A NOVEL WEB-BASED DECISION SUPPORT TOOL FOR ENHANCING URBAN RESILIENCE AND SUSTAINABILITY

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ABSTRACT

Urban areas are currently facing significant new and/or aggravated existing challenges due to the impacts of climate change, including increased frequency and intensity of extreme weather events, urban greenness loss, urban flash floods, air quality degradation and increased greenhouse gas emissions, geo-hazards, and urban heat fluxes among others. To enhance urban resilience and efficiently mitigate those impacts, sophisticated digital tools and Decision Support Systems (DSS) could play a determinant role in assisting decision-makers by means of providing access to pertinent data, analytical models as well as thorough insights for prioritizing the most effective mitigation strategies. The Horizon 2020 research and innovation project entitled “Development of a Support System for Improved Resilience and Sustainable Urban areas to cope with Climate Change and Extreme Events based on GEOSS and Advanced Modelling Tools - HARMONIA GA 101003517” introduces a series of innovative digital tools along with novel data services and products. This paper outlines the functioning of an urban-planning DSS that exploits the Harmonia multiparametric risk assessment methodology for a spectrum of different urban perils to eventually offer comprehensive and tangible urban recommendations for mitigating future hazard-driven adverse impacts. The proposed solution will be offered as a web-based application with a user-friendly interface, able to efficiently handle and visualize multidimensional (4D) geospatial information. The overall methodology and the capabilities of the DSS will be demonstrated in four different and diverse European urban environments, i.e., the cities of Milan, Piraeus, Sofia, and Ixelles.

Keywords: Remote Sensing, Urban Resilience, Decision Support System, Urban Planning, Risk Assessment

1. INTRODUCTION

Cities concentrate people, infrastructure, social and commercial activities as well as many other resources and assets into tight spaces, which means that *per se* are particularly vulnerable to the effects of multiple perils that are likely to be further aggravated by climate change (CC). Nowadays, about 54% of the world’s population which is currently approximately 8 billion people, lives in urban areas, even though the latter amounts to only 2% of the Earth’s surface[1]. The aforementioned percentage of the population living in urban areas is also anticipated to rise up to nearly 70% by the year 2050[2]. As CC intensifies, it severely impacts (and vise-versa is impacted by) the urban environment that experiences several adverse consequences, such as urban greenness loss, urban flash floodings events, reduced air quality, geo-hazards (i.e., landslides and ground deformations), urban heat islands (UHIs), urban fires, etc. Therefore, there is an emerging need for European cities to cope with the aforementioned challenges in a timely and efficient manner by providing resilient environments that address simultaneously security, prosperity, and public health.

As urban populations grow, holistic frameworks for the efficient management and adaptation to CC are becoming increasingly important, especially in view that a spectrum of unique features, which characterize the contemporary cities, contribute to the intensification of the CC impacts. For instance, the high impervious cover of the European urban surface exacerbates the impacts of climate warming through the UHI effect and those of heavy rainfalls by magnifying runoff and flash flooding events. As a matter of fact, extreme events are anticipated to have a rather direct and apparent impact on the majority of people during their lifetimes[3]. The 11th goal of the Sustainable Development Goals, which was adopted by the United Nations[4], targets the sustainability of European cities and communities, among others via

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proposing increased access to green spaces, reducing the number of deaths and the number of people affected by disasters, and city planning enhancement, aiming to create safe, inclusive, resilient, and sustainable cities.

Decision Support Systems (DSSs) have been introduced for urban planning and related applications since the early ‘90s[5], however, their main goal has gradually changed to eventually enhance stakeholder engagement for better informed and societally supported decisions[6]. These systems do not constitute individual models, assessments, or decision trees, but instead are comprehensive ones having the capacity to aid in structuring and resolving contested problems, while also increasing the transparency of decision-making, essentially providing end-users with a better understanding of the problem situation, and promoting knowledge[7]. Therefore, DSSs deal with unique challenges related to the decision-making process in a manner that could not be attained by traditional models or system design[8,9].

The Horizon 2020 HARMONIA project aims to provide targeted services for different groups of end-users in order to actively support urban decision-makers in strategic decisions and planning as well as citizens in facing the daily effects and risks of CC. Under this framework, we herein introduce a methodology to support the materialization of an urban-planning (DSS) that will support policy-makers implementing more efficient and suitable urban planning strategies, in terms of compatibility and sustainability, for an urban environment. In general, the urban planning approach can be considered a multi-sided concept that includes socioeconomic, ecological, technical, political, and ethical perspectives[10]. In this paper, the various technical aspects of a detailed decision-making methodology are outlined, introducing a novel multiparametric and scalable web-based urban-planning DSS for enhancing urban resilience and sustainability, with the integration of multidimensional urban context data. The DSS is functionalized to create different scenarios depending on the end-users’ preferences, the characteristics of the case study typology, and the hazard intensity in order to determine appropriate solutions. In these situations, the evaluation of alternative scenarios is consequently a complex problem and many aspects must be taken under consideration; from technical elements, based on empirical examinations, to non-technical ones, based on preferences and social concepts[10].

