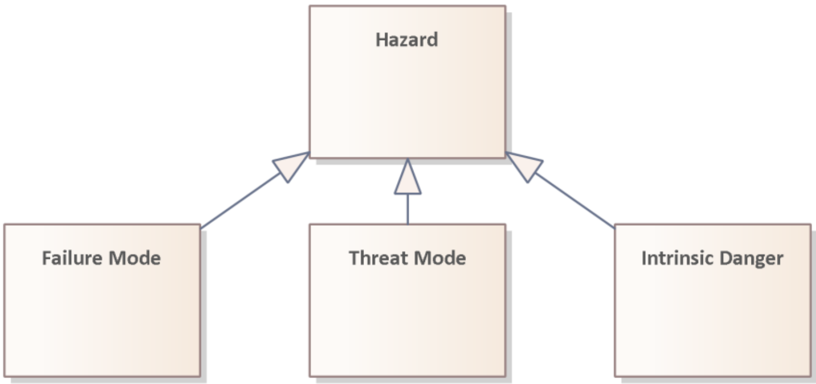

Figure 26 - RAFT Hazards Classification

The failure mode is a way in which a component of a system or a process can fail and has a probability to happen. It depends on the probability of the failure, i.e. a defect in the operation (sometimes caused by a defect in design, but the operation, from our perspective, is the focus, because we are not yet developing a methodology for designing at this phase).

The threat mode is how a system can be deliberately attacked and leverages a vulnerability, i.e. a defect in the protection.

The intrinsic danger is a danger that arises from the imperfection of the activity and so it depends on this imperfection (i.e. a defect in the activity). This imperfection in the activity is often originated from the objects used to perform the activity and, for this reason, it should be considered a defect of the entire process, meaning with the process the composition of tasks in a given sequence, manipulating some objects through some tools. The process is a conceptual representation of real human activities that are process instances. In this sense, the imperfection in the process (on tasks and/or objects and/or tools) is a defect of the process.

As stated before, there is another element that limits the FMVEA: the lack of failure paths. While in the diamond model, these paths are considered, FMVEA acts as a single-stage model. But the reality is different: a failure can introduce a vulnerability that can cause a threat mode that can cause a failure.

This different FMVEA is depicted in the diagram below.

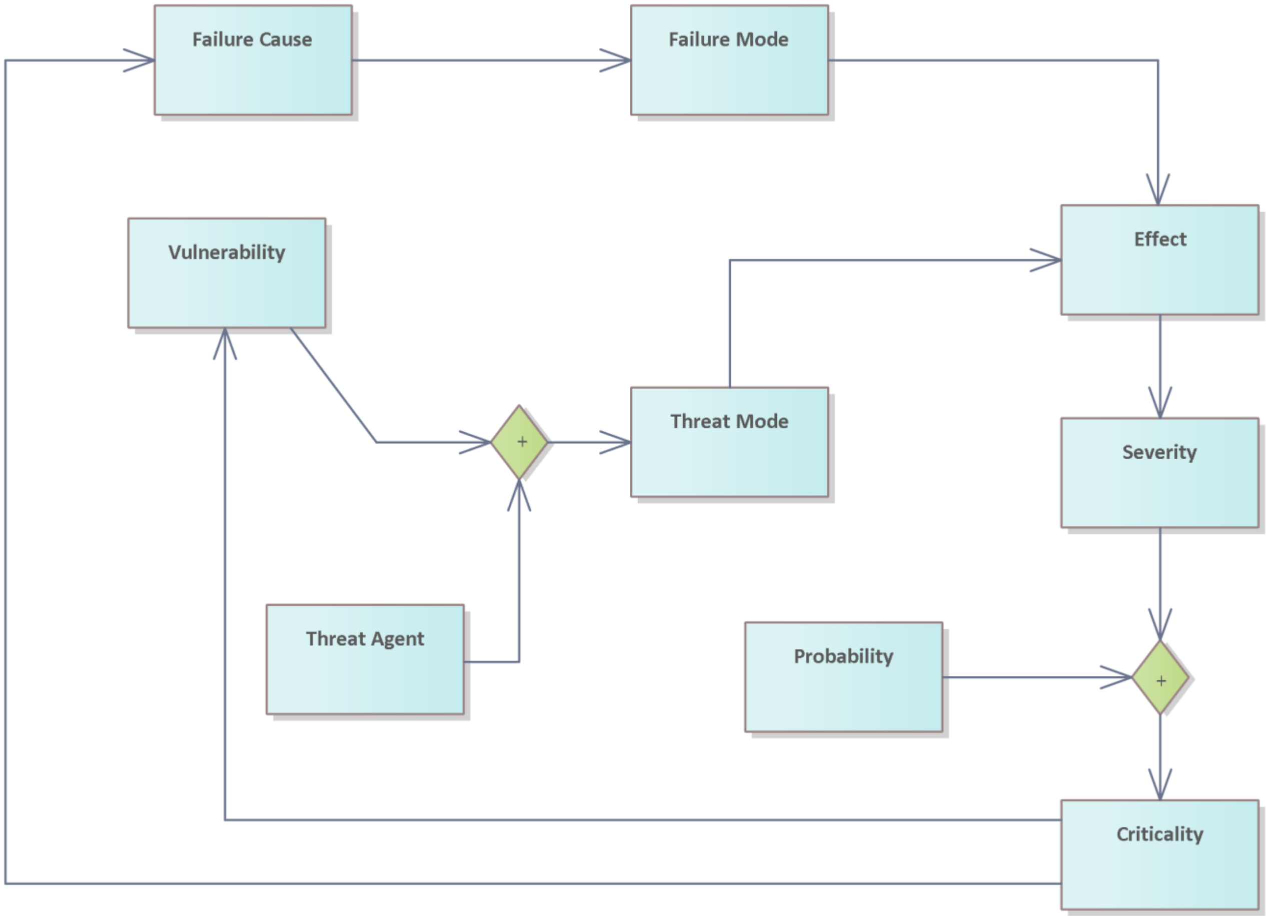

Figure 27 - RAFT modified FMVEA

In this diagram, the concepts that criticality can be the cause of a failure and that it can introduce a vulnerability are represented through the relationships that flow from criticality towards vulnerability and failure cause.

But how to handle such a recursion? One approach could be using a Markov process, another is using an enrollment approach.

Using Markov chains, the probability that a criticality causes a failure mode is expressed as a probability in a matrix. Rows of the matrix are the effects (of a failure mode or a threat mode) and columns are the failure causes and vulnerabilities. This approach will be further depicted later.

Using an enrollment approach means computing an FMVEA level and then propagating criticalities to underline possible vulnerabilities and failure, calculating a second level of FMVEA and so on. Ignoring negligible paths (i.e. those with very low probability) will produce a risk path that can be analyzed.

Before further analysing this issue, we will integrate the hazard classification with RAFT FMVEA, obtaining the following diagram.

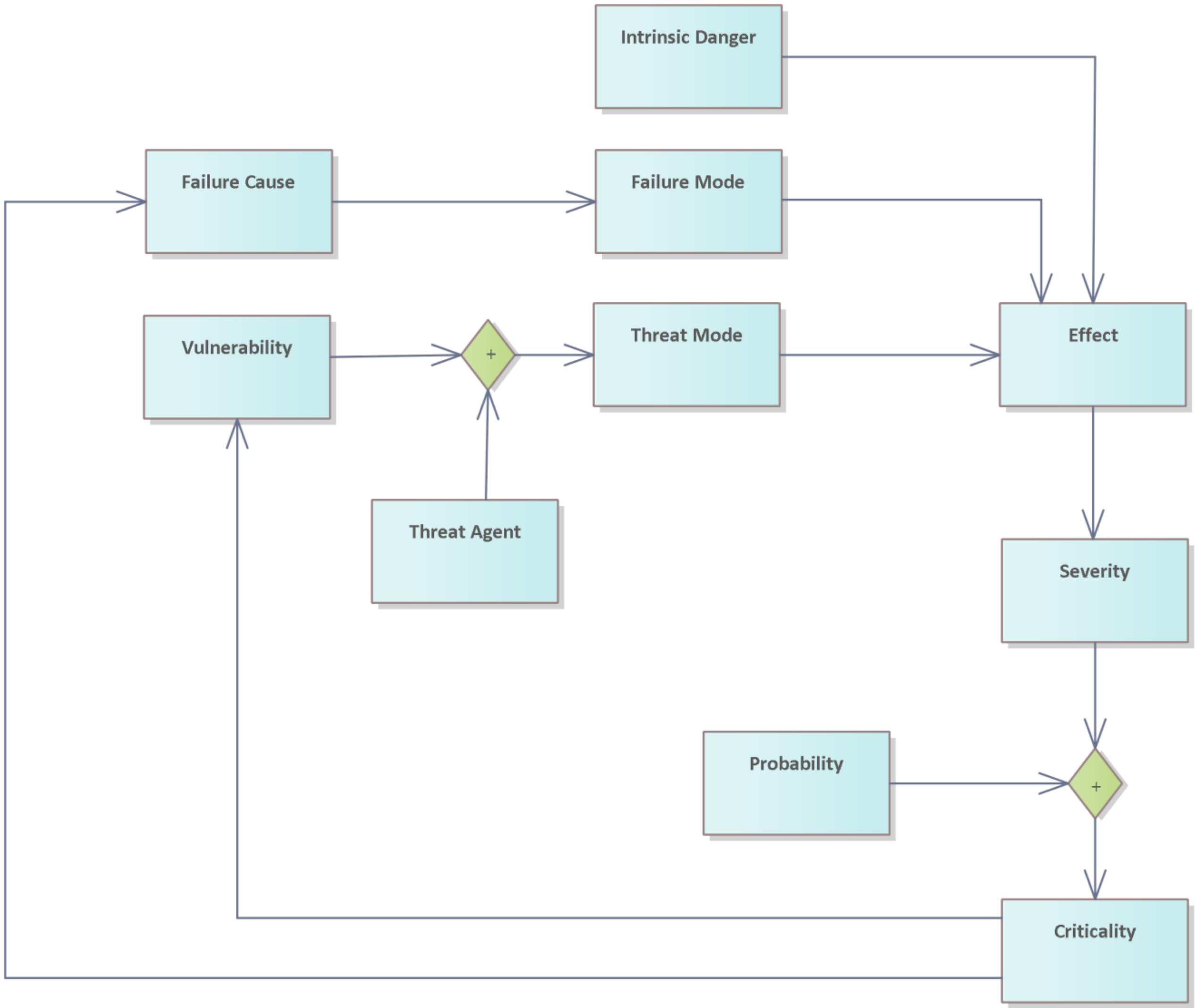

Figure 28 - RAFT FMVEA with intrinsic danger

Observing the diagram of RAFT FMVEA with the representation of the intrinsic danger, some issues are evident.

The first one is that the effect is caused by the threaded mode, or by the failure mode or the intrinsic danger, substantiating a symmetry that can be used to get a more general model.

The second one is that the probability depends on these three elements, on their likelihood to happen. Consequently, leaving it "between" severity and criticality is not the right representation.

A third issue is that if the effect can be timely detected, its impact could be acceptable. For this reason, a detectability element has been added to the process.

To solve this second issue and move toward a more general and unified model, single-involved probabilities have been considered. The result has been drawn in the following diagram.

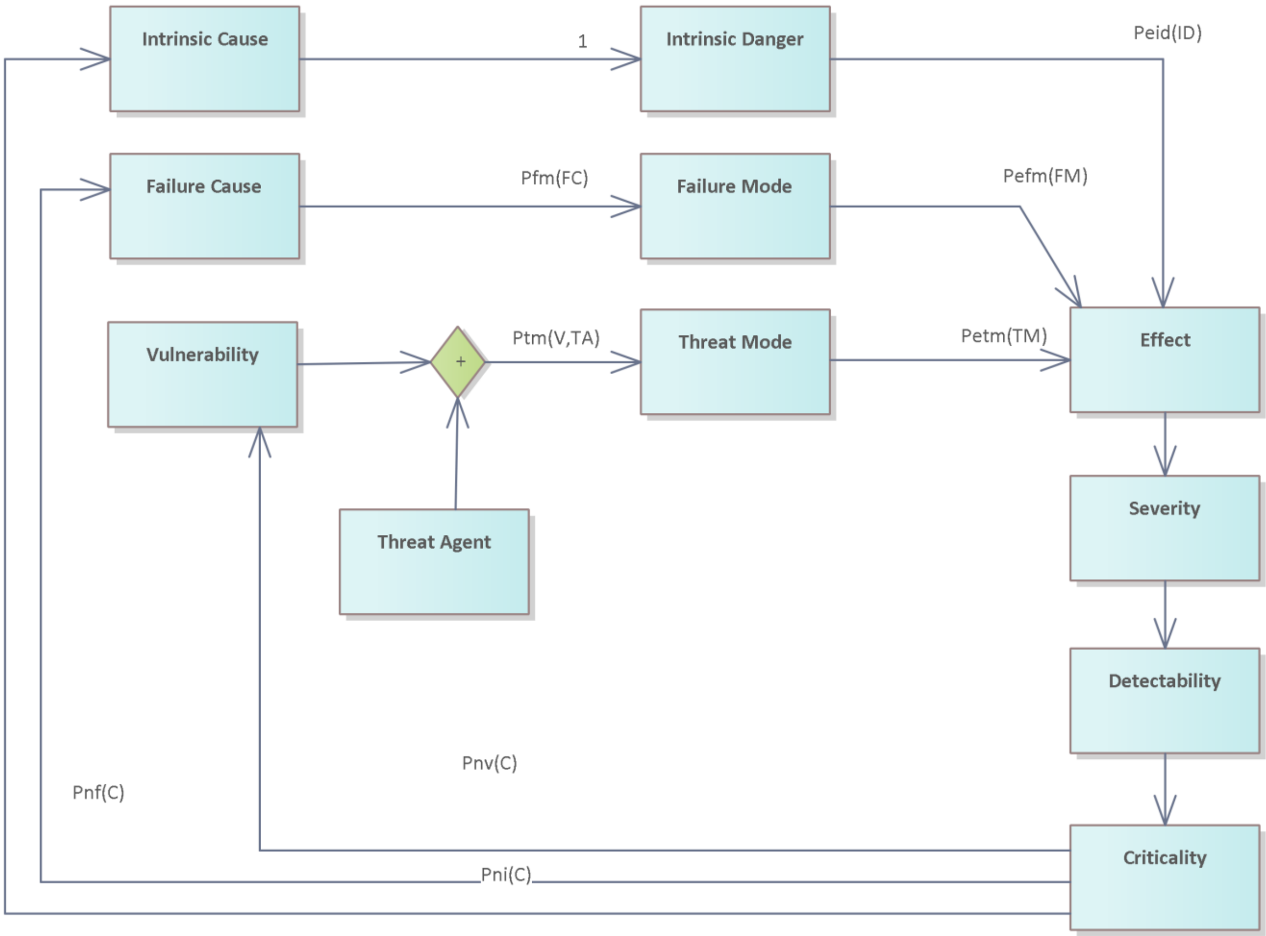

Figure 29 - RAFT FMVEA with explicit probabilities

In this diagram, on the various edges, probabilities have been evidenced. In addition, to further evidence the symmetry already identified, a placeholder for "Intrinsic Cause" has been introduced, setting the transition probability towards Intrinsic Danger as 1.

In the following table, each probability is reported:

Table 14 - Probabilities in explicit RAFT-FMVEA

Symbol	Description
Pfm(FC)	The probability that a failure mode occurs in the presence of a failure cause (FC)
Ptm(V, TA)	The probability that a threat mode occurs in the presence of a vulnerability (V) and a threat agent (TA)
Peid(ID)	The probability that an effect occurs given an intrinsic danger (ID)
Pefm(FM)	The probability that an effect occurs given a failure mode (FM)
Petm(TM)	The probability that an effect occurs given thread mode (TM)
Pnv(C)	The probability that a new vulnerability occurs given a criticality
Pnf(C)	The probability that a failure cause occurs given a criticality
Pni(C)	The probability that an "intrinsic cause" occurs given a criticality

Severity and detectability are given as discrete values in a qualitative form.

Given these probabilities and this schema, it is possible to simplify the problem by expressing it in a different, more generic, way. Leveraging the symmetry found in the last diagram, it is possible to reduce the entire risk assessment to the image below.

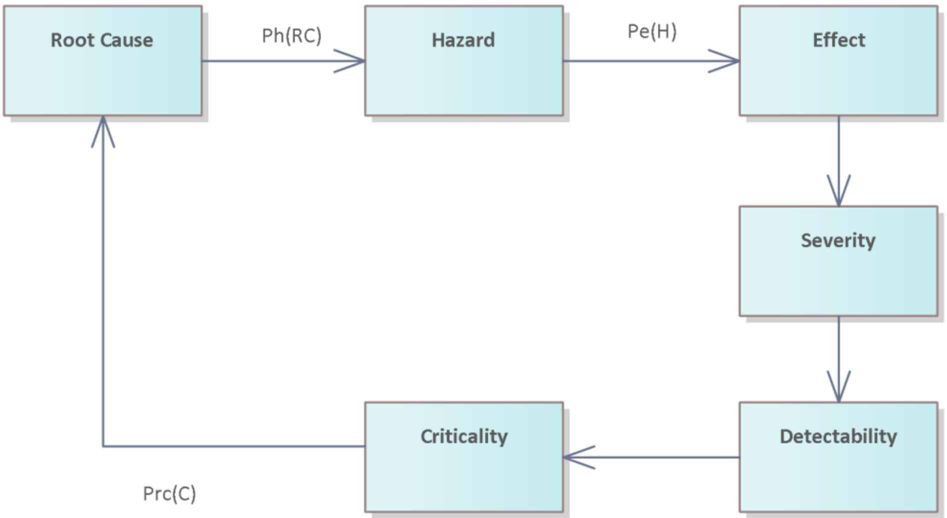

Figure 30 - RAFT basic loop

In this basic loop, we have the following elements:

Table 15 - Variables in RAFT-FMVEA basic loop

Variable name	Type	Description
RC	Vector of root causes	
H	Vector of hazards	
E	Vector of Effects	
S	Vector of Severities	
D	Vector of Detectabilities	
Ph(RC, H)		Matrix of the probability of falling in the hazard in the event of a root cause
Pe(RC, H, E)		Matrix of probability that given the root cause the hazard becomes real and an effect happens
Ps(E)		Matrix of the probability of having a severity given an event

Variable name	Type	Description
Pd(E)		Matrix of the probability of an event being detectable
Cr(RC, H, E)		Matrix of criticalities given a root cause, an hazard and an event
Prc(RC, H, E)		Matrix of probabilities that a given root cause is the consequence of a criticality

We are designing the RAFT framework for a public space in a Smart City, then it is time to better understand the context.

In systems engineering, methodologies like FMEA, FMECA, FMVEA and other risk assessment strategies are applied to each component of the system and the effect of a problem is the effect on the single component and, then, on the system as a whole.

In our case, the system is a very complex one (it is a Smart City) but its complexity is increased by our aim to consider not only the functions of the ICT system (for example) but also include the "functions" of the Smart City.

In previous sections, we approached Ramaprasad's framework to have an ontology to describe any component (illustrative elements) of the Smart City. Each component is conceived to support one function (the outcomes) that we have defined in terms of alphas and sub-alphas.

Ramaprasad's generative formula was:

<Structure> to <Functions> + <Focus> + <Semiotics> by/from/to <Stakeholders> for <Outcomes>

In our approach, the risk we are analysing is about losing one or more outcomes. For this reason, we will consider the cause-effect chain that starts from the single structure element, analyse it with RAFT, derive from this analysis what can lead to loose one or more functions and then evaluate how the loss of this function will impact the related outcome. This aspect will be deeper analysed in the following section.

4.2.3 The risk magnitude

The risk is usually quantified as the product of two variables: the probability (p) of happening of the event that causes a risk and the severity (s) of the effects of the risky event happens. In such a sense the risk magnitude (Rm) can be defined as:

$$R_m = p \cdot s$$

Usually, p and s are natural numbers in the range from 1 to 10 or 1 to 3. In our study, the zero value is allowed for both variables that will range from 0 to 10. Different ranges can be used, and our results will be valid independently from the chosen range (but narrowing below 1-3 or 1-5 could leave to poor results). Even the constraint that the values are integer numbers can be relaxed and they could be real numbers (e.g. if they are derived from statistical analysis). Using real numbers doesn't change the validity of the results. In this research integer values have been considered because they are more complex to be managed in the optimisation problem that will be considered in the RAFT framework. In this case, we will get a solution that can be used even for real-valued numbers.

Due to the addition of the detectability element, our risk magnitude can be now considered as the product of the three elements, where d, the detectability, is expressed qualitatively with a number ranging, again, from 0 to 10. The new formula is now:

$$R_{psd} = p \cdot s \cdot d$$

The meaning of the values is, then:

Table 16 - Probability values

Probability (p)	
Which is the probability that the hazard can happen?	
0	Impossible
1	Negligible
2	Unlikely
3-4	Low
5-6	Occasionally
7-8	Frequent
9-10	Critical

Table 17 - Severity levels

Severity (s)	
Which is the severity of the hazard if it happens?	
0	No effect
1	Negligible
2	Low

3-4	Average
5-6	High
7-8	Very High
9-10	Critical

Table 18 - Detectability levels

Detectability (s)	
What is the probability to detect the hazard in time before impacts, if it happens?	
0-1	Always
2	Frequent
3-4	Average
5-6	Unlikely
7-8	Very hard
9-10	Impossible

The resulting magnitude Rpsd can range from 0 to 1,000, with the following meaning:

Table 19 - Overall risk magnitude Rpsd

Risk magnitude (Rpsd)	
Which is the estimated overall risk level?	
0-1	Negligible
2-50	Low
51-100	Average
101-200	High
200-500	Very High
500-1,000	Critical

4.3 The RAFT framework – part three

4.3.1 The Recursive Decomposition

The way to represent a Smart City in a form that can be used for the risk assessment we are approaching is based on a recursive decomposition, which principles will be exposed in the following.

The basic idea is that a Smart City is a system of systems, using the word system with an almost abstract meaning, being agnostic about any specific technology. Our starting point will be, as it should be, the Urban Planning high-level concepts that we are applying (and customising) in each Smart City implementation.

4.3.1.1 The Smart City functions to be protected

In our approach, we will consider the outcomes proposed in section 2.2.1.12.2.1.1-The Ramaprasad approach and further detailed in 2.2.2-Analysis of the Ramaprasad's framework. For the sake of simplicity, we recall the table Table 3 - Values and sub-values for the Smart City (that will also be later depicted in the form of an Essence diagram):

Table 20 - Outcomes model for a Smart City

Value	Sub-values
Sustainability	optimize current use of fossil fuels, eliminate waste, recycle, recover energy, save time, and reduce, or eliminate, pollution
Quality of Life	wealth, employment, the environment, physical and mental health, education, recreation and leisure time, social belonging, religious beliefs, safety, security and freedom
Equity	Absence of unfair, avoidable or remediable differences among groups of people, The groups are defined socially, economically, demographically, geographically or among another dimension (sex, ethnicity, disability, …)
Livability	safety, mobility options, employment and educational opportunities, public space, and political stability
Resilience	local knowledge, community networks and relationships, communication, health, governance and leadership, resources, economic investment, preparedness, mental outlook

These are all the possible outcomes of our Smart City (i.e. the "functions" desired by its designers, the urban planners and the urban designers) according to our framework. Changing such a framework will result in different outcomes but the methodology will be yet fully applicable. These outcomes are provided to stakeholders, so, they must be considered for each stakeholder. For example, we do not have an "eliminate waste" outcome alone, we will have the eliminate waste for Citizens, for Professionals, for Communities, and so on.

Each outcome is measured by its alpha states, which are a discrete representation of how much it has been accomplished. For each pair (stakeholder, outcome) we will have a life cycle made by alpha states. This life cycle can be the same for each pair with the same outcome or with the same stakeholder or be different from one pair to another, but this is not important, the reasoning will remain valid considering the general case where all the pairs can have different life cycles.

So we can conclude, for now, that the Smart City functions are all the elements in the set made by all possible pairs (stakeholder, outcome), each one of them measured through its alpha states life cycle. We will call this set “the whole set of smart city functions”, shortened in W. Each pair will be denoted as Wij, where i is the stakeholder i-th and j is the outcome j-th. For each Wij we will have a life-cycle LCij whose alpha-states will be named LFWijk, where k is the k-th state, numbering states from the less complete to the most complete state.

4.3.1.2 The Operational Alpha-States Set

In the life cycles, we have three subsets: the subset of states that are considered insufficient to affirm that the function is performing (i.e. the function is not performing), the subset of states that the function is performing at a basic level that could be tolerated for some time, and then the subset that represents the states that indicate that the function is performing as desired or better.

These life cycles must not be confused with the life cycles used during development to assess the state of the development.

In our risk model, we have two different state sets for each alpha (or sub-alpha): the development progress states set and the operational states set.

The development progress states set is the set of states that indicate at which progress level is the development/deployment of the alpha. This type of set is the usual set of alpha states developed when applying Essence as a descriptive theory for software engineering, a discipline which is interested in managing software life cycles. This type of state also contains a description of the operational state of the software solution but this description is very simplified and at a very general and abstract level. To implement our risk analysis model we need a second type of set of alpha states, a set that describes how the selected alpha is operating in reality or not.

An example of this last type can be about the possible states of Wealth sub-alpha in Quality-of-Life alpha. These states could be: poor (almost all people live in poverty), few riches (few people are rich and most are poor), average (poor people and rich/middle class are quite balanced), middle class (most people are in the middle class, few riches, few poors), wealthy (no poverty, people are almost all in middle class or rich).

In an urban planning requirement, we can focus on the minimum tolerable state (basic performance) to be average or more and desired performance to be middle class. Acting on hazards can alter the current state in this life cycle, up to arriving below the basic threshold (i.e. the Smart City has lost one function) or moving up the desired threshold (the Smart City is performing very well).

In this vision, the main risk analysis idea can be drafted in the following diagram:

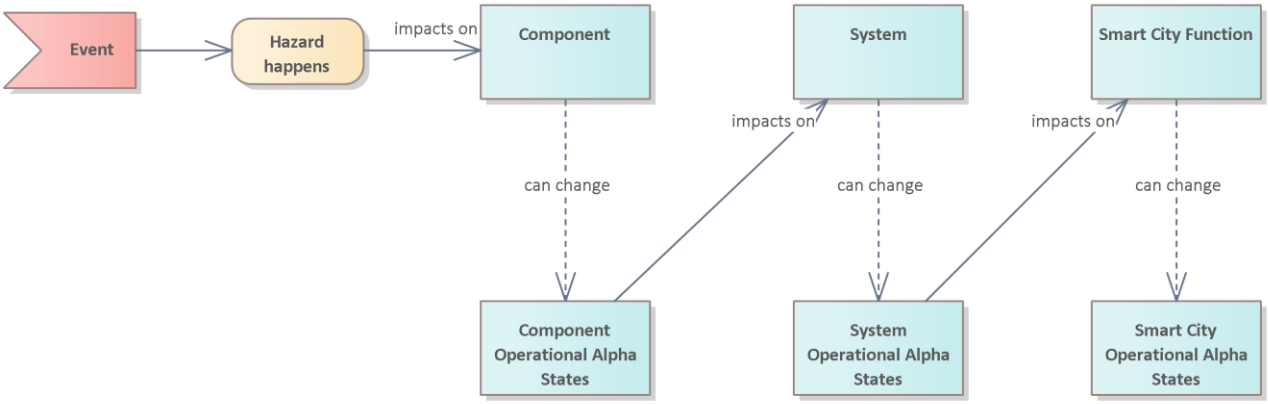

Figure 31 - Event - hazard - effect chain

Given an event that triggers a hazard, there is an impact at the component level, potentially changing its current operational alpha state. This impact is then transferred, as a consequential impact, on the system level, causing a possible change in its current operational alpha state. This change can be reflected in a Smart City function, changing its current operational alpha state.

Because the Smart City is a complex system-of-systems, the layers are not the three depicted above for the sake of simplicity (component, system and smart city) but can be more. So, a more general (recursive) representation of the risk analysis simplified schema could be:

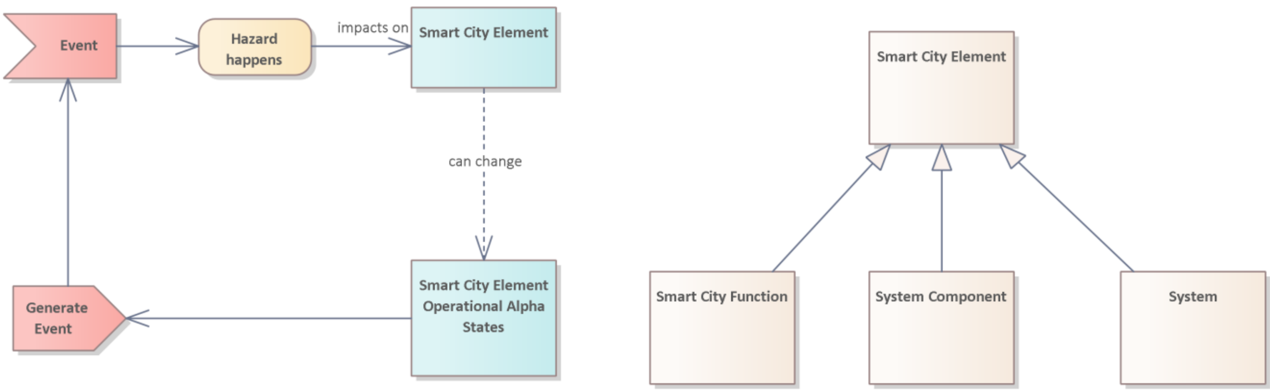

Figure 32 - Smart City's risk propagation DAG

In this diagram, the Smart City can be considered as a graph where nodes are single Smart City elements, that can be Smart City Functions, System Components and Systems. Each node can be connected to any other node making it a generic graph. To approach the risk methodology progressively, a hypothesis will be assumed at this point: the graph is a directed acyclic graph (DAG).

With the DAG hypothesis, the Smart City will be represented by a network where the impact will propagate in one direction only. Usually, the functions will be on the leaves (i.e. nodes with no outbound connections with other nodes) of the DAG but it is not forbidden to also have functions that are connected on internal nodes (e.g. the typical case is when one smart city function can impact on another smart city function, like reducing waste can impact on pollution, both functions).

An example of such a DAG could be the following:

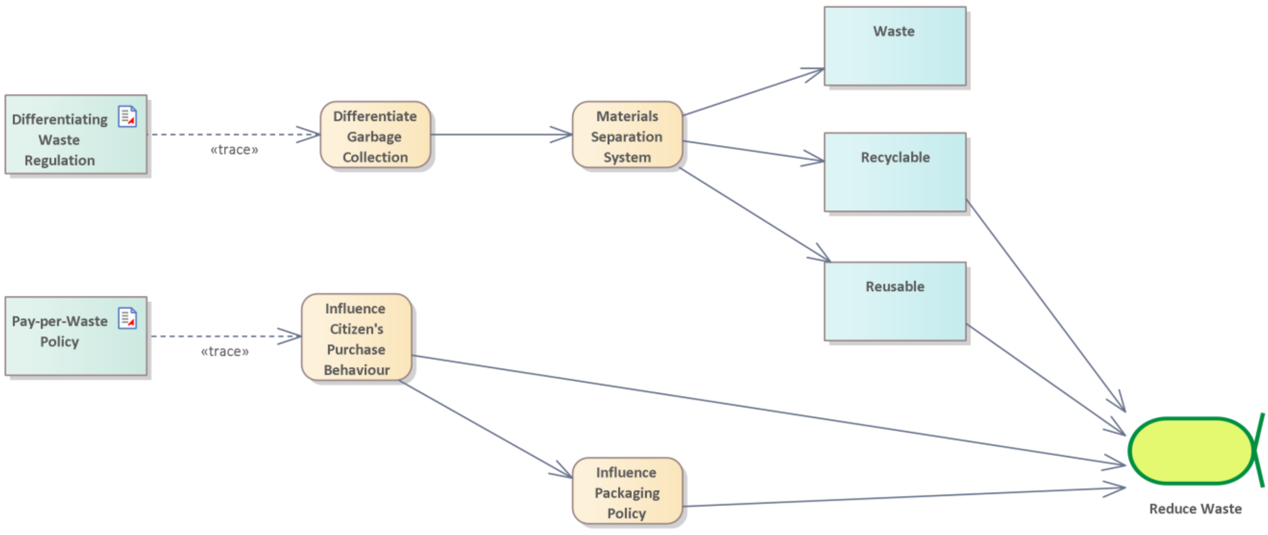

Figure 33 - Sample DAG for waste reduction

In this diagram, two policies have been defined, one is a regulation to implement waste differentiation, and the other is a policy that implements a tax proportional to produced non-recyclable and non-reusable waste.

Differentiating waste implies a "System" of differentiated garbage collection. This system is composed, in Ramaparasad's ontology, of sense, monitor, process, translate and communicate functions (omitted in the diagram). Each function is used to manage the Semiotics through the Structure. So, from such a system (differentiated garbage collection) many illustrative elements can be defined, each one having an implementation of the Generating Formula. The same for another system which is materials separation.

In the case of the pay-per-waste policy we have, again, two systems that can be described by Ramaprasad's ontology, omitted here for the same reason.

Let's now imagine that the materials separation system is one single plant. Attacking it and blocking it, for example with a computer virus, will let the waste processing fail and lose the ability to recycle or reuse. The operational alpha states for both recycle and reuse will fall below the basic threshold and, then, also the reduced waste alpha will fall below its basic threshold state or, in the most optimistic case, fall below the desired threshold being in a degraded operational state. This is similar to a chain reaction and, as a typical chain reaction, needs a critical mass, i.e. a critical level of events able to overcome all the countermeasures in place in different nodes of the path "under pressure".

4.3.1.3 Representation of DAG

The DAG can be represented using the concept of a node. A node of the DAG can be a systematic unit, a structure or an alpha (requirement, stakeholder, opportunity but also those of Essence that we have not considered but could be used in the future, that are endeavour, way of working and team).

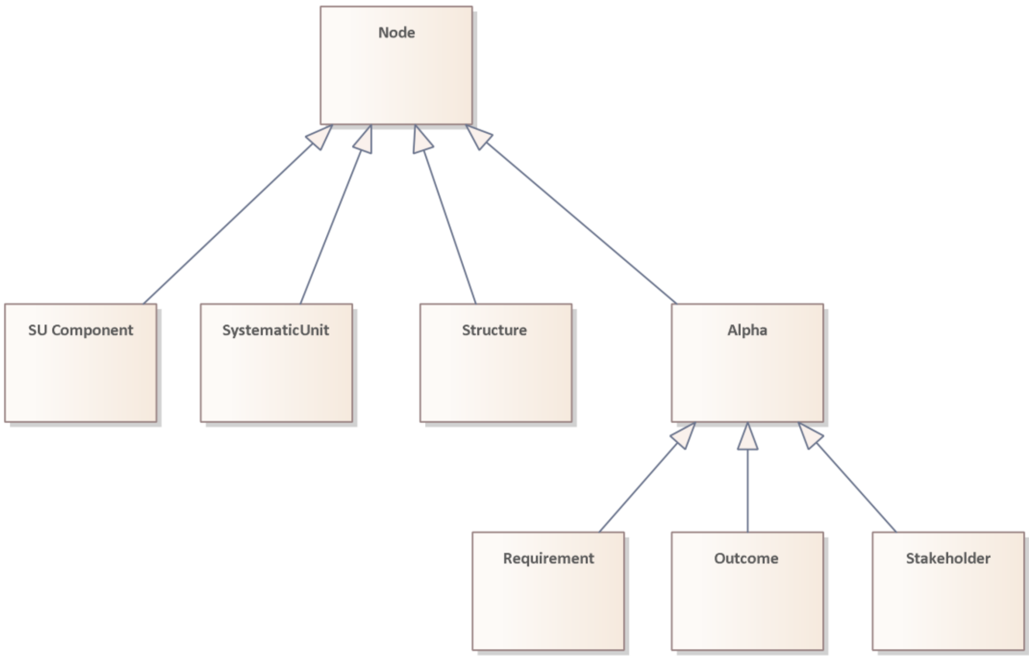

Figure 34 - Types of DAG nodes

So the DAG can be represented as a matrix that has, on both rows and columns, the nodes. At the intersection, we can put the value we want, for example, 1 or 0 to represent that the two nodes are connected in the sense row towards the column, or a number that represents a value to be associated with that connection (i.e. edge).

Let us define this matrix as a DAG matrix D. It has size Nnodes x Nnodes, where Nnodes is the number of nodes of the DAG.

We have different DAG matrices:

- D is a generic matrix structure that serves as a template for other DAG matrices
- Dc is the DAG connection matrix, that contains 0 if the nodes are not connected, 1 if they are connected

There is also a list L of nodes that has Nnodes elements.

We have different lists of nodes:

- L is the generic vector that has size Nnodes and is the template to be used for other vectors

- La is the list of mutually exclusive alternatives for a given node (usually this applies to systematic units and structures and will be further explained in section 5.2.2.1-Design, implementation and operation degrees of freedom)
- Ls is the list of alpha states for the node
- Lo is the list of operational states for the node

To model the RAFT FMVEA-based approach, we can consider a “parallel” of cause and effect.

If we consider the RAFT FMVEA risk analysis approach we can describe it as follows.

A list of Root Causes exists for each node. The union of these lists for all the nodes can be referenced with C. It has size Nc.

A list of Hazards exists for each node. The union of these lists for all the nodes can be referenced with H. It has size Nh.

A list of Effects exists for each node. The union of these lists for all the nodes can be referenced with E. It has size Ne.

The matrix mapping the root causes onto the hazards can be referenced as CH, has size Nc x Nh and contains the probability to have the hazard given the root cause.