The introduced novel urban-planning DSS, developed within the framework of the HARMONIA project, aims at supporting public administrators in developing alternative strategies for intervention in urban-planning and urban regeneration processes focusing on the mitigation of CC and hazard-driven impacts.

2. URBAN HAZARDS AND CASE STUDIES

2.1 Urban hazards types

This section provides an overview of all the hazard types considered within this research project and therefore within the introduced urban planning DSS.

In urban areas, temperature patterns are significantly warmer than in the surrounding rural environment. This condition leads to the so-called UHI effect. Exposure to extreme heat can lead to heat stress which, in turn, can result in heat stroke, heat exhaustion, heat cramps, or heat rashes. Therefore, UHIs influence the well-being of the urban population. In particular, UHIs occur when cities replace the natural land cover with dense concentrations of pavement, buildings, and other surfaces that absorb or retain heat. Green areas, on the other hand, can alleviate the perception of thermal discomfort during periods of heat stress[11]. However, the increasing frequency and intensity of heat waves[12], coupled with the rapidly ongoing urbanization[13], make urban heat an important hazard type to be considered in our research.

Apart from being warmer than their surrounding rural areas, cities are also generally hotspots for air pollution. In turn, air pollution can affect human health when pollutants reach high enough concentrations. In fact, the so-called poor ambient air quality is thought to cause a considerable number of premature deaths in European cities[14]. While urban traffic constitutes a major source of air pollutants, wildfires that occur near highly populated cities add to urban pollution levels, as was the case for the 2009 Attica wildfire near Athens[15]. This is particularly concerning, considering that fire activity worldwide is projected to increase with anthropogenic CC[16]. Therefore, urban air quality is a crucial hazard type for European cities. Also driven by CC, heavy precipitation events are projected to become more frequent in many extra-tropical regions[17]. Coupled with land use changes[18], the hazard imposed by flash flooding is, therefore, expected to increase in frequency and severity[19]. This is particularly concerning for urban environments where natural areas are substituted with artificial surfaces that are mostly impermeable to water as part of the ongoing urbanization[13]. Flash flooding in the context of the HARMONIA project was identified as a critical hazard for Milan, Piraeus, and Sofia.

Landslides are defined as the movement of a mass of rock, debris, or earth down a slope. This natural hazard type poses a significant life threat in some European countries; in fact, increasing trends of fatal landslides have been observed in various countries throughout Europe[20]. Furthermore, CC may have a noteworthy impact on the occurrence of landslides with the increase of the water content of the soil when regarding future long periods[21].

2.2 Case studies

In order to achieve the set goals, four (4) European cities have been chosen as case studies in the HARMONIA project. Those cities are located from the southern-Mediterranean region to northwestern Europe and hence represent different and diverse European urban environments. Table 1 provides a synoptic overview of the different urban hazard monitoring components per pilot city that are considered in our research.

Table 1. Allocation matrix of the urban hazard monitoring components per HARMONIA pilot city.

Monitored Component	**Pilot Cities**			
	Milan	**Piraeus**	**Ixelles**	**Sofia**
Air Quality	✓	✓		
Urban Heat Islands	✓			✓
Urban flash flooding	✓	✓		✓
Geohazards / Land deformation	✓	✓		✓
Multiparametric Urban Planning DSS	✓	✓	✓	✓