The relationship between nodes to support risk analysis in the operational phase is depicted below (it is an evolution of the diagram Figure 49 - Engineering domain with evidence of components for Systematic Units provided later that we anticipate to better understand our aim):

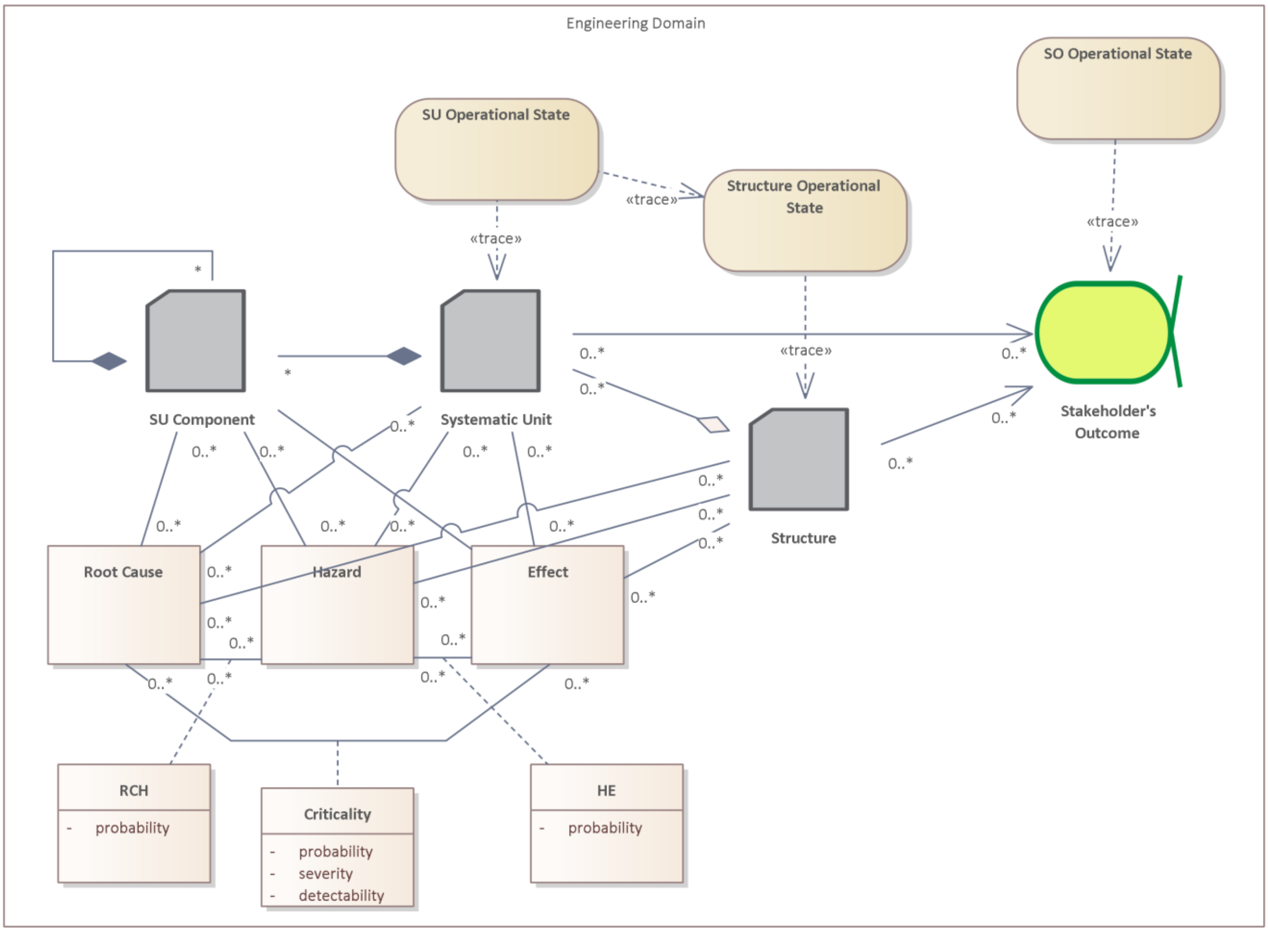

Figure 35 - Diagram to support risk analysis - Engineering domain

In the above diagram, it is clear that each node of type SU Component, Systematic Unit and Structure can have an associated RAFT model that allows relationships from one effect to a root cause. The same structure can be associated with alphas too. This complete diagram (missing SU Components for simplicity, relationships' attributes and cardinality of relationships):

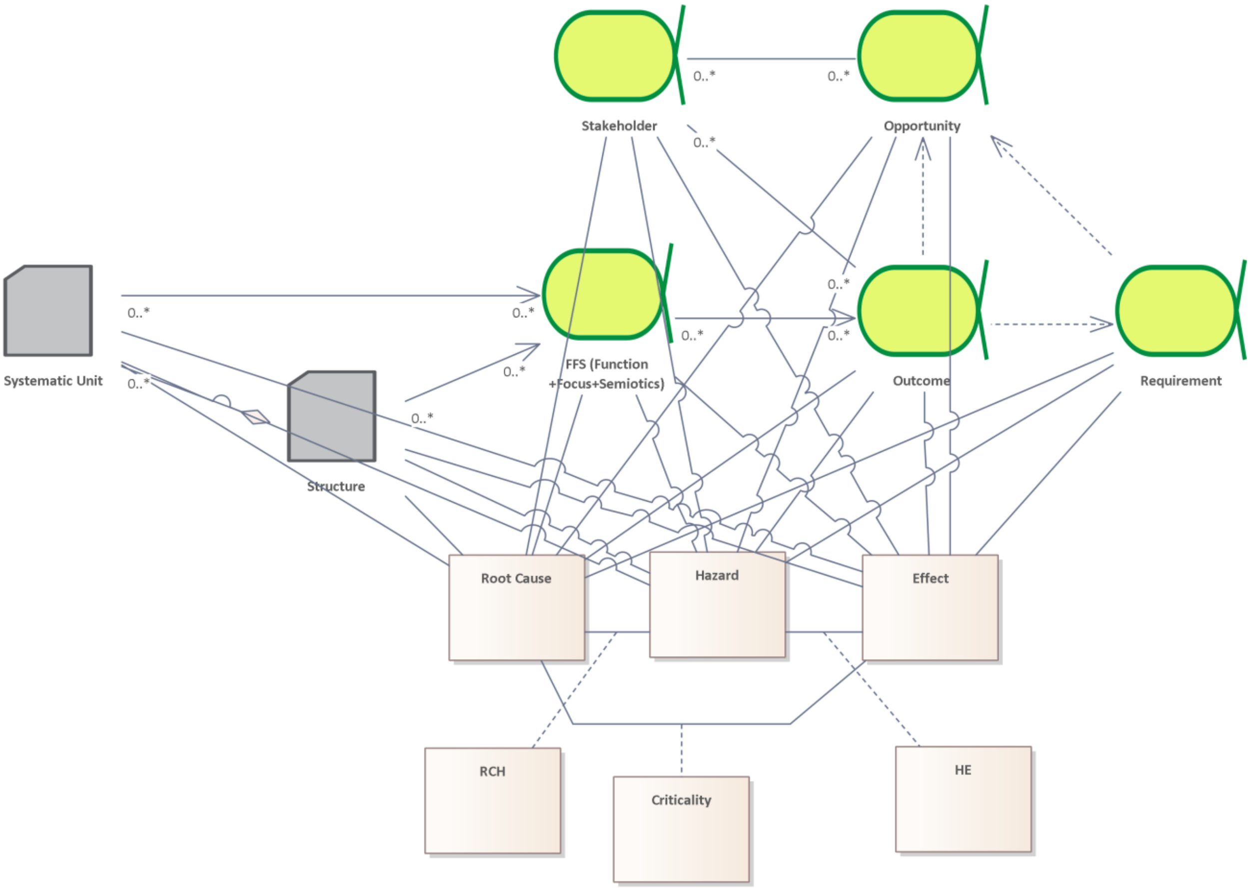

Figure 36 - Complete diagram for Risk Analysis in Smart City

Considering the definition of a node given before, the above diagram can be written in a more simple and general form as follows:

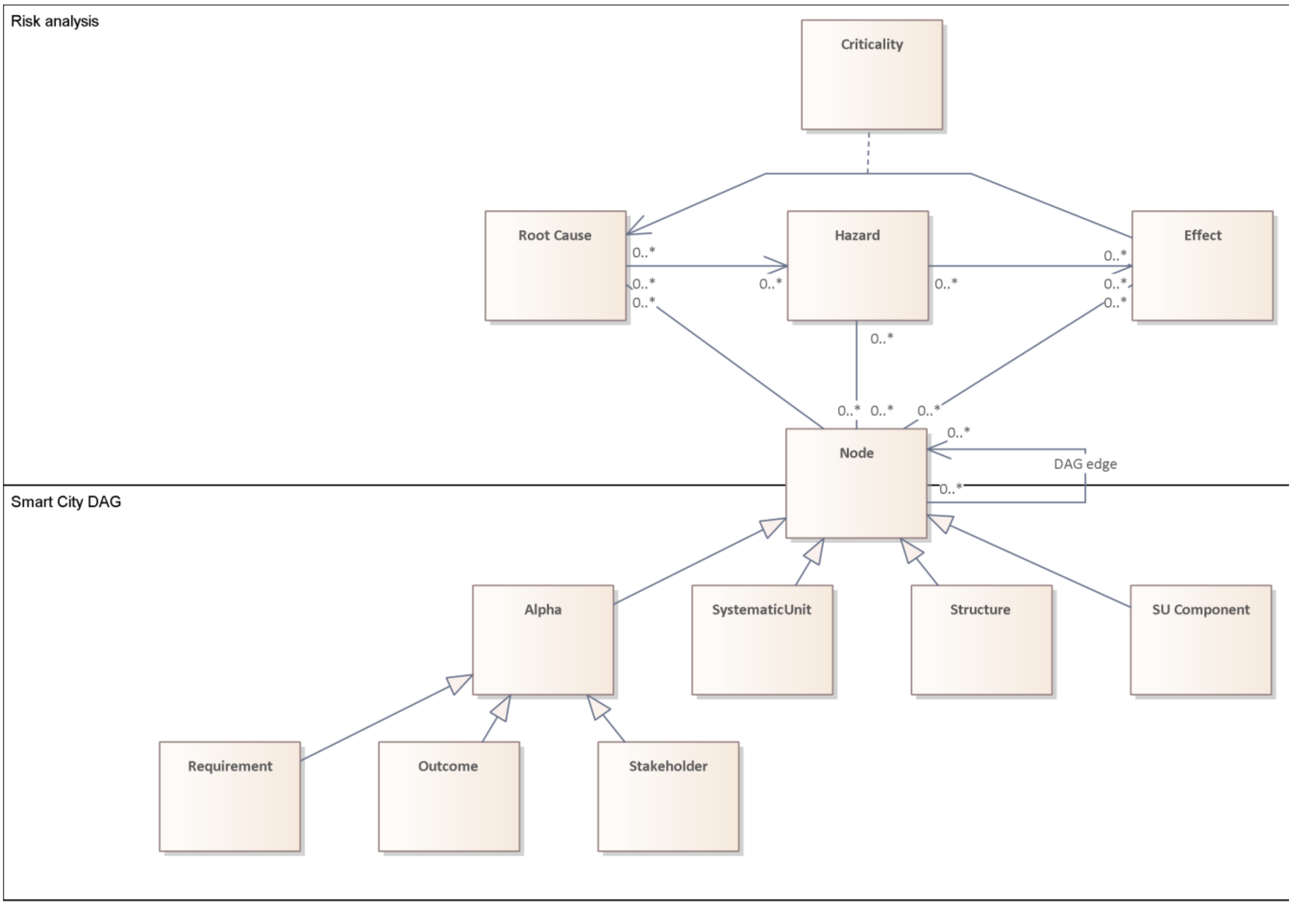

Figure 37 - General Risk Analysis Diagram for Smart Cities

In this diagram, we evidence two swimlanes, the upper and the lower. In the upper we have all data structure related to risk analysis, while in the lower we have the DAG that represents the Smart City and that we will build with the Aufbau, as explained in the following section. Having defined the general concept of a node to represent each element of the DAG, we can apply our risk analysis to any element and propagate its effect, because each criticality (i.e. event with probability, severity and detectability) can become a root cause for any other element in the DAG, with the only constraint of the absence of loops, i.e. feedbacks.

In the following sections, we will define both the Aufbau and the risk analysis structure.

4.3.1.4 Aufbau of the Smart City DAG

The process that leads to the creation of a DAG representing the Smart City's risk model has been called, in this research, "Aufbau", borrowing the term from Vienna's Circle vision (Carnap, 1928), but also used in chemistry, "Aufbau", is a German word meaning "Construction". Choosing such a foreign term is aimed to avoid confusion between the risk model building and the physical Smart City process of building it because this approach can also be used during Smart City's development phase.

Aufbau can be done in three different cases. The first one is when a smart city is being designed from scratch. Normally, urban planners and urban designers define their ideas and concepts and prepare an urban plan/design that represents the smart city. In our approach, they could use the Aufbau for getting support in defining such an urban plan/design and obtaining, at the same time, also a risk analysis model. This is the Aufbau-from-scratch and will be discussed later. The second one is when the Smart City's urban plan/design has been completely defined and the Aufbau needs only to create the DAG for the risk analysis. This is the Descriptive Aufbau. There is a third case which is the combination of Descriptive Aufbau and Aufbau from scratch that is used when the Smart City's plan/design has been partially defined. This Aufbau will be named the Mixed Aufbau.

The implementation stage of the plan (i.e. the level of development and realization of technological elements and the level of construction activities already completed or in progress) is not important because it will impact only the technological section of the Smart City DAG increasing its detail level and can be upgraded when further information will be available.

4.3.2 Aufbau-from-scratch

This Aufau is used when the Smart City has been fully designed. To proceed with Aufbau, all outcomes are considered. In this research, we will use those of Table 20 - Outcomes model for a Smart City, for both values and sub-values. For different models of outcomes, the discourse remains unchanged.

We will start from values (the higher level outcomes) and detail them into sub-values. These are the functions that must be preserved. Such functions are derived from stakeholders' opportunities (according to Essence areas of concern structure), i.e. from the value provided to the stakeholders by the Smart City. When an urban planner/designer shapes the Smart City, it should consider the Stakeholders and their values and the opportunities that the Smart City can represent for them. In this vision, it is expected that various outcomes will be a value for stakeholders. In our model, these values are the alphas (and sub-alphas) that represent the outcomes of the Smart City.

In a few words, if a Stakeholder wants to get from the Smart City a specific value (e.g. equity), this is one of the outcomes that the Smart City will provide.

To implement each outcome, the Smart City has to satisfy one or more requirements, like the actions in Lehmann's Green Urbanism model. Each one of these requirements will be traced towards the outcome(s) that it will provide. Which is the difference between the requirements and the opportunities? According to Essence, the opportunity is the reason because the Stakeholder asks for a Smart City, the value that the Smart City will provide him or her, while the requirement is a constraint to be satisfied to provide such value, i.e. an action to be done by the Smart City.

So, in our descriptive Aufbau, the Stakeholders must be identified, then their opportunities must be identified too, and consequent requirements must be defined. This process seems to be linear but it is an incremental process. Starting from an initial core, they are evolved step by step. It also increases the participation of Stakeholders in its definition.

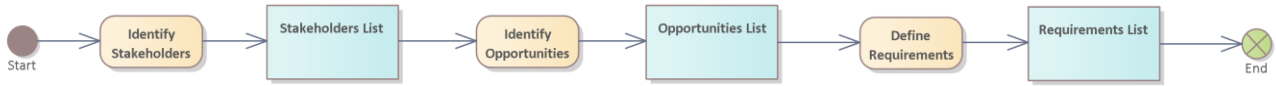

Figure 38 - Aufbau from scratch, first steps

Stakeholders, Opportunity and Requirements are also the three alphas that, in Essence, make the Customer area of concern, i.e. the first set of alphas to describe the software product, in our case the Smart City.

Having defined them, we can start defining risk. In our model, risk will be the probability to lose a requirement satisfaction and/or to miss an opportunity. Missing a stakeholder is not included in our risk analysis.

As already stated, according to Essence, each alpha is measured by an alpha state. Consequently, for each opportunity, we will have a sub-alpha and for each requirement, we will have a sub-alpha. Each of them (alpha or sub-alpha) will be measured by its own set of states (i.e. its life cycle).

An example is given below. In the continuation, alpha and sub-alpha will not be distinguished, except in the case that we want to remark such a relationship. So we will talk always about alphas. To also introduce the next step of the process, we will use Ramaprasad's framework and its illustrative elements.

As a first application example of connecting the elements, it will be considered the Cultural Heritage Principle in Lehmann's model. Putting this alpha into the framework means combining the applicable elements of the framework to get the expected outcomes for cultural heritage.

Considering the Quality-of-Life definition given by WHO "an individual's perception of their position in life in the context of the culture and value systems in which they live and concerning their goals, expectations, standards and concerns", Cultural Heritage alpha influences the Quality of Life alpha, and this connection must be described in terms of illustrative components of the framework. To serve as an example of application it will be considered the following simplified set of illustrative components, each of them identified by a unique identifier:

- IC01: Architecture to communicate cultural data to citizens for quality of life
- IC02: Infrastructure to sense social data from citizens for quality of life
- IC03: Systems to process cultural information to citizens for quality of life

- IC04: Policies to communicate technical knowledge to professionals for the quality of life

Other illustrative components are omitted for simplicity.

The illustrative components are Work Products (according to Essence language) that must be built to implement the QoL, that is to progress the alpha state of QoL alpha up to the desired configuration. In the following diagram, the QoL alpha is described by the four illustrative elements generated through the framework.

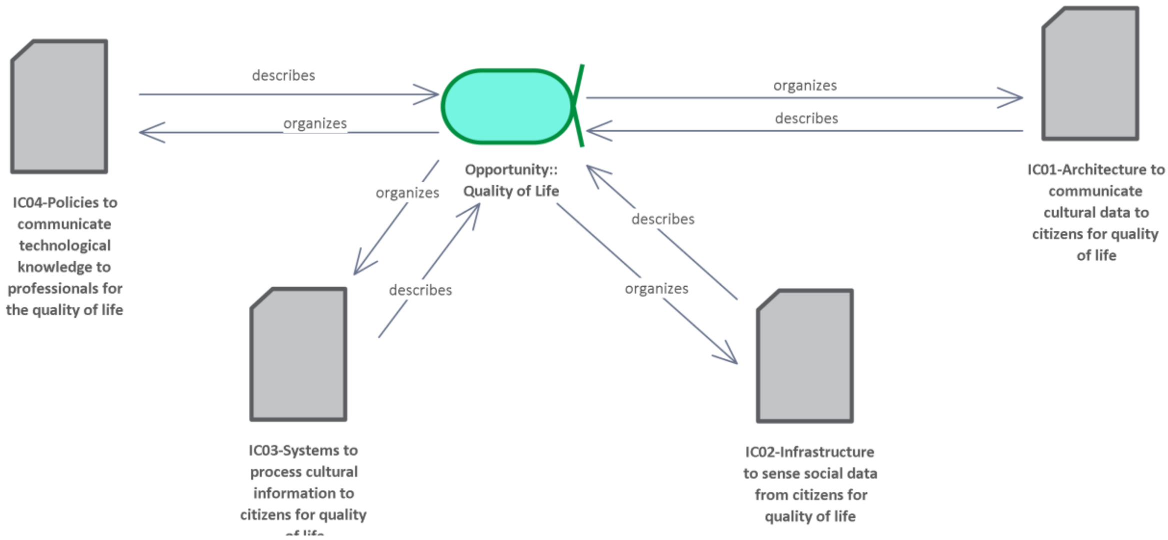

Figure 39 - Essentialised illustrative components for QoL (image of the author)

This diagram shows that the QoL alpha is described by the Work Products that are the illustrative components, as Essence requires. Practically, the diagram states that the QoL value (i.e. outcome in Ramaprasad's framework) is provided through some "components" (or systems) of the Smart City.

To improve the diagram, it is necessary to describe the relationship between the illustrative components and the alpha states of QoL. But in Essence, one element can have only one life cycle so it is needed to define four sub-alphas, one for each illustrative component. In Essence, Work Products do not have states but levels of detail so, for each component it is also needed the relationships with all the activities that contribute to the creation or evolution of the Work Product through its detail levels. The resulting diagram is the following (only one sub-alpha has been detailed and some relationships have been grouped in a single line:

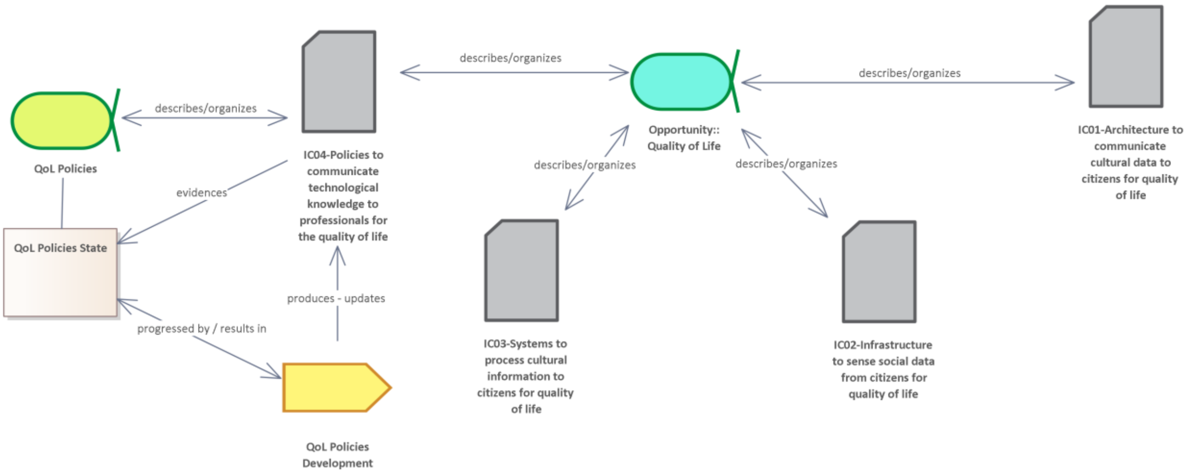

Figure 40 - Complete Essence diagram after essentialisation of QoL (image of the author)

In the above example, we have identified the QoL as an opportunity, i.e. a value that we have to provide to our Stakeholders and the QoL Policies as a requirement. The illustrative elements are Work Products, according to Essence, and are described using Ramaprasad's ontology. To each work product, one or more requirements are associated and each of them will have an alpha state. This alpha state is a development alpha state and is the usual state set requested by Essence. Later we will develop another state set, the operational set.

The same essentialisation process must be done for each work product and sub-alpha and is omitted here.

The Work Product detail level is part of the definition of the work product itself. For the IC04 element, the level of detail is shown in the following table:

Table 21 - Product detail levels for the illustrative element IC04

Detail level	Description
Initial	The main concepts of the policies have been defined
Structured	All sections of the policies have been detailed and rearranged in a discursive flow
Approved	The policies have been approved by the interested Stakeholders
Deployed	The policies have been distributed, communication has been done, and training has been provided
Effective	The policies have been adopted in practice and are followed

The activity QoL policies development will influence both the IC04 detail level and QoL Policies alpha state. The last step is then to define the alpha states (the life cycle) for QoL policies, using all the available information (from the Green Urbanism model, from the framework and ISO standards).

The result is described in the following state table below (in this case they are very similar to those of the Opportunity alpha directly from the Essence kernel):

Table 22 - Alpha states for QoL Policies

Alpha State	Conditions
Identified	The main ideas of policies have been identified At least one investing stakeholder is interested Other stakeholders identified
Solution Needed	Draft schema of policies has been identified Stakeholders' needs identified Issues that are solved by policies have been identified Need for a policy confirmed by all Stakeholders
Value Established	QoL quantified in terms of KPIs (from standards) and in terms of sub-alphas to be accomplished (if available) QoL impact understood Smart city value in terms of QoL understood Success criteria for QoL defined and understood Outcomes for QoL are clear and quantified
Viable	A QoL solution has been outlined Possible constraints to the solution have been identified Main risks identified, quantified and considered acceptable or manageable The solution is cost-effective The reasons to develop the solution have been clearly understood and explicitly stated The target is viable (in the sense of sustainable)
Addressed	The QoL values have been fully addressed The selected solution is considered worthy to be deployed Stakeholders are satisfied
Benefit Accrued	The solution implemented for QoL has been considered in line with the expected benefits Return on Investment (ROI) is considered acceptable

For the Cultural Heritage alpha, an alpha states life cycle has been developed rearranging the Essence typical life cycle for requirements alpha:

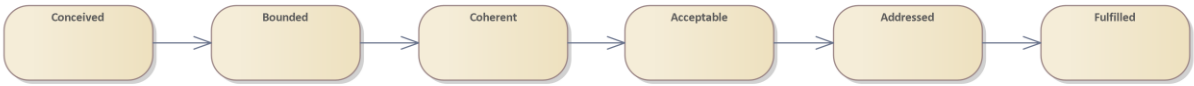

Figure 41 - Alpha states for Cultural Heritage alpha (image of the author)

Table 23 - Alpha states for Cultural Heritage alpha

Alpha State	Conditions
Conceived	Stakeholders agree about the need to preserve CH Targets of CH identified Funding Stakeholders identified QoL opportunity clear
Bounded	Acquisition Stakeholders identified CH borders agreed CH acquisition success criteria agreed Shared roadmap exists Priority scheme clear Constraints and risks identified Hypothesis and assumptions are clear Acquisition requirements defined
Coherent	Conflicts addressed Roadmap shared Key stakeholders identified Priorities are clear and defined CH acquisition team identified Acquisition requirements are completely defined
Acceptable	Roadmap considered acceptable Financial issues have been solved The acquisition management process defined CH value is clear How QoL is influenced is clear Acquisition requirements are considered acceptable
Addressed	The acquisition has gone enough far to be considered accepted Initial acquisition requirements and final results match Realized value is clear Acquisition requirements have been addressed

Fulfilled	Stakeholders accept final results No missing requirements All requirements have been fulfilled

The same has been done for the Quality of Life alpha, with a completely new alpha life cycle. In this case, it is possible to identify some work products and some activities that are omitted for the sake of simplicity.

Summarizing this last part, we have defined, for each requirement's alpha, a set of states, this set represents the development life cycle of the alpha and allows us to measure which development state is the alpha.

If the alpha is a requirement, we can define the implementation level of the requirement, i.e. the satisfaction level of it, and manage the progress in Smart City development clearly and concisely that also allows comparison between different Smart Cities if they behave to the same (even partially) model.

Now, our process for Aufbau from scratch becomes the following:

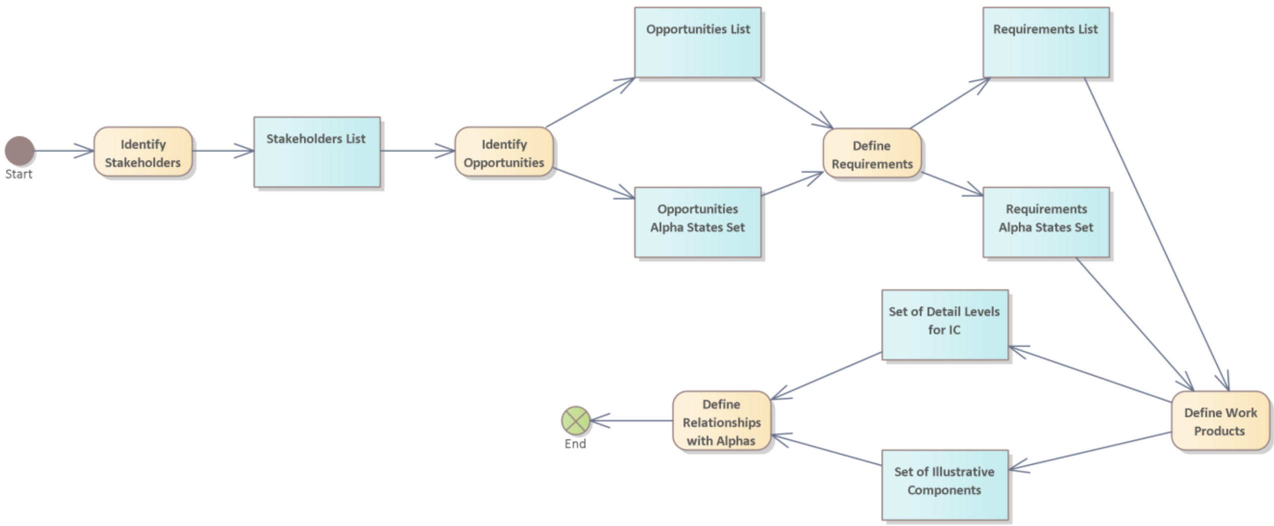

Figure 42 - Aufbau from the scratch process with all the steps

After underlining that this is an incremental process that evolves as a spiral, it is easy to represent it as a sequential one for the sake of simplicity.

In the above diagram, the alpha states set and the detail levels sets have been added. The alpha states sets are the way we measure the implementation grade of the alpha. The details level sets are the measure of the completeness of a given work product.

To better understand the various meanings, let's describe better what they are.

A work product is a desired result in the implementation process. It can be a design document, a requirements document, a user's manual or even an entire system or sub-system. In a few words, a work product is something that is built during the realization, while the alpha is what you have to monitor to assess the progress and the health of the projects. In a general perspective, alphas are abstractions of work products. For example, we do not physically construct the QoL but we create a QoL policy. So, QoL is an alpha and QoL policy is a work product. The less or the more detailed the work product (the policy) will be, the less or the more healthy and complete the alpha (QoL) will be.

Work Products represent the concrete things to work with, providing evidence for the states an Alpha is at a given moment. The alpha state depends, in fact, on the detail level of one or more work products.

In our Aufbau, the work products will be the elements we have to build and keep operational, while the alpha states are a measure of their health and completeness. Up to now, we have distinguished between the development alpha states and the operational alpha states. For now, this concept will remain unchanged but will be further revised later.

After this clarification, it should be evident that there are more relationships that must be explicated. They are shown in the new version of the previous diagram depicted below:

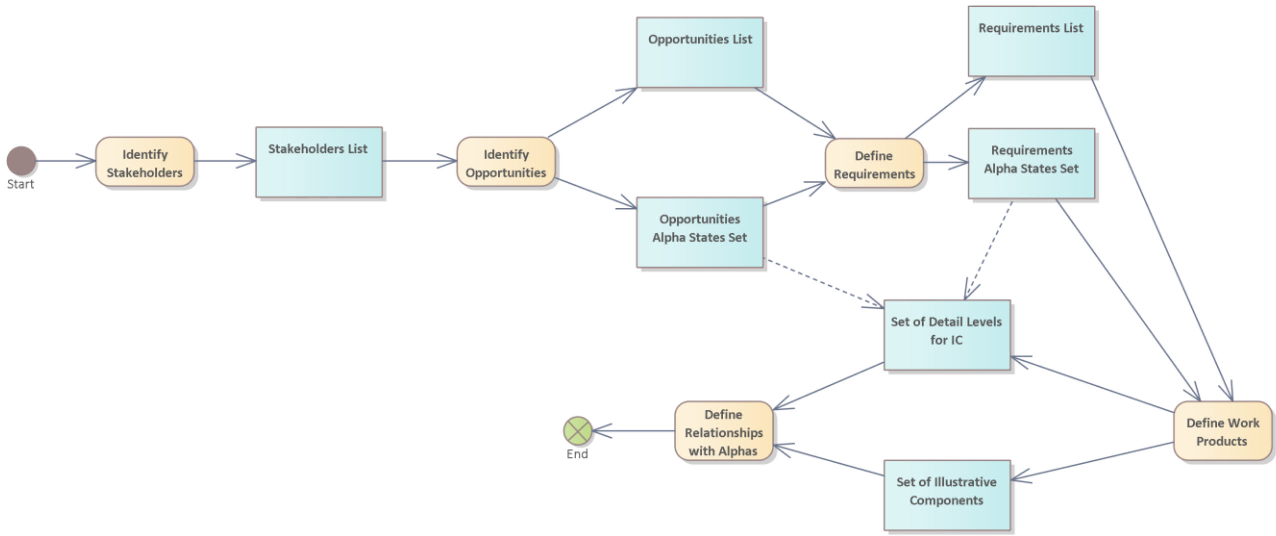

Figure 43 - Aufbau with detail levels

The dashed arrows from the alpha set to the detail levels set are, in UML, dependency relationships. This means that the definition of the alpha states depends on the definition of the detail levels.

This underlines again that the process is incremental and not linear.

We will see in the next chapter a complete example of application but, for now, the process should be clear.

At this point, it is time to discuss the operational state set.

When the physical components that build the Smart City are ready to work, as already explained, they can have different levels of operability. These levels are: below basic (i.e. it is not operating), between basic and desired (i.e. it is operational but should perform better) and above desired (i.e. it is fully working). To define these three ranges we have defined two thresholds: the basic threshold and the desired threshold.

These thresholds are related to another set of states that we called operational states.

When we consider the alpha states for development they measure the evolution of one or more work products (because the state depends on the detail level of one or more work products). In this way, we can use the alpha state to measure the health and the progress of the alpha related to some work products (because, usually, one or more work products impact one alpha). But in the risk analysis, we are faced with the description of the operativity of an illustrative component, i.e. of a physical element, that, if loses some functions impacts the alpha. In such a description, it seems that the alpha state for operativity s different from the alpha state of development. But let`s enter in a more detailed view.

The operativity of a single work product can be considered another (or more) level in its levels of details set but, at this time, we can have that level of details depending on two factors: the stage of implementation and the functioning level. In many cases, the functioning levels are levels of detail after the implementation levels. In other cases, the path would be more complex. In our model, we will consider a more general case with two different sets of detail levels. We will add a new set that will be the operational levels set to the work product. In this way, we can distinguish between development progression and operational state.

As a consequence, the work product will have another set that will impact the alpha(s) that depends on it.

But the same discourse is valid for the alphas, which will have an operational state set. Given these changes, the process of the Aufbau from scratch becomes the following:

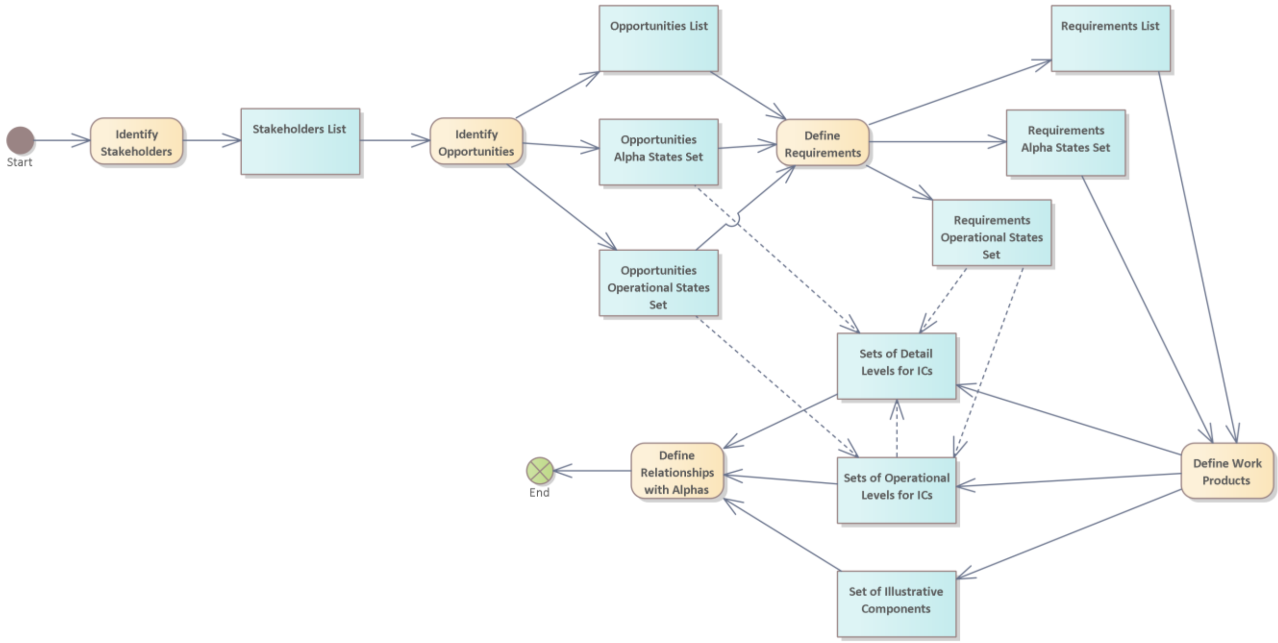

Figure 44 - Aufbau from the scratch process with operational evidence

In the above diagram have been added the operational state sets for both opportunities and requirements and these states depend on both detail levels and operational levels. If a work product has not been completed, its operational state will be "not working". This is represented by the dependency of the operational levels on the detail levels. The operational alpha states will depend on the operational levels of the work products.

To complete our process, we must deeper investigate the illustrative components generated by Ramaprasad's ontology.

As depicted above, when designing the implementation of an opportunity and/or a requirement, we define some physical elements that are the illustrative components. To generate these elements, we enumerate all the possible pairs of outcomes and stakeholders and for each of them, we generate the remaining part of the illustrative component. Because of the generating formula, fixed in it the last two variables (stakeholders and outcomes) we can generate at least 7*5*8*3 = 840 different elements (we have not considered the further factor 3 derived from the "by/from/to" alternatives in the generation formula) to provide the desired outcome for the chosen stakeholder. After having generated all these elements, we have to consider what can fail (for failure or attack). The results are reported in the following table:

Table 24 - Failure modes of Ramaprasad's variables

Variable	Values	Failure mode
Structure (7 values)	Architecture, infrastructure, systems, services, policies, processes, personnel	Any of these values can fail due to attack or failure.

Variable	Values	Failure mode
Functions (5 values)	Sense, monitor, process, translate, and communicate	These functions are operational or lost in case of failure
Focus (8 values)	Cultural, economic, demographic, environmental, political, social, technological, infrastructural	Characterizes semiotics
Semiotics (3 values)	Data, information, Knowledge	Is the Smart element to be managed
Stakeholders		Are the end-user of outcomes and we do not consider their "failure" in this model
Outcomes		Are the values provided by the Smart City and can be lost due to other elements' failure

At this point, we have two possibilities among which choose the model architecture. This branching opportunity derives from the fact that a structure can be implemented by different physical elements. For example, we can talk about a communication infrastructure for the entire smart city or different infrastructures for telecommunications related to various areas, geographical or conceptual is the same, that provide the overall capability of communications. In this second case, we could have, for example, the internet backbone, the wireless services, the IoT network and the optical fibre network.

The first approach can consider a single system of systems as a unique structure, the second approach could consider distinct elements as different structures that are interconnected.

In the systems of systems approach, we can benefit from the systems engineering methodologies for designing the entire element (e.g. structure) for the whole Smart City but, on the other side, we can have issues due to the huge complexity of each element. This complexity is also increased by the fact that a single structure can provide support for different functions and different focuses and semiotics.

In the second approach, we operate with single systems (that can yet be systems of systems but they are not widened to the entire Smart City) but we have to introduce a new degree of freedom in the model. This new degree of freedom is the systemic unit (intended in a wide sense of system) and is simply an identifier of the single system among all those that fall into the structure type (e.g.

all the communications systems that compose the infrastructure structure, or all the architecture places that compose the smart city architecture).