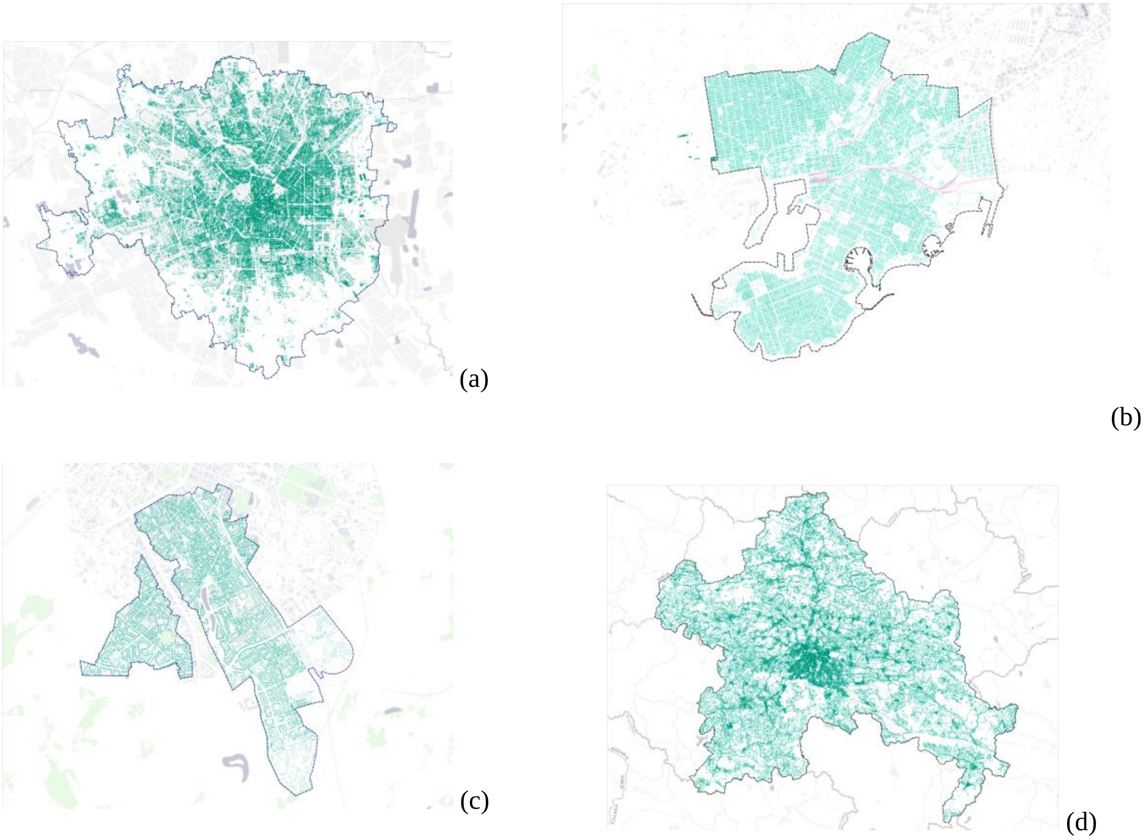
The city of Milan is considered the project's "super-pilot", as it involves the deployment of all the components and features of HARMONIA. Being the second most populous Metropolitan City in Italy[22], is the economic capital of Italy being located in one of the most industrialized regions in Europe. The high percentage of concrete surfaces, at an altitude ranging from 98 to 199m above the sea level[23], in combination with the complex network of underground rivers, constitute a morphology that generates a large variety of threats to the city's environment and population.

The second pilot city, Piraeus, is a seaside city. Piraeus is considered also to be the largest industrial center of Greece, ranking as one of the major European ports in terms of traffic volume[24]. Additionally, this city-port hosts a great variety of land use typologies and also counts as the 5th largest city in Greece in terms of population. The latter along with the lack of free spaces, parks, and high-density built environment contribute both to air pollution and to the high likelihood of flash flooding events, whereas the big percentage of critical infrastructures increase the environmental challenges and urban risks that Piraeus needs to address.

Corresponding problems are also found in one of the nineteen municipalities of Brussels, Ixelles, which is the third pilot site of this research project. As a densely built area, with very few green spaces and mixed constructions has been, the past few years, extensively affected by CC-aggravated perils, such as heavy storms, urban flooding, air pollution, and urban heat fluxes. These issues significantly affect the built environment and the health of the citizens in general.

The fourth HARMONIA case study city is Sofia. Sofia is the capital of Bulgaria, located in the Sofia Valley, next to the Balkan Mountains. The Iskar River along with two artificial river beds, which channel the rivers across the center of the city, have defined Sofia's urban planning since the late 19th century. Due to its geographic characteristics, Sofia is exposed to multiple urban perils such as air pollution, flash flooding, and landslides[25]. Hence, a multiple hazard risk mitigation approach is required to efficiently mitigate their consequences.

Considering the diverse topology of the four pilot cities, it becomes easily perceptible that the structure of the densely built-up urban environment, as illustrated in Figure 1, along with the surrounding area landscape generates diverse multiple-hazard scenarios for each of the four pilot cities.



(a)

(b)

(c)

(d)

Figure 1. Illustrated maps of the built-up urban environment for the pilot cities: (a) Milan, (b) Piraeus, (c) Ixelles, and (d) Sofia.