In this way, Table 24 - Failure modes of Ramaprasad's variables will become:

Table 25 - Failure modes of Ramaprasad's variables with systematic unit and Essence elements

<table>
<tr><td>Variable</td><td>Values</td><td>Failure mode</td><td>Essence</td></tr>
<tr><td>Systematic Unit (variable number of values, depending on the related structure type)</td><td>Can be any system (in a wide sense of system) that realizes a part of the chosen structure</td><td>Being a system, a systematic unit can fail due to attack or failure, impacting the structure it belongs</td><td>Work Product</td></tr>
<tr><td>Structure (7 values)</td><td>Architecture, infrastructure, systems, services, policies, processes, and personnel, are all now defined at the whole Smart City level.</td><td>Any of these values can fail due to attack or failure on them and their systematic units.</td><td>Work Product</td></tr>
<tr><td>Functions (5 values)</td><td>Sense, monitor, process, translate, and communicate</td><td>These functions are operational or lost in case of failure</td><td rowspan="3">Alpha. This alpha is composed of the Function, the Focus and the Semiotics.
We will name it by combining the values of the variables.
E.g. sense cultural data alpha.</td></tr>
<tr><td>Focus (8 values)</td><td>Cultural, economic, demographic, environmental, political, social, technological, infrastructural</td><td>Characterizes semiotics</td></tr>
<tr><td>Semiotics (3 values)</td><td>Data, information, Knowledge</td><td>Is the Smart element to be managed</td></tr>
<tr><td>Stakeholders</td><td></td><td>Are the end-user of outcomes and we do not consider their “failure” in this model</td><td>Alpha</td></tr>
</table>

Variable	Values	Failure mode	Essence
Outcomes		Are the values provided by the Smart City and can be lost due to other elements' failure	Alpha

Adding the systematic unit level we are simply extracting the complexity of the system of systems outside the black box of the generic structure. In this way we allow the ontology to reuse in a more precise way a system that is common to many cases and have better control of the risk analysis while keeping the possibility to use the simplified ontology (Ramaprasad's original) without the systematic units. Consequently, Ramaprasad's generation formula changes as below:

<Systematic Unit> in <Structure> to <Functions> + <Focus> + <Semiotics> by/from/to <Stakeholders> for <Outcomes>

With this last form of generation formula, we can now describe all the elements in terms of these extended Ramaprasad's ontology and map them onto Essence. It is important to highlight that each combination of Function + Focus + Semiotics is an alpha, which can measure health and has its own set of states.

Now it is possible to start merging the risk analysis approach drafted above with the Aufbau process.

At the end of the Aufbau from scratch process, we have a complete description of the Smart City that starts from Stakeholders and Outcomes and moves top-down towards physical implementation systems. This representation is the skeleton on which we will build our risk analysis.

A schematic representation of this DAG is provided below, distinguishing conceptual elements that are related to the conception phase of the Smart City (i.e. Stakeholders and Opportunities identification) from those that are related to the implementation phase:

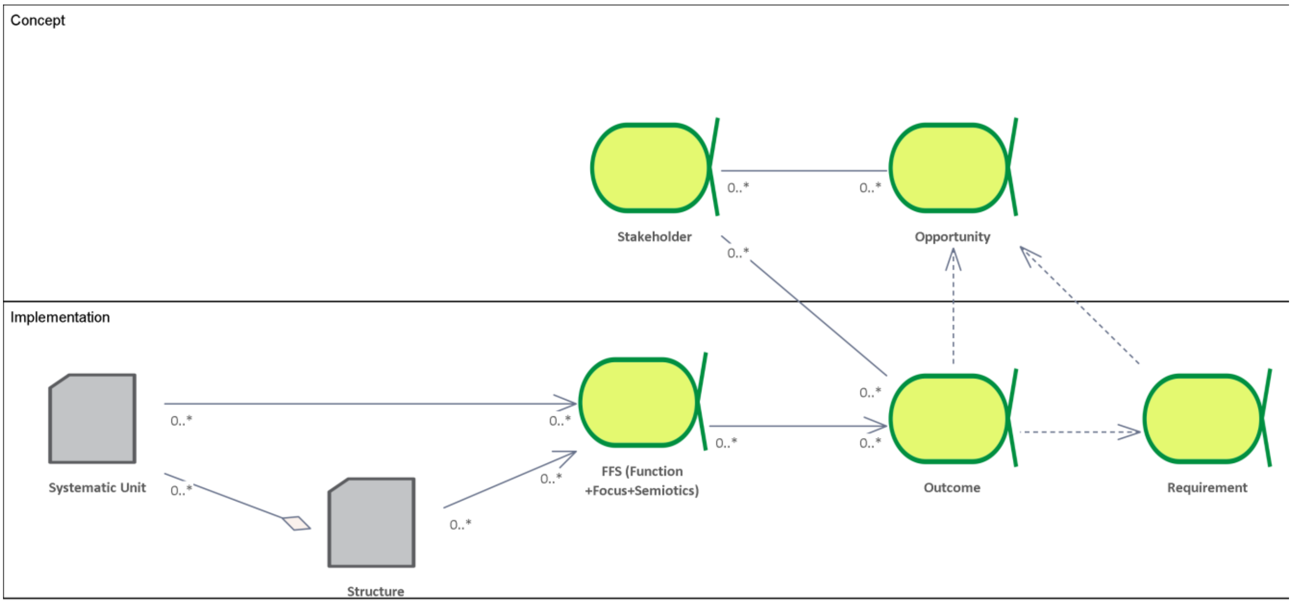

Figure 45 - Basic DAG Structure with Concept and Implementation

Work products are the physical elements of the Smart City (i.e. hardware, software, buildings, physical infrastructures, …) and they are represented by the Structure element of the ontology. As stated above, this element has been decomposed into one or more Systematic Units. The spear-shaped arrow means that the Structure is an aggregation of Systematic Units. But the Systematic units provide the Function, Focus and Semiotics (FFS) both directly or indirectly through the Structure (during the steps from concept to implementation we will use Structures to trace provided FFS but, in the end, we will use only the direct connection, keeping the indirect one to ensure correct traceability.

The first alpha we get in our DAG, travelling it from left to right, is the FFS but it should be the combination of FFS + Outcome + Stakeholders, because the output of the implementation is the provision of some FFS to some Stakeholder to get some Outcome. So the above DAG can be updated as follows:

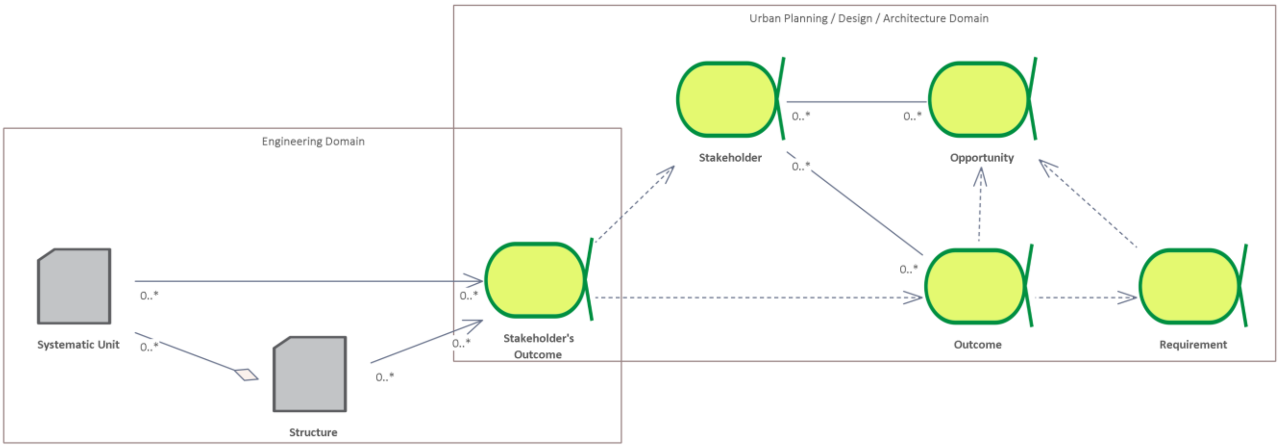

Figure 46 - Basic DAG with domains' boundaries and Stakeholder's Outcome Alpha

In this diagram, the swimlanes have been removed for simplicity and replaced by two boundaries that delimit the two domains we want to meet together: the Urban Planning / Design / Architecture Domain and the Engineering Domain. The cornerstone of this meeting between the two domains is in the intersection of the two sets. It is the Stakeholder's Outcome Alpha (actually it is a matrix of alphas, Stakeholders x Outcomes).

Through the Stakeholder's Outcome Alpha, we have got the complete traceability between engineering systems (construction engineering, ICT, organisational engineering and more) and the Urban Planning, Design and Architectural Concepts that are the drivers, the real reason for the existence of the engineering part.

Thanks to the ontology derived from Ramaprasad's framework, we have described all the possible elements of the Smart City in terms of both origins (i.e. Stakeholders, Opportunities, Outcomes, Requirements) and tangible realizations (e.g. hardware, software, constructions, processes, people, policies, …) of them. A bridge between the two worlds has been established. Now it is time to quantify it to measure.

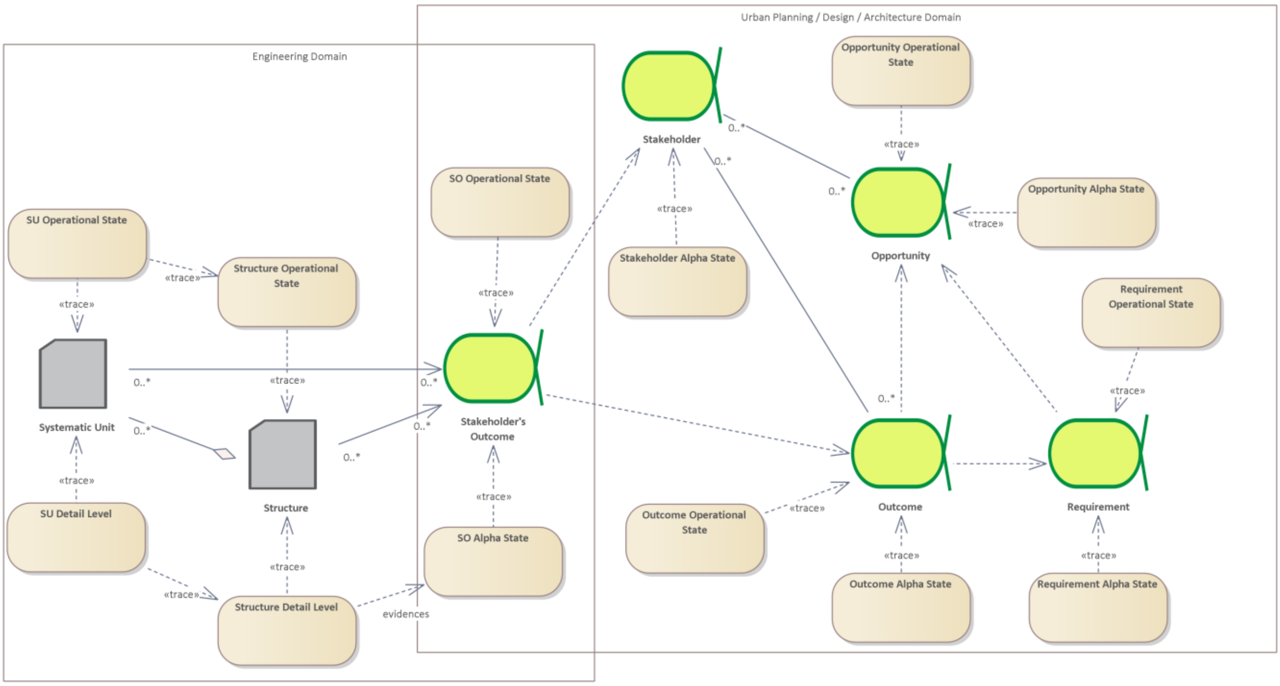

Figure 47 - Smart City Basic DAG with Alpha States and Details Level

In this diagram, alpha states and detail levels have been added to the various Essence elements to measure them. It is important to underline a few aspects.

First, there are two sets for each work product, the level of detail, which states the maturity of the work product, and the operational state, which states the grade of the ability to provide the desired output of the work product. Although these two sets are related, such a relationship has been omitted for simplicity in the above diagram.

Second, Alpha states are mainly used during the conceptualization and development phase while operational states are mainly used during the operation phase of the Smart City, i.e. after an element has become enough mature to provide its functions(s).

Third, all the alphas have both operational and alpha states except for Stakeholders that, in our model, do not need to be measured from the operational perspective but only about its conceptualization and development phases.

The diagram above can be recursively drawn to represent the complexity of the Smart City considering our original DAG of Figure 32 - Smart City's risk propagation DAG, reported below once again, and merging both representations. But this further detail is not investigated in this research.

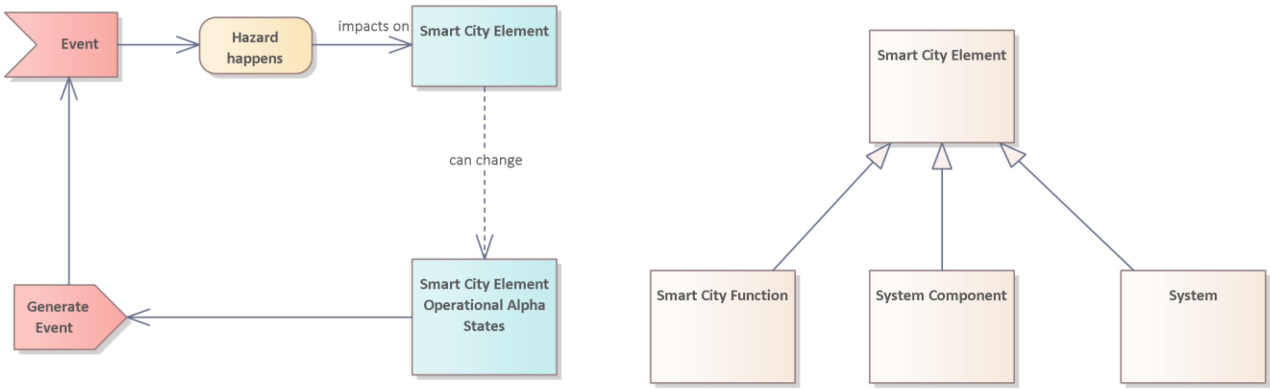

Figure 48 - RAFT risk propagation DAG

As stated above, this loop must be applied to any element that can fail, and these elements are of three types: Smart City Function, System Component and System. Having defined, with Aufbau, the basic structure of a Smart City we can translate this diagram into a mapping over the Aufbau results and introduce risk factors. Before doing this, we will complete the description of the other types of Aufbau.

4.3.3 Descriptive Aufbau

In the descriptive Aufbau, the process is a simplification of the Aufbau from the scratch process. In this case, all the elements of the Smart City depicted in Figure 47 - Smart City Basic DAG with Alpha States and Details Level are described with the Essence extension.

4.3.4 Mixed Aufbau

In the mixed Aufbau, we have to adapt both the descriptive and from scratch Aufbaus. This case is very common due to the existence of cities that are going to become Smart. In this case, we have five partitions of the problem:

1. Elements of the Smart City that are already fully operational. In this case, we will use the descriptive Aufbau to describe these elements
2. Elements of the City that are going to become Smart and then operational. In this case, we will use from scratch Aufbau to describe, follow the development and monitor the operation of them
3. Elements of the City that are Smart and are partially designed/developed/operational. In this case, we will use a descriptive Aufbau to describe their current state and then proceed with Aufbau from scratch
4. Elements of the City that are not Smart but that impact some Smart Elements. The descriptive Aufbau is used to match their impact on Smart elements
5. Elements of the City that are not Smart and do not impact Smart elements. They are ignored in the Aufbau

4.3.5 Conclusions about the Aufbau

The Aufbau is a process that can be used to develop a sort of digital twin for any Smart City to then apply a risk analysis methodology.

The Aufbau can even be applied to normal cities but this is out of the scope of this research.

5 RAFT-Risk Analysis Methodology

5.1 Introduction

In this section, we will first analyse the RAFT methodology in its components and as a general-purpose risk analysis methodology, then we will apply it to the specific case of safety and security in public spaces

5.2 RAFT in general

As a result of an Aufbau process, we have got a model tracing the relationships from stakeholders' values to be provided, passing through urban planning / urban design / architectural requirements, up to the physical realization (in hardware, software, construction, organisation and more) of them. And vice versa.

To let this become a risk analysis framework we need to complete it with already given elements of risk and then we will get a complete risk model mapped onto the Smart City described by the extended Ramaprasad's ontology.

5.2.1 Building risk over Aufbau resulting in DAG

Let's start from Figure 30 - RAFT basic loop and put it into Figure 47 - Smart City Basic DAG with Alpha States and Details Level. The result of this operation is depicted in the following diagrams.

As a first step, let's consider only the engineering domain expanding it to show the Systematic Unit's components, i.e. those elements that can fail or be attacked.

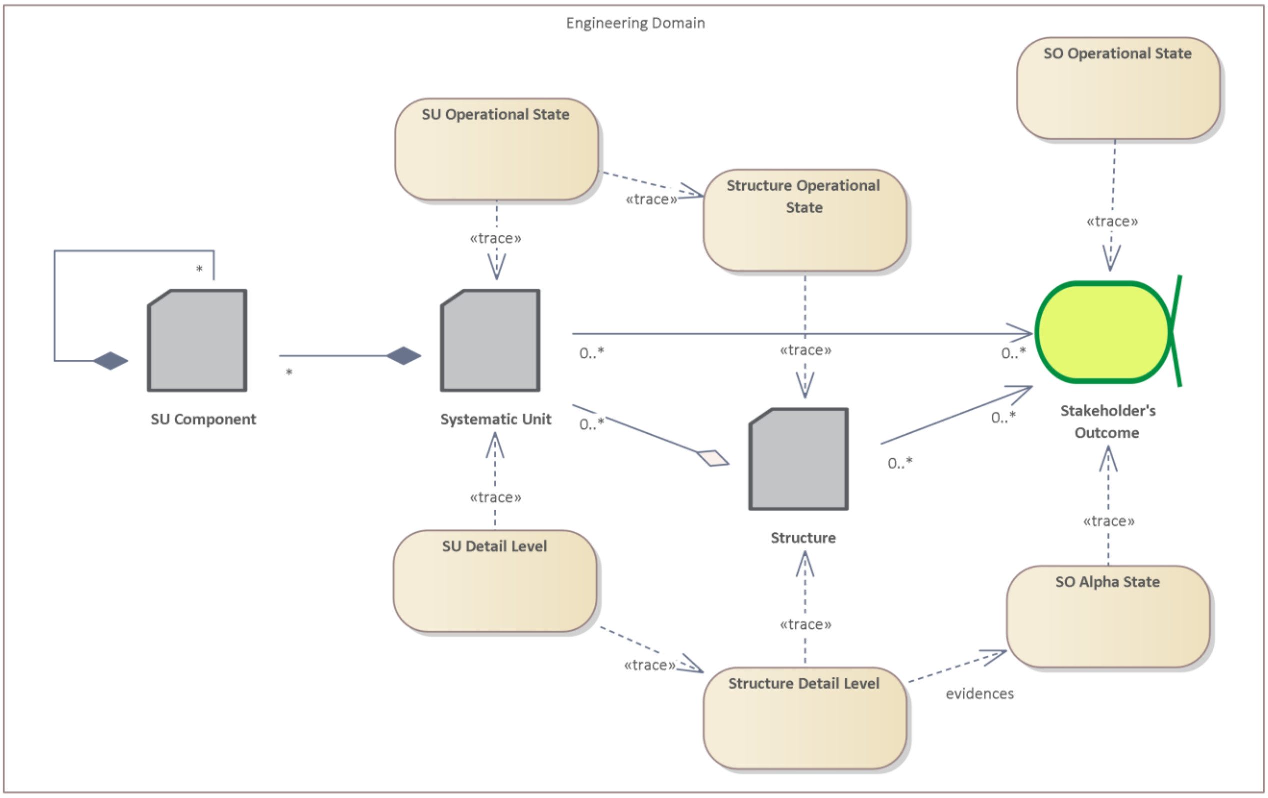

Figure 49 - Engineering domain with evidence of components for Systematic Units

The SU Component work product is related to a composition relationship (spear with dark diamond), where the SU Component(s) compose the Systematic Unit. An SU Component can be, at the same time, composed of other sub-components. This feature is described by the recursive composition relationship onto SU Component. This new structural diagram contains a recursion but this recursion can be resolved by creating a sort of hierarchical unroll like the diagram below:

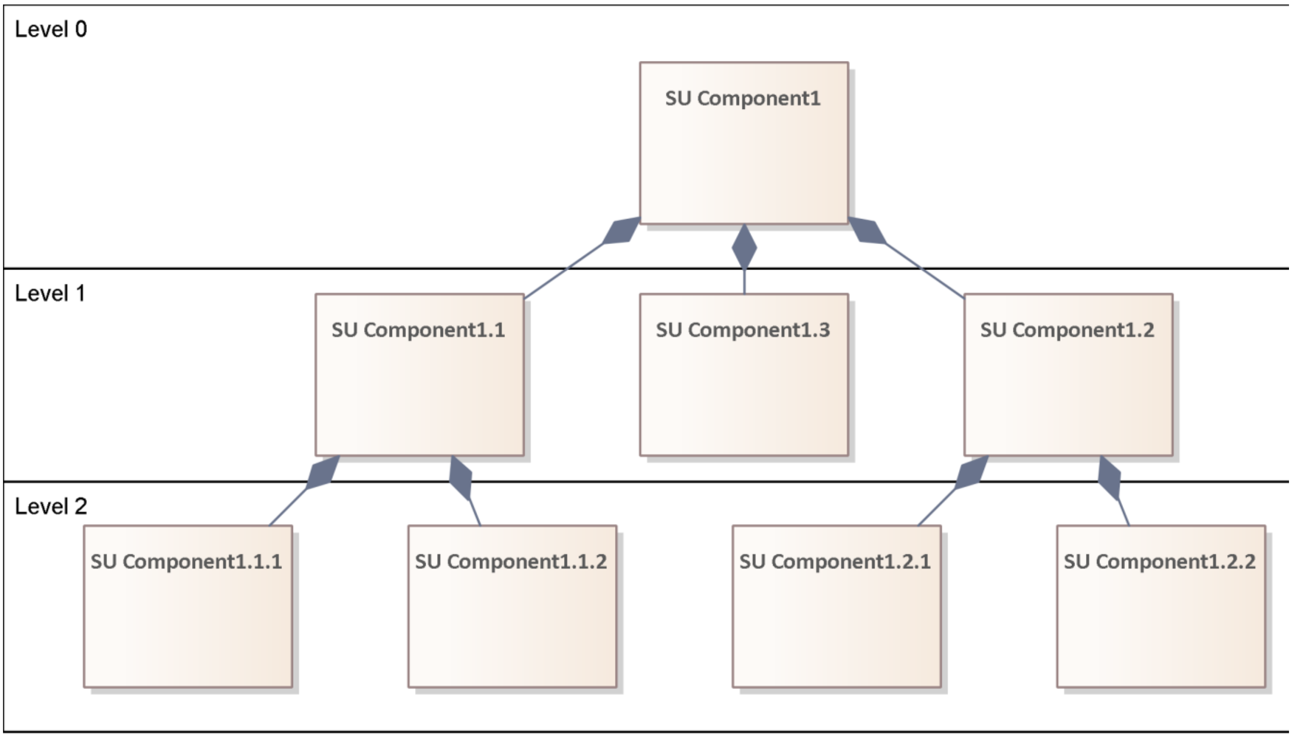

Figure 50 - Unrolling recursive relationship as a hierarchical structure

This structure can be partitioned into levels. Each level can be numbered from zero to Ndl, where Ndl is the number of the deepest level in this tree. In our example above, Ndl is 2 because the deepest level is Level 2.

About Figure 30 - RAFT basic loop we can apply it to all the levels to define the RAFT-FMVEA analysis for each component of a Systematic Unit. In this operation, we assume that each component in level i-th is connected only with elements at level (i-1) (where I is greater than zero). The RAFT basic loop can be unrolled too and the result (for the above hierarchy) is represented in the diagrams below.

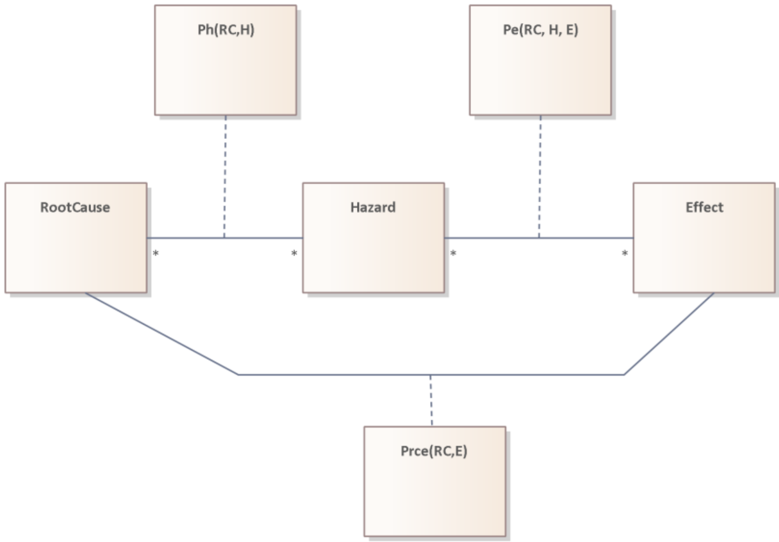

Figure 51 - Probabilities Summary for Root Cause and Effect

In the above diagram, the root cause, the hazard and the effect are associated through probabilities. Ph is the probability that for a given root cause a specific hazard becomes real. Pe is the probability that given a root cause that causes a specific hazard, a specific event happens. Prce is the probability that, given a root cause, a given event happens. Given that Ph and Pe are sparse matrices mapping from root causes (rows) and hazards (columns), for Ph, while Prce is from hazards to events.

In a few words, given a vector of the root causes RC (size Nrc) and another of hazards H (size Nh) and another of events E (size Ne), Ph(i,j) = probability(RCi, Hj). The same for Pe(i,j) = probability(Hi,Ej).

The probability is related to events (hazard or event) that are not mutually exclusive, this means that the total probability must be calculated by removing the intersection of probabilities (Probability addition theorem)

$$p(A \cup B) = p(A) + P(B) - P(A \cap B)$$

Assuming these variables, the likelihood of having an effect given a root cause becomes:

$$p_{rce*}(k) = p_h(i,k) \cdot p_e(k,i)$$

$$p_{rce'} = \sum p_{rce*}(i) \cdot p_{rce*}(j) \;\; (i,j) s.t.\, i < j \text{ and } i,j \epsilon [0, N_h]$$

So final probability of having an event j caused by a root cause i is:

$$p_{rce}(i,j) = (\sum p_h(i,k) \cdot p_e(k,i)) - p_{rce'} \; s.t.\, i,j,k \epsilon [0, N_h]$$

Being the probability between 0 and 1, it is possible to map it onto the 0-10 scale defined in table Table 16 - Probability values. One way could be using a binning approach by multiplying it by 10. Another approach could be reasoning in terms of standardized value

$$z = \frac{(x - x_m)}{\sigma}$$

and considering σ as the unit for the likelihood of events (e.g. x > 5 σ means 0, 4 σ <x<5 σ means negligible and so on). For our research, it is not important which way is used. For the sake of simplicity, we will choose multiplying by 10, but all reasonings will remain valid for any kind of mapping.

Each given effect has a severity that is graded from 0 to 10 and has a detectability that can be ranked 0 to 10.

So the criticality can be calculated as the product of the discretized probability, the severity and the detectability.

The result will be the criticality of root cause I causing the event j.

Now, according to diagram Figure 30 - RAFT basic loop, the criticality can become a root cause travelling through the DAG that represents the smart city in terms of illustrative components. The overall risk assessment process can be applied to each layer of the DAG, arriving at a final DAG where on each edge there is a risk criticality value (that is an array). Given the acceptable risk level threshold, each edge that goes beyond such threshold is a critical edge to be resolved.

We can now define a global risk function travelling the DAG from the systematic units up to the outcomes, where the criticality of each layer, can be mapped as source on the next layer.

Let us call define a cumulative risk function CRF(node), where the node is any node in the DAG and the risk criticality is calculated considering all the nodes in the path before the nodes. Applying as a node an outcome we have the risk criticality about such an outcome.

Let us call the global requirement risk criticality function GRRC() the highest criticality for any outcome, i.e. the max(CRF(requirement)) where the requirement is any of the requirements related to stakeholders.

Let us call the global outcome risk criticality function GORC() the highest criticality for any outcome, i.e. the max(CRF(outcome)) where the outcome is any of the outcomes related to stakeholders.

5.2.2 Risk minimisation problem

To define an overall risk metric that can be the target of a nonlinear optimisation problem, we consider a specific layer, that could even be the one with the highest level outcomes. This layer will be the target layer for which to optimise risk. Reasoning for a generic layer allows us to solve partial problems instead of attacking the system with a big-bang approach.

Having defined a layer in the DAG, we consider all the nodes in such a layer. If they are outcomes or requirements or illustrative components it is not important. We are evaluating risk for high-level concepts, moving out from the engineering domain towards the architecture / urban planning / urban design domain.

Let us define Nlayer as the number of these nodes. They do not have the same importance and then we must consider an array of weights, made by real numbers from 0 to 1, of weights to be used to implement a utility-value analysis with le linear combination of the vector of the selected nodes CRF(node-i) multiplied by the weights Wnode(i), obtaining a value that is the result of the utility value analysis. This value can be considered a function to be minimized with appropriate design, implementation and operation. The function to be minimized in an optimisation problem is called objective function and is referred to as RUVAlayer(X), meaning it is a utility value analysis of risk for a given layer (where the layer is constant) and X will be further explained later. This is the objective function of the risk minimisation problem.

The risk function is subjected to some constraints that are related to the need to have some systems operational or not. But, before proceeding, it is needed to introduce the degree of freedom.

5.2.2.1 Design, implementation and operation degrees of freedom

When designing, at any level, a system of any kind, often there are many possible design solutions. Each design solution has its advantage and its issues. So, we can consider the possibility of different solutions as a degree of freedom in our analysis, with the constraint that only one solution will be used after having chosen the best. The same is about implementation. Often, different devices with the same form, fit and function can be used as replacements but they have different failure rates, for example, or different costs, and choosing between them impacts reliability and something else. The same for architectural or planning solutions. Again, in maintenance, we can adopt different strategies and get different performances (and risks). So, in general, we can apply different "tactics" to obtain the same result, at any layer of the DAG, and we must choose which "tactic" to use. Given the number of alternative (mutually exclusive as a hypothesis) tactics, we can define them, for a single node, FD(node), that is a vector Ntactics(node) size.

Having defined these tactics, there is an essential constraint that cannot be violated, that is that only one is acceptable for each node. So the vector of selection FDS(node) will be made by binary elements where 0 means solution not applied and 1 means solution applied. On each FDS(node) exist the constraint that only one of them must be equal to 1, that is that their sum is always 1. For optional systems, the constraint can be relaxed as the sum less or equal to 1.

Each FD has a cost and it is described in the vector FDC(node). This cost and its scope will be better described in the next sections.

So, our optimisation problem has, for now, the following structure:

$$\min\,(RUVA_{layer}(X))$$

subject to constraint

$$\sum FSD(node) = 1\ \forall node\ in\ layer\ before\ selected\ layer$$

And where X contains FDS for all nodes as decisional variables.

5.2.2.2 Criticality factors as decisional variables

Considering the risk analysis approach, it is essentially based on probability, severity and detectability. So, to reduce risk, we have to change the value of these variables. For example, if a node has a risk function too high we can improve the node by changing the probability of the failure mode or reducing its severity. For example, an electronic board that can be damaged with an average probability by lightning can be hardened with proper shielding and become a low probability of damage. So this is another kind of intervention to mitigate risk. But these interventions have a cost. They are another type of degree of freedom but the difference with the previous one is that they can be cumulated (i.e. they are not mutually exclusive).

This can be done on probability, severity and detectability. So we have three vectors about different countermeasures that can be activated or not: CMp (i.e. countermeasures for probability), CMs (i.e. countermeasures of severity), CMd (i.e. countermeasures of detectability). Activating any one of these countermeasures will impact on probability or severity or detectability of one node.

These countermeasures arrays are a function of different variables and contain the value for the parameter after their implementation:

- CMp(node, RC, H, E) – an array of values of probability P(node, RC, H, E) to get the effect E for the node, caused by the root cause RC, for hazard H if the corresponding countermeasure is activated
- CMs(node, E) – an array of values of the severity of the effect E for the given node if the corresponding countermeasure is activated
- CMd(node, E) – an array of values of detectability of the effect E for the given node if the corresponding countermeasure is activated

As in the section before, we can define a selection vector made by binary values indicating if the countermeasure has been activated or not: CMSp(node, RC, H, E), CMSs(node, E), CMSd(node, E). Each one of them is an array of 0 and 1, meaning countermeasures adopted (1) or not (0). The resulting value of the related variable (probability, severity or detectability) will be the minimum (for detectability) or the maximum (for probability and severity) of the values of CM with a corresponding CMS value of 1. In this case, we consider a worst-case approach.

But selecting countermeasures has a cost. This cost can be in terms of money, power consumption, weight, size and more. We will then define a cost function based on a discrete scale like the following:

Table 26 - Cost class of a countermeasure

Cost of countermeasure	
Which is the estimated impact on the cost of applying the countermeasure?	
0-1	Negligible
2-50	Low
51-100	Average
101-200	High
200-500	Very High
500-1,000	Critical

So we will have, for each countermeasure another vector CMC with a cost in this scale. The cost is generic and should be qualified case by case.

So we have other three vectors CMCp(node, RC, H, E), CMCs(node, E) and CMCd(node, E).

Now we can add the following elements to our optimization problem:

X contains CMSp, CMSs, CMSd.

Global cost is defined as a function gc(CMSp, CMSs, CMSd, DFS)

$$gc \leq maximum\ allowed\ cost$$

5.2.2.3 The fitness function

An optimization problem like the one above is very complex to be solved at its optimum so we will follow a strategy to find an optimal solution, that is not the best (probably) but it is very next to the optimum.

To solve these intractable problems, often are used a special set of algorithms called “evolutionary algorithms”. These algorithms (like genetic algorithms, particle swarm optimization, and others) start from a point in the solution space and try to find a better solution than the previous one using techniques from biology like evolutionism.

An example could be a genetic algorithm where the solution is expressed in the form of a genetic sequence that is split and recombined with other sequences to obtain new solutions, that can be feasible (i.e. they respect constraints) or unfeasible (i.e. they violate constraints) (Lezzerini, 2005). The strength of these algorithms is that they keep, at each iteration (generation) both feasible and unfeasible solutions because by mixing them there is a probability to get better solutions. Because at each generation the number of solutions doubles (previous generation + new generation obtained recombining the previous genomes), it is necessary to select those who are the best. For this selection, solutions are ranked according to a value called fitness function.

A fitness function is a function of the solution generated using a penalization scheme. Some constraints are removed and then added into the objective function as a penalty, with specific weights.

In this case, we will use as a fitness function the sum of the objective function (to be minimized), the global cost, and the sum of FDS, each one with a specific weight that is needed to adapt different dynamic ranges to avoid overwhelming.

So, our fitness function can be expressed in the form:

$$fit(X) = a \cdot RUVA_{layer}(X) + b \cdot gc(X) + c \cdot \sum FDS(X)$$

Where a,b, c are coefficients of linear combination to adjust values with different dynamic ranges to avoid overwhelming.

The above fitness function can be used as a strategy for a meta-heuristic algorithm to look for optimal solutions, but it is important to underline that this approach leads to many solutions that are not feasible and should be used only as the most-promising direction indicator for a search algorithm. The development of this meta-heuristic is left to further research.

5.3 RAFT for public spaces

Having defined RAFT for the general case, it is now possible to refine it in its application to public space, virtual or physical is indifferent.

To develop this tailoring, we will refer to the diagram of Figure 49 - Engineering domain with evidence of components for Systematic Units.

In this diagram, we will consider the factors influencing safety and security in public space as "components" of the public space Structure. So, each public space has to be considered "composed" by the influencing factors that should be considered as Systematic Units.

The influence factors cited above are those evidenced in section 2.3-The RAFT Framework – part one – include safety and security.

Below is this updated diagram as been reported:

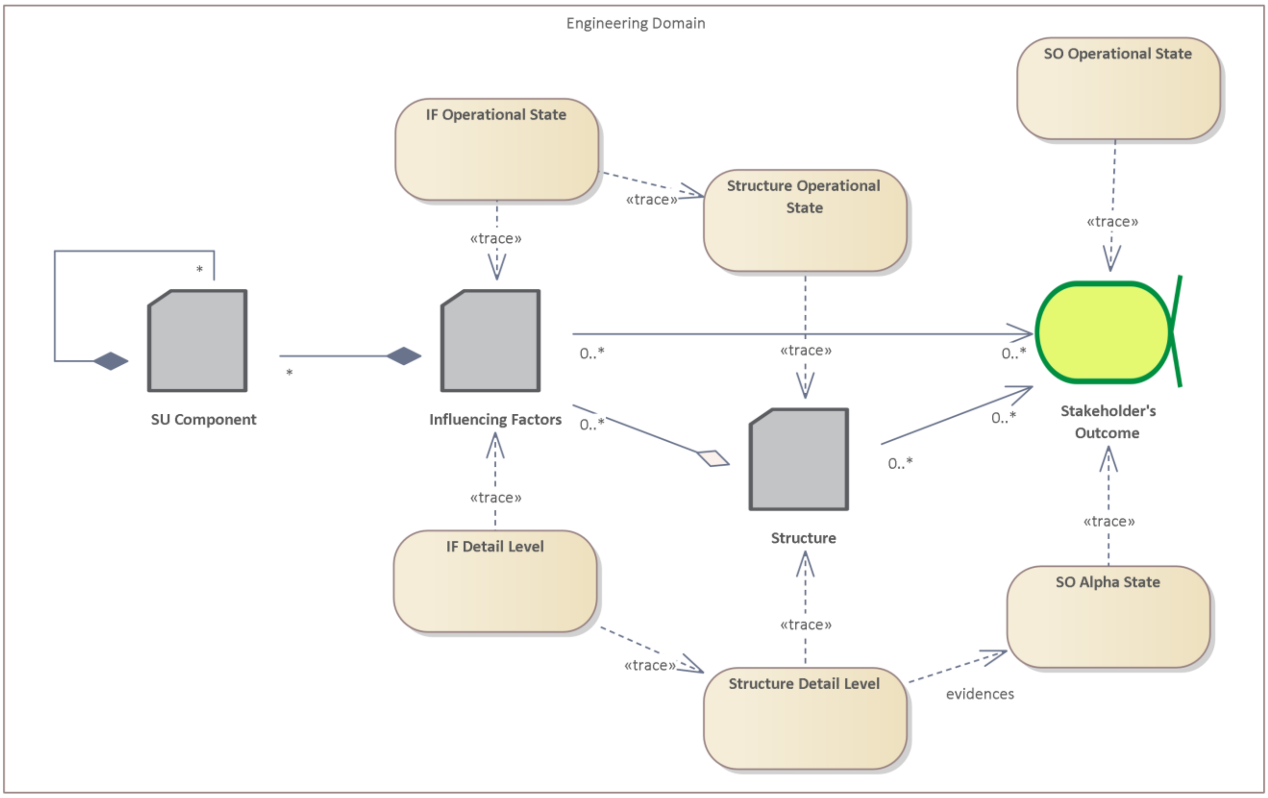

Figure 52 – RAFT tailoring for public spaces with influencing factors evidenced

As can be seen, the Systematic Unit artefact has been changed as Influencing Factors to evidence their position in the DAG. It is important to underline that we can define, below these factors, and also other elements (that are SU Components) to define how these factors are generated.

But the above diagram is missing the Systematic Units that, in any case, are yet present. In the following UML class diagram, a new hierarchy is proposed for Systematic Units.

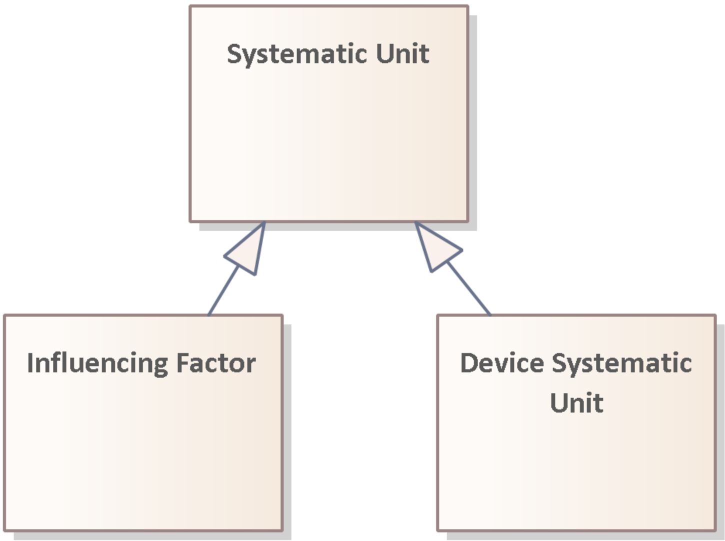

Figure 53 - Systematic Unit Specialization

In this representation, the Systematic Unit has been seen as a general case with a specialized element that can be the influencing factor and another specialized element that is the Device Systematic Unit. This means that, while the diagram of Figure 49 - Engineering domain with evidence of components for Systematic Units remains unchanged, it contains the representation of both elements: the influencing factors and the real systematic unit (the Device Systematic Unit).

With this hierarchy is now possible to extend, into the engineering domain, other elements coming from Urban Planning / Urban Design / Architecture / Sociological / Psychological domains, to be considered as elements of the Structure implementation (they are elements in the sense of risk analysis).

After this tailoring, RAFT can be applied as already explained.

6 Application Example: Milan, Public Park Giuseppe Lazzati

6.1 Introduction

To test the framework and give an example of its application a real place has been considered. The scope of this example is not to develop a complete project but only to assess the capability of the framework to support safety and security in public spaces in smart cities, tracing from original requirements from an urban planning /urban design/architecture up to the final technological systems or infrastructures.

6.2 Place description

A first application example to test the framework has been a public park entitled Giuseppe Lazzati. This park, crossing via Vincenzo Monti, adjoins Garden Valentino Bompiani to NE, with a

Carabinieri's barrack (Lombardy Legion's Headquarters), on SW with a school and on NW with residential buildings.

Below it, there is an underground parking lot. At the end of via Vincenzo Monti, there is an important district, the City Life District, with a mall, cinema, a lot of business offices in three skyscrapers, a luxury residential area, an auditorium and a gigantic public park. So via Monti could be, in some cases, an important traffic arteria. Through it, there are two tram lines.

Figure 54 - Park Giuseppe Lazzati, aerial view

In the image below it is possible to see, on the left, the high school facing the park and a portion of the park itself.

Figure 55 - Park Giuseppe Lazzati, SE View

The park includes a small building that can host most of the devices used to manage (on the edge) the IoT systems that will be installed around. It is visible on the right of the image below. Also should be noted one pedestrian access to the underground garage.

Figure 56 - Park Giuseppe Lazzati, NW View

6.3 Aufbau from scratch application

We will apply the Aufbau-from-scratch approach defined in section 4.3.2.

6.3.1 Stakeholders and outcomes

To apply the risk analysis methodology to this area, first, it is needed to define the stakeholders and the outcomes that we want to get from smartifying this place.

The stakeholders can be chosen from Ramaprasad’s list: Citizens (CIT), Professionals (PRO), Communities (COM), Institutions (INS), Businesses (BIZ), and Governments (GOV). We can ignore, in this example, businesses, professionals and communities, adding two types of citizens: students (STU), and teachers (TEA). So, in the following, we will have generic Citizens (CIT), Students (STU) and Teachers (TEA)

Let us take the sub-alphas for outcomes and choose which take (underlined):

Table 27 - Desired outcomes for Park Giuseppe Lazzati

Value	Sub-values
Sustainability	optimize current use of fossil fuels, eliminate waste, recycle, recover energy, save time, and reduce, or eliminate, pollution
Quality of Life	wealth, employment, the environment, physical and mental health, education, recreation and leisure time, social belonging, religious beliefs, safety, security and freedom
Equity	Absence of unfair, avoidable or remediable differences among groups of people, The groups are defined socially, economically, demographically, geographically or among another dimension (sex, ethnicity, disability, …)
Livability	safety, mobility options, employment and educational opportunities, public space, and political stability
Resilience	local knowledge, community networks and relationships, communication, health, governance and leadership, resources, economic investment, preparedness, mental outlook

So, the matrix for mapping stakeholders onto outcomes is:

Table 28 - Example of mapping between outcomes and stakeholders

Outcome	CIT	STU	TEA	INS	GOV
The environment (QoL)	Yes	Yes	Yes	Yes	
Physical and mental health (QoL)	Yes	Yes	Yes		
Safety (QoL)	Yes	Yes	Yes	Yes	Yes
Security (QoL)	Yes	Yes	Yes	Yes	Yes
Mobility options (L)	Yes	Yes	Yes	Yes	Yes
Public space (L)	Yes	Yes	Yes	Yes	

In this mapping we have supposed that some values are not required from the Government and the Institution stakeholders, just to show how the methodology works.

6.3.2 Requirements

For each outcome, we have to define the requirements. These requirements come from an urban planning/design/architecture (like those from Green Urbanism according to Lehmann described in section 3.3) but can also be chosen among the results of the analysis of factors impacting safety and security defined in section 2.3.2 or according to other approaches (e.g. ISO standards, …).

Table 29 - Requirements for outcomes in Lazzati Park

Outcome	Requirement
The environment (QoL)	Plants, waste bins, no high buildings on the borders, photovoltaic lighting
Physical and mental health (QoL) (Hematian et al., 2022)	Reduce traffic noise lower than 65dB, reduce tramways noise lower than 65dB, good lighting, public transportation stop, daylight and night lights, easiness of access, attractiveness and aesthetics, screens projecting mind-relaxing contents
Safety (QoL)	Protection of underground garage accesses, the no-slipping pavement on pedestrian paths, compact ground on pedestrian grass areas, playground for children far from the road and with fence around, fenced area for dogs, public defibrillator units (at least 1 outside and 1 inside)
Security (QoL)	Visible security; attendance increase through fitness tools, playgrounds, dog areas, benches; attractiveness with good urban furniture and lighting, small snack bar; cleanliness, spaces to meet in groups (neighbouring benches and cyberspace)
Mobility options (L)	Public transportation stop very next to the park, parking areas for car sharing and bike sharing, parking areas for motorbikes (high school on one side) and bicycles
Public space (L)	Free WiFi area, many access points to the park, many benches both without sun shields or with sun shields

A more detailed view of the park is provided below.

Figure 57 - Park Giuseppe Lazzati, aerial detail view

Some of the requirements defined above have been underlined because they require technological support (i.e. will be Systematic Units). They are:

Table 30 - Requirements for outcomes that require systematic units

Reduce traffic noise lower than 65dB, reduce tramways noise lower than 65dB,	Active devices for noise suppression can be used to remove noise-producing complementary noise. Losing these functions will create additional noise that can impact health.
Good lighting, daylight and night lights¸ lighting	Lighting should be dosed to save energy but also provide enough illumination. Then it requires sensing people in one area and arranging light intensity accordingly.
Screens projecting mind-relaxing contents	The jumbo screen can create a relaxed oasis where people can lower their internal tension, and meditate. Programs can be changed by using a control app. Also, holograms can be used.
Visible security	Cameras should be evident and also frequent police patrol will be provided, with AI that detects potential security risks in advance, requiring further patrol activity

Spaces to meet in groups	Such spaces should include a cyberspace to include people not present or arriving, through holograms, virtual reality, augmented reality and wearable displays.
Free WiFi area	Local free WiFi connection to increase accessibility to the Internet.
Both without sun shields or with sun shields	Mobile shields to repair people on benches from direct sunlight when it is hot and trees are not in the right position to create enough shadow. Shields are positioned according to skin temperature and the feeling of citizens on the benches.

6.3.3 Illustrative components

According to the selected Aufbau process, it is now time to define illustrative components using Ramaprasad's ontology. We will explore only some of them to give an example of the application of ontology.

Let's start with the first requirement, the one about noise reduction. This requirement, as Essence states, is an alpha (it is a sub-alpha of the sub-alpha Environment of the sub-alpha QoL of the alpha Smart City, but indeed it is an alpha). The illustrative components needed are:

Table 31 - Illustrative components example for noise reduction

RQ01-Architecture to sense environmental data to citizens for noise reduction	These are the constructive elements to support and protect sensors for noise reduction
RQ02-Infrastructure to sense environmental data to citizens for noise reduction	These are the sensors to measure noise and convert it into digital signals
RQ03-Systems to process environmental data to citizens for noise reduction	These are the digital signal processors to calculate the noise suppression patterns to be produced to compensate for noise from the road and from the tramlines
RQ04-Systems to monitor environmental data to citizens for noise reduction	These are systems that detect noise after suppression and evidence deviations for expected results, ensuring that the noise will comply with requirements.
RQ05-Systems to translate environmental data to citizens for noise reduction	These are the actuators to produce a complementary sound pattern to reduce noise in specific areas of the park.

RQ06-Systems to communicate environmental data to citizens for noise reduction	These are the systems to transfer information about noise reduction locally
RQ07-Infrastructure to communicate environmental data to citizens for noise reduction	This is the local infrastructure to transfer data about noise reduction
RQ08-Systems to monitor environmental information to the government for noise reduction	These are the systems that monitor the effect of noise reduction to transfer it to the local government to monitor noise reduction performance
RQ09-Infrastructure to communicate information to the government for noise reduction	This is the communication infrastructure to transfer the information (essentially KPIs but not only) about noise reduction to the local government

In the above table, we have defined some illustrative elements for the requirements for noise suppression. We have supposed to use a technology known as active noise suppression that uses specific complementary sounds to cancel noise sounds. Practically some microphones detect the noise, then signal processors calculate signals that summed to them will produce something near zero (the requirement is to reduce the noise to the level of a loud voice conversation, the lower the better) and emit these sounds in a specific direction to be summed to original noise. The result will be a lower noise signal in some areas of the park. The wider the areas, the more complex the system. This technology has been chosen to demonstrate how risk methodology can be applied.

We should have considered other requirements and other illustrative components but, for our application example purpose, it is enough. In a real more complex case we will have hundreds of thousands of illustrative components (or millions) and a computer will be required to handle such complexity. This is already possible through the BIM approach to building. So our risk management methodology can be seen as an extension of the BIM approach.

Now that we have the illustrative components according to Ramaprasad, we can detail them into systematic units that represent the instances of technological systems we have to develop and the factors influencing safety and security in the public space.

6.3.4 Alpha and operational states

Before proceeding with systematic units, we should define alpha states for each requirement. These alpha states are a measure of the level of implementation (development) of the requirements during the construction of the Smart City. For our purposes this detail is not needed, because we do not want to monitor the construction of the Smart City but analyse the risk during design and operation. Nevertheless, it should be clear that this opportunity exists and that, given the alpha states for each requirement it is possible to measure the "health" of the development process for each requirement and, consequently for each outcome. It should be remembered that each alpha state is a checklist that can be used to define the level of completeness of the state.

Having defined alpha states (we have skipped them for the reasons explained above) also operational alpha states must be defined these operational states are checklists that evidence if the alpha is fully operational, if it is in a state of graceful degradation (i.e. yet operational in acceptable performance limits) or not operational (i.e below minimum required performance). Although these three states are enough in most cases, it is possible to have more or less (minimum two, operational and not operational) depending on the case. In our example, we will consider the following operational alpha states with three states for each alpha but also for each illustrative component. In this example, we will consider only some illustrative components for the sake of simplicity. Illustrative components not considered will not be reported in the table below.

Table 32 - Operational states example for illustrative components

Illustrative component	Operational	Graceful degradation	Not Operational
IC01-Architecture to sense environmental data to the citizens for noise reduction	Architectural elements to support sensors are all stable	At least 1 architectural element supporting sensors is not stable but it is not at risk of collapsing in less than one week	At least 1 architectural element supporting sensors is not stable but it is at risk of collapsing in less than one week
IC02-Infrastructure to sense environmental data to the citizens for noise reduction	Data are sensed by all sensors and Data precision is 1% or lower	Data are sensed by at least half sensors and Data precision is 5% or lower	Data are sensed by less than 50% of sensors Or Data precision is greater than 5%
IC03-Systems to process environmental data to citizens for noise reduction	Hardware is fully operational Firmware is updated Software is updated	Hardware is fully operational Firmware or software are not updated (not more than two patch releases only are missing)	Hardware is not fully operational Or Firmware or software are not updated (missing at least a minor release)

Having summarized the operational states in the above table, let's explain how they have been defined and how to understand them.

6.3.4.1 Architecture to sense environmental data to the citizen for noise reduction

These elements are construction elements (technical rooms, technical racks, …) or urban furniture (poles, joints, …) used to contain the components needed to sense (i.e. sensors and their edge interfaces).

These are architectural elements because they are tied to space shaping. They are almost made of plastic, metal and some binding concrete. Their operational state can be distinguished by their stability to support the elements that will provide the sense function (i.e. the sensors infrastructure). If one of these architectural elements is not stable it can be dangerous (e.g. falling or exposing hazardous voltage), make the sensor unuseful (bad orienting, vibrating, …) or become vulnerable to attacks (e.g. unlocked rack or without front door). All these cases, to ease the discourse, have been summarized with the term stable.

When the component passes into a non-operational state, the function is lost and the maintenance should be immediately activated. In graceful degradation, the function is kept but maintenance is needed in a short time.

6.3.4.2 Infrastructure to sense environmental data to citizens for noise reduction

In this illustrative component, we are considering the devices used to sense, their connections and interfaces (i.e. sensors, cables, wireless connections and local interfaces).

Their operational states depend on two elements: the precision of the measure and the operativity of the sensors (in a wider sense, for example, they can be operational but not reachable due to issues with connections or electromagnetic noise).

Depending on the values of these two elements, the operational state can be defined.

6.3.4.3 Systems to process environmental data to citizens for noise reduction

These systems are digital signal processors that are usually composed of hardware, firmware (i.e. software that directly interacts with the hardware) and software (that can be both the operative system or an application). To simplify the example we have considered only the update status of the software and firmware and the operativity of the hardware.

Each software and firmware has a release version that, usually, is composed of three numbers in the form of version.minor.patch. An example could be 2.7.12, where the version is 2, the minor is 7 and the patch is 12. Usually, a change in the patch means that some bugs have been solved but no change in functions has been done. A minor version means small changes in functions or optimisations. A version change means an important change in the software specifications that sometimes leads to incompatibility with previous versions.

In our definition of operational states, we have considered the update of the version of both firmware and software. Updating is important from both security/safety and functional points of view. For this reason, it has been assumed (as it is normally in practice) that all the software (including firmware) should be always updated to the last release. It is tolerable having skipped a few patches but not having skipped a minor o version release. So, for our example, remaining back on installed releases leads to graceful degradation first and not operational then.

As before, graceful degradation implies maintenance in a short time, not operational implies immediate maintenance.

6.3.5 Systematic units

Having defined the illustrative components we have completed Ramaprasad's framework but in our extension, there are two improvements of it: the alpha and operational states and the systematic units.

In our example, we will simplify the technological implementation of the systematic units but the logic will remain valid.

Let us now describe this implementation.

6.3.5.1 Architecture to sense environmental data to the citizen for noise reduction

This architecture consists of twelve poles with joints to hold sensors (up to four sensors) and their solar panel.

Poles are inserted into the ground.

Our systematic units, in this case, will be the poles and the joints. From the engineering perspective, the whole group of joints and poles can be assumed to be a single unit.

6.3.5.2 Infrastructure to sense environmental data to citizens for noise reduction

This infrastructure consists of a sensor, a local hub to accept up to four sensors, a solar panel with an inverter and a battery to provide power supply to each one of them (no main supply is required) and a wireless interface to provide connectivity.

6.3.5.3 Systems to process environmental data to citizens for noise reduction

This system consists in a single rack where are hosted two digital signal processing units that, in parallel, processes data. Losing one unit allows the other to continue working but noise reduction will be less performant. The rack is powered by a main supply with an emergency battery with 1 hour of autonomy.

6.4 Application of RAFT

Having defined the DAG to represent the smartification of Lazzati Park (like the one in Figure 47 - Smart City Basic DAG with Alpha States and Details Level), we can start to apply the risk analysis methodology.

First of all let us define the following table (it is not complete, it is an example) for the first systematic unit (type): the pole with joints.

Table 33 - Sample values for systematic units

Root Cause	Failure mode	Effect	Probability	Severity	Detectability	Criticality
Bad weather conditions	Sensor joint damage	Misalignment of sensors	4	6	10	240 Very High
Bad weather conditions	Solar panel joint damage	Lack of power supply	4	6	1	24 Low
Lightning	Sensor damage	Sensor destroyed	2	9	10	180 High
Vandalism	Sensor damage	Sensor destroyed	2	9	10	180 High
Vandalism	Sensor misalignment	Misalignment of sensors	2	6	10	120 High
Theft	Solar panel stolen	Missing power supply after a few days	6	10	1	60 Average
Theft	Battery stolen	Immediate missing power supply	5	10	10	500 Very High

We have considered only some root causes and in a simplified form but interesting results can be evidenced.

Damage to solar panel support due to bad weather can be easily detected because its failure can be communicated to a central control system but the power supply will last for some other days (or even weeks, depending on the battery) and a maintenance task can be scheduled and performed to solve the issue. This is a good example of detectability that detects the event but allows solving it without impact)or negligible impact) on the system. The same is for the theft of the solar panel. In this analysis, we are not considering the life cycle cost of the risk because out of scope.

The misalignment or the miss of sensors is a problem that seriously impacts with high criticality but that can be solved at a higher level. For example, in the operational states of the infrastructure to provide noise reduction we considered at least 50% of sensors operational to stay in graceful degradation. This means that a criticality at one level can be compensated at a higher level with redundancy or other techniques from reliability engineering.

The stealing of the battery will imply a very high criticality on one or more sensors that are on a single pole. Even here, redundancy can help in avoiding not operational state.

7 Conclusions

7.1 Research results

The research has led to many important results that are reported and explained in the present section.

Some of these results have been direct consequences of the research statement, while others are side effects that emerged during the research and that have been collected to be highlighted because can be useful in other disciplines or subjects for further research.

Results are proposed in an order that starts from those directly related to the research question, leaving last the others.

For each result, a description of its application to Urban Planning / Urban Design / Architecture is provided.

7.1.1 Cyberspace is a public space

The first result comes from section 2.3.4 and is the analysis of the question of whether cyberspace (or a portion of it) present in a Smart City is a public space, a virtual one that belongs to the public sphere.

The answer to the question is that cyberspace can be often considered a public space, different from the physical one, but with all the elements that characterize a public space in the physical world, like being a place, having an identity and allowing socio-political impact.

This kind of result is not limited to Smart Cities only but can be extended to cyberspace in many other cases, but this is out of the scope of this section.

Having defined public cyberspace as a kind of public space has allowed us to extend our research into this new domain that, in Smart Cities, has an important presence.

Considering the virtual public space as a public space has some implications for Urban Planning / Design / Architecture.

The first consequence is that it is possible to rethink Urban Planning and Urban Design to act on virtual public spaces. This can happen in two ways: designing virtual elements of the virtual public spaces according to the main Urban Plan and/or Urban Design and including such virtual spaces into Urban Plans and/or Designs.

A second consequence is that Urban Planning and Urban Design must plan the real space considering the existence of the virtual and its needs to be developed.

A third consequence is for Architecture. Even if cyberspace does not imply physical space reshaping, it can influence the physical public space.

A last, partially trivial, result is that virtual public space can increase stakeholders' participation in Urban Planning and Design.

Let's now analyse these results in detail.

7.1.1.1 Designing virtual elements of the virtual public spaces

Many cyberspaces will be based on virtual or augmented reality. This fact gives a further degree of freedom in planning and designing urban space. This new kind of virtual space planning is different from usual but can follow the same principles and aims, using tools that are different and incredibly flexible. In the virtual universe, almost anything is possible and a new generation of urban planners and designers will have the task to populate this new frontier with specifically designed elements.

The automated physical space reconfiguration of the Smart City will also imply the existence of a virtual multi-space where forms of physical space that are inactive are arranged and designed. In a few words, urban planning and urban design computer-aided tools enter the life of the Smart City and become tools of government. Each configuration of the physical public space can be considered a virtual space with its own identity to be fully planned and designed. Also, architecture will change to find physical elements that can have multi-role use without (or with small) changes. So, when the configuration will be activated by the smart city, everything will be arranged properly by the Smart City itself.

7.1.1.2 Including such virtual spaces in Urban Plans and/or Designs

But not only designing the elements of the virtual public space will be important, but also considering the existence of this virtual public space will be mandatory to define new areas in the Smart City that are not physical but virtual. This means adding further space where no space exists anymore. For example, using augmented reality is possible to add descriptions to images of historical buildings (it has already been done) and this means that urban designers can avoid adding billboards or signals. This is a simple example but the space can be used differently. For example, in Milano, the façade of a building damaged during WWII has been covered by a billboard because it has not been built again. Today, in a Smart City, a different use of the space can be done by avoiding these billboards.

Figure 58 – Milan, Armani's billboard to cover ruined wall

In addition, places to allow the socialization of people can now be defined also in virtual space, giving more freedom to urban planners.

7.1.1.3 Plan the real public space considering the existence of the virtual one

When planning the real space, the existence of (planned) virtual spaces should be considered because, often, the presence of virtual space can reshape the physical one. For example, building high skyscrapers to be used as offices when, today, work is moving towards smart working, i.e. working in a virtual public space, could be rethought. For example, many business skyscrapers in Milan are not filled by people due to remote working. New strategies have to be developed by urban planners and designers to win this challenge.

Figure 59 - Milano City Life skyscrapers

7.1.1.4 Increase in stakeholders' participation

The use of virtual spaces in urban planning and design can increase the participation of the Stakeholders. This has been happening for the last few years but a portion of the effort in developing new urban planning and design tools should be oriented to leverage virtual public spaces to involve stakeholders.

But not only during planning and design the participation can be increased. Using digital twins or augmented reality can also involve stakeholders during the operation of the Smart City, gathering requirements, suggestions and warnings and putting them, immediately, in a virtual public space to show results. If this information is related to virtual public spaces, they can be put into operation in a very short time.

Virtual public spaces can also be another way to feed Open Data to citizens, allowing them to create applications on these databases to provide new services to other citizens, increasing democracy and an open-source approach.

Also, Government stakeholders can use virtual public spaces to involve other Stakeholders. And Stakeholders like Professionnels, Institutions or Entrepreneurs can easier organise in guilds or corporations (both in the mediaeval meaning) but, using virtual public space, they can better interact with Citizens (the target of their activity) and Government and Institutions Stakeholders (for policies), to improve their business in a synergic and cooperative manner.

7.1.1.5 Influence the physical public space

The physical public space should be designed and planned, as already affirmed above, considering the presence of the virtual public space. But we can go further, stating that the physical public space is influenced by the virtual one. This influence derives from the fact that virtualising some social behaviours will change the use of physical public space. Consequently, a new generation of use adaptation methodologies for public spaces should be developed.

7.1.2 Cyberspace Impacts on Safety and Security

Given that cyberspace can be often considered a public space, it has an impact on the security and safety of public spaces (section 2.3.4).

While the security issue is well-known cyberspace (at the beginning of the research was evident that almost all risk analysis frameworks for smart cities were focused on this kind of issue), its impact on safety has not been deeply analysed. Cyberspace can cause dependency, alienation, and psychiatric and neurological problems and this is a typical impact on safety (i.e. on people's health).

Cyberspace can impact security in three different ways.

The first one is that virtual public space can be attacked by malicious users to violate its security, targeting the availability, confidentiality and integrity of semiotics (i.e. data, information and knowledge). So, protecting the virtual public space from such attacks is mandatory, especially in a complex system with a huge cyberspace presence.

The second one is that public cyberspace can be used as an attack surface to penetrate underlying structures. Structures are intended as some of the structures defined in Ramaprasad ontology like infrastructure, systems, processes, services, and people. This can happen in various ways but one of the most dangerous is social engineering. The virtual public space is, in fact, a place where it is easy for an attacker to camouflage itself and influence people's behaviour with fake news or malicious advice.

The third one is that in a Smart City, there are a lot of digital twins that are used to let the Smart City operate. All these digital twins are often used by many users and can become a virtual public space. Compromising a digital twin can have serious impacts on both security and safety.

Virtual public spaces impact safety through two different mechanisms.

The first one is generation psychosomatic, neurological or psychiatric pathologies. Virtual reality and, in general, virtual public spaces can be very stressful on mental health and generate dependence and alienation. They can also activate neurological issues through stress, fast-changing lights and other sensorial effects. The same for psychiatric and psychological issues. Some literature for reference about this part is Regan (1995), Dukuev and Kriklenko and Kovaleva (2022), Hong (2014), Vinchhi (2022), Aisha and Ratra (2022), Khawar and Abbasi et al. (2021). This issue has been particularly evident after the COVID-19 pandemic due to the large number of studies that have been conducted to assess the impact of virtual relationships caused by lockdowns and, in general, social distancing.

A second effect on safety is caused by the malfunctioning of a virtual public space. Cyberspace is often a medium to apply actions in real space. One way, just described above, is the one of the digital twin but the other is related to the use of devices controlled through cyberspace. These devices can become dangerous for health in case of failure, indifferently if caused by an attack or incidental.

But now let us get further detail on them.

7.1.2.1 Direct cyberspace attack

When a virtual public space is used by Smart City's Stakeholders, a cybersecurity risk arises. In every public space, many security requirements can be summarized in three categories, confidentiality, availability and integrity, the three pillars of information security.

Possible attacks on these requirements in virtual public spaces must be a concern in designing it. And this is one of the most common tasks in cybersecurity. So, the virtual public space should be protected by doing a specific risk analysis using an appropriate methodology. Many of them have been already developed and we considered the example of STRIDE. Using the RAFT methodology developed in this research can conjugate safety and security risk analysis at a very detailed level with very effective results.

7.1.2.2 Public virtual space as an attack surface

The virtual public space can also be seen as an opportunity (i.e. vulnerability) to attack underlying systems. This is becoming a preferential behaviour of crackers (i.e. bad hackers) because the virtual public space is crowded and subject to frequent releases of management software.

Crowding, in the virtual sphere, makes it easier for an attacker to hide in the mess, giving him or her more chances to drive the attack to desired scope.

Frequent releases mean a higher risk of regressions with the introduction of security vulnerabilities. And this is another important opportunity for crackers.

Using RAFT, or another risk analysis methodology that includes cybersecurity, can help in minimising the risk of the use of public space as an attack surface.

7.1.2.3 Compromission of digital twins

Compromising a digital twin can have different effects. On one side it could simply be losing a minor function. For example, losing the tourist information augmented reality service is a minor issue that can be compensated by googling for alternative information.

On another side, compromising a digital twin can be critical and lead to serious disasters. For example, a digital twin of the traffic in the Smart City can jam the entire city if compromised. Analogously, compromising a digital twin controlling the HVAC system in a Skyscraper can create serious issues for people inside it, especially for air renewal and temperature control in case of extreme external temperatures. Then their penetration by an attacker can impact both safety and security.

Using the RAFT framework allows a strong reduction of the risk of having compromised digital twins with intolerable effects.

7.1.2.4 Neurological and mental health issues

Virtual public spaces can become the source of neurological issues and, in general, mental health problems. excessive digital use is associated with many mental health issues including depression, irritability, stress, paranoid ideation, somatic symptoms, and psychoses, among others. It can also lead to reduced physical activity which is the cause of many other pathologies (Montag, 2019; Schwartz, 2014).

This kind of problem impact on safety and must be considered during virtual public space risk analysis.

The RAFT methodology is suitable for them because it also includes safety depending on environmental intrinsic elements (the virtual public space in this case).

7.1.2.5 Dangerous interaction with real world

Many virtual spaces have an impact on the real world and, because this integration will become more and more deep every year, the failure or sabotage of the virtual sphere can impact safety due to wrong actions in the physical world.

Due to the direct (direct interaction through actuators) or indirect (as an attack surface of failure mode) influence of virtual public spaces on the physical world, they must be considered in their failure modes or threat modes, that in RAFT have been generalised as Hazards and Effects. So, for each virtual public space, specific concerns must result about its possible hazardous events and take the appropriate countermeasures.

7.1.3 Ontology to describe a Smart City at both UP/UD/A and Engineering levels

The main objective of the research was to create a connection between two domains that usually have a gap in their communication, the Urban Planning / Urban Design / Architecture domain and the Engineering domain. Using the extended Ramaprasad's framework as an ontology to describe from one domain to the other, with full traceability, has created a safe bridge connecting the two worlds that, before, did not communicate smoothly.

Through ontology is now possible not only to connect the requirements from one side to the implementation on the other side. It is also possible to generate all possible elements of the Smart City and use them as drivers for both Urban Planning / Urban Design / Architecture and Engineering conception and design. Thanks to the extended generative formula, all possible elements can be produced.

The ontology has high flexibility because it allows the complete change of both Stakeholders and Outcomes and remains valid in its structure. Even changes in the generative formula (like including new functions or new focuses) will maintain the overall approach valid.

The use of the extended Essence 1.2 language has also added further value thanks to the introduction of the alpha states and alpha operational states. In this way, it is possible to describe the operational status and development stage in both domains. While for engineering it was already possible with various approaches, for Urban Planning/Urban Design/Architecture the evaluation was possible at the development level (but not with this detailed and formalized approach) but missing the perspective of the operational state of a Stakeholder (not considered in this research but perfectly possible due to the extended Essence structure) or of an Outcome. These aspects will be further detailed in the next section.

This ontology adds new degrees of freedom and new opportunities to urban planners, designers and architects allowing an expressive and formal representation of the Smart Cities in terms of sentences, overlapping both domains.

7.1.4 Extension of Essence 1.2 to become a formal descriptive theory for Smart Cities

With the extension of Essence 1.2 to the Smart City, many advantages are made available to Urban Planners, Urban Designers and Architects.

The first one is the ability to measure the development state of any Stakeholder (not evidenced in this research) or of any Opportunity (i.e. Outcome), at any detail level, in terms of alpha states.

The second one is the possibility (not explored in this research) to also managing different ways of development of the Smart Cities. This would require specific research but is one of the main reasons for the Essence birth.

A third one is the addition of operational alpha states that include the operation in the Urban Planning / Design / Architecture domain, giving more control over the transformation, during the time, of the Smart City.

7.1.5 Definition of a general risk analysis framework

An important result is that the RAFT methodology can be applied to any kind of Smart Cities and, with appropriate tailoring, to any kind of complex system with both ICT and non-ICT elements. Adapting it to different cases will require the adaptation of the ontology and, consequently, of the Aufbau process.

The generality of RAFT is that it has many integrations:

- Security and information security risk analysis capabilities
- Safety for systems at any criticality level
- Safety for health protection due to environmental intrinsic risk factors

RAFT has, anyway, some limitations, the most important of which are:

- Partial path attack prevention
- Use of qualitative analysis instead of quantitative (in a Smart City context, quantitative data can be easily got over time)
- Impossibility to start with a qualitative approach and switch to quantitative when big data are available

- Use of directed acyclic graphs that do not allow to manage the analysis on complex systems with feedback (feedback can be considered only inside Systematic Units and in their components)

Urban planners, urban designers, architects, and engineers of any kind can use the same RAFT methodology, applying their domain's concepts but keeping them all together.

7.1.6 RAFT Tailoring on public spaces

The RAFT tailoring onto public spaces is easy. It is sufficient to limit the analysis to the public space (including cyberspace) and consider its components and the factors influencing its safety and security. Positive factors among them are to be preserved and can be easily managed and changed, evaluating risk at both Engineering and Urban Planning levels.

This tailoring is a very good example of the flexibility of the RAFT methodology, although it was the primary objective of the research, can be seen as a special case of a more general approach.

RAFT tailoring to public spaces preserves all RAFT capabilities (and issues too) and integrates both kinds of spaces, virtual and physical. Allowing a complete risk analysis in the case of the Smart City's public spaces.

7.1.7 Definition of a non-linear optimisation problem to minimize risk in public space

Using the nonlinear programming theory from operational research, a nonlinear optimisation problem has been defined to minimize risk for a given node or globally (section 5.2.2).

Thanks to this risk optimisation problem it is possible to help urban planners, urban designers, architects and engineers to be supported in their decisions about planning, design and operational tasks.

Because the optimisation problem considers design/plan alternatives or considers additional, optional, countermeasures with their cost, the use of the problem definition can allow the manual or automated selection of the best combination of these elements, best from the risk minimisation perspective.

For example, an engineer can evaluate the impact on the risk of different design alternatives, also considering requirements from Urban Planning/Urban Design/Architecture. But the same can be done by urban planners, using different plan solutions, and verifying how the risk changes.

Another example is that a resolution algorithm (that should be investigated in successive research) can be used to generate optimal solution patterns to the two previous examples.

7.1.8 Literature review of factors influencing risks in public space

A literature review has been done to evaluate factors impacting public space. This review can be useful to designers and planners to try to shape both the physical and virtual public space safely and securely handling these factors.

Very important to be underlined is that some of these factors (environmental factors) can be managed in real-time or in near-real-time, while the individual factors are manageable with medium or long-term interventions. According to this result, it is important to also specifically plan the individual factors improvement to allow more effective risk mitigation.

7.2 Future research

7.2.1 Application of the Aufbau and ontology to logistic support

In this research, the Aufbau has been used to describe the Smart City. Like any other complex (and critical) infrastructure, the Smart City needs adequate maintenance to operate in the specifications ranges that have been defined.

Today, dimensioning such maintenance management systems can be done in many different ways (Integrated Logistic Support, Reliability Centered Maintenance, …). But the Smart City generates so much data that it can be used to make a very effective and efficient maintenance system, whichever it is.

The Aufbau and the RAFT methodology can be both, theoretically, applied to maintenance and, in general, to logistic support, from an holistic perspective. But more studies are needed on this topic.

Developing a customisation of the Aufbau and the RAFT methodology to define maintenance models and, in general, integrate logistic support strategies or methodologies for high-complexity systems like Smart Cities will further increase their ability to provide desired outcomes with reduced life cycle cost.

Important challenges are the progressive holistic approach due to the continuous evolution, since its initial development, of the Smart City, meaning that the maintenance and logistic support must grow with the city.

Today this problem is approached with a system focus on maintenance but this lacks a holistic view and introduces inefficiency and a higher risk of missing requirements due to failures.

7.2.2 Resolution of a non-linear optimisation problem with meta-heuristics

The optimisation problem has been defined but not solved, due to its high complexity. The use of meta-heuristics, a collection of algorithms designed to search for an optimal solution, can be the way to solve it.

The most important challenge is computational time but in normal operational modes (i.e. not in an emergency) time available is in the order of weeks or months and could be sufficient, with high-performance parallel computing, to solve this problem.

For the case of a short time, for example in the case of a human or natural disaster, where problems are a lot and time availability is dramatically reduced, the same approach should be sufficient, accepting a lower level of optimisation.

But, anyway, these issues will require specific further research. Until this will be done, no automated optimal solution search will be possible.

The use of an evolutionary approach moves the problem into the perspective of an "organism" that evolves to find better ways of managing risk. This metaphor recalls perspectives of the past and the present where the city is considered a living body but represents them in a form suitable to be managed by machines, to help professionals to manage an enormous complexity, even if limited to risk assessment. This metaphor also allows the use of machine learning to let The City suggest to Architects, Planners, Designers and Engineers the best options for managing risks, further empowering their expertise, their knowledge and their understanding of the Smart City with a holistic sight.

7.2.3 Application of RAFT principles to different outcomes models

RAFT methodology does not depend on outcomes and stakeholders and could be interesting to analyse different structures of them, i.e. different business models for Smart Cities, to verify its applicability.

Also interesting could be using different frameworks (like the IBM, introduced in this research but not considered for RAFT, where Ramaparasad's has been used) and evaluating and solving deriving issues.

7.2.4 RAFT application to multi-level attacks/failures as a cause-effect methodology

RAFT has a limited capability to support risk analysis in case of multi-level attacks or multi-level failures. Even if it starts from methodologies that support attack path analysis, due t the complexity of the problem it has some restrictions.

Analysing these restrictions and solving them, with an evolution of RAFT should be an interesting (and useful) element for future research.

7.2.5 Definition of a decision support tool for UP/UD to minimise risk in public spaces

The Aufbau and RAFT methodologies practically define the algorithm for a decision support tool. A specific software analysis and design task can be done as a research activity to define both a set of requirements and a feasible design of software to support Urban Planners and Urban Designers in their activity.

This research should be interdisciplinary, involving both ICT experts and Urban Planning / Urban Design experts, defining possible use cases and expected results

7.2.6 New kind of BIM

What the Aufbau and RAFT represent is a set of data and algorithms to handle risk in a Smart City. This can be read as how a new generation of BIM (Building Information Modeling) systems extended to the whole Smart City and at both Engineering and Urban Planning/Urban Design levels.

This new kind of BIM should be better defined and specific research could be very useful to enhance expert capabilities to plan, design and build on both domains.

7.2.7 New kind of digital twin of a Smart City

The RAFT approach can be read as a way to model in real-time the risk assessment of a Smart City. This means that it can be used to build a digital twin of the whole Smart City that allows precise and strategic risk management in the Smart City.

This is a new kind of digital twin that should be investigated and that will be very useful as a control dashboard of the risk level in the Smart City.

7.2.8 Application to future pandemics or biological attacks or other severe events

Due to the research limitation to the public space, no specific COVID-19, pandemic event or terrorist biological attack has been considered. Nevertheless, the RAFT framework and all its consequences can be applied to risk management in case of these events, changing the perspective from the illustrative components to a different concept.

This concept can be called a “strategic component” and should represent illustrative components that are critical for the considered case. In other words, the strategic components are a subset of the illustrative components set. To quickly derive this subset from the original one, a new attribute should be added to the illustrative component class which is a list of tags assigning the illustrative component to one or more sets of strategic components. For example, a stadium can be assigned to sports strategic components but also to mass emergency strategic components, because it can be used as a shelter for thousands of people in case of emergency.

Tagging the illustrative components to quickly filter among them is only the first step. A second step should be the evolution of the ontology to better represent the health of stakeholders and also introduce, among them, law enforcement or military stakeholders.

Doing these changes, the RAFT methodology can be applied even to severe events like mass emergencies, riots, terroristic attacks, pandemics, crowded events and so on.

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