3. METHODOLOGICAL APPROACH

3.1 Indicator-based risk assessment methodology

An indicator-based risk assessment methodology will form the engine for the HARMONIA risk-aware DSS. In this methodology, the risk is defined as a function of three components,

$$\text{Risk} = f\,(\text{H, V, E}) \tag{1}$$

where H is the hazard, V is the vulnerability of the exposed assets and E is the exposure. The hazard (H) denotes herein the intensity (severity) of the peril under investigation (that could be spatially variable across the city) and the likelihood of that intensity to occur. The vulnerability (V) component of the risk is defined in the present methodology again as a function of the assets' susceptibility to damages and losses (on account of certain peril-tailored attributes which drive their potential performance), when those are exposed to certain perils, along with the lack of Coping Capacity (1-COP). The COP essentially accounts for those preventative local or city-scale measures/actions that could be implemented to mitigate the vulnerability of the exposed assets to the peril. By implementing a spectrum of preventative measures, one could mitigate the susceptibility and eventually reduce risk. Finally, the exposure (E) component accounts for the assets across the city that are exposed to the peril and are likely to sustain/experience some kind of damage/loss.

Among the most challenging risk components to evaluate in a city-level, is the vulnerability of the built environment and people when exposed to certain perils, mainly due to the former being highly variable in terms of their distinct attributes which determine to a large extent their performance when exposed to a peril. Apart from the above, this process becomes even more complex and challenging when one targets the development of a unified risk assessment methodology to address multiple perils, since, in several cases, the attributes/characteristics that determine the susceptibility of a certain asset to one peril, may not be relevant[26] or even negatively correlated to another one.

In the literature, there exist several different approaches for defining vulnerability. Hence, one may adopt analytical, empirical or hybrid methodologies for assessing the vulnerability of either individual assets or classes against a certain peril. In the latter case, index assets are utilized to characterize a certain class that is formulated from assets with similar influential characteristics and relatively homogeneous anticipated performance−although this is not always the case, as it is for instance showcased by relevant studies[27]. Other vulnerability methodologies are those founded upon vulnerability matrices or a set of attributes or indicators. Apparently, each one of the aforementioned methods requires a different amount of resources and input data as well level of expertise for its implementation. Given that the targeted methodology aims to assess the vulnerability component across a highly complex urban network, inevitably there is a need to trade some accuracy for efficiency. Hence, an indicator-based methodology was adopted herein. In fact, this approach is deemed to be relatively straightforward in its definition, since essentially it prescribes a set of indicators (reflecting certain attributes of the exposed physical and social elements) to eventually form a proxy for assessing the susceptibility (or COP) of an asset against the investigated peril. Hence, one may assume for instance that the conservation status, the number of stories and the type of the construction material are among those building attributes that are likely to affect the performance of the buildings should a flash flooding occur in the investigated city. Appropriate indicators could be also employed to denote the vulnerability of certain population segments to the said peril (e.g., senior citizens are often considered more vulnerable to a spectrum of perils).

Compared to the other vulnerability approaches, the indicator-based one is among the simplest to apply for assessing the vulnerability at large scales and in complex environments. Yet, it should be pointed out that, at least in its basic form, is an intensity-agnostic vulnerability methodology[28]. The latter essentially implies that the susceptibility of the evaluated assets remains uniform across different levels of intensities. Yet, in our methodology this is deemed to be a reasonable simplification. Should more data becomes available, the proposed methodology could be refined in this perspective, for instance by means of applying appropriate corrections factors that will account for the possibility the vulnerability of a certain asset being substantially deamplified or amplified (e.g., in those cases that a structural asset is exposed to a hazard intensity that exceeds the intensity for which it was designed for) should the intensity of a peril is below or above a certain threshold, respectively.

Following the definition of the vulnerability indicators (which involves peril-specific attributes for both the susceptibility and the coping capacity of the investigated urban network), each of those indicators was assessed per building block level (or to any other resolution level for which the needed data are offered) and was translated at this spatial scale to a score that could theoretically vary between 0 and 1. In fact, 0 denotes for the susceptibility and coping capacity indicators "non-existence of this attribute" to any of the assets (structures, people) forming or living in the building block whereas 1 denotes "full existence of this attribute" to all assets forming or living in the building block. Hence, if one considers the number of stories as a proxy (among others) for characterizing the vulnerability of a building to a flash flooding event then the following scores may be assigned (as per[29]): (a) for buildings with just one storey a score of 1 may be given to the pertinent indicator to essentially denote that all assets in this building are exposed to the hazard (since they are located at the ground level) and also to reflect the fact that no vertical evacuation routes are available to the occupants of this building, (b) for buildings with two stories a lower score of 0.5 may be assigned to reflect a lower susceptibility due to the fact that only half of the occupied stories of the building are exposed to flood peril and to also denote the presence of a vertical evacuation route to the occupants of the ground storey through the second floor and (c) for buildings with three or more stories the pertinent vulnerability indicator may be capped to a value of 0.3 to denote the lower percentage of the exposed stories and the presence of a vertical evacuation route to the occupants of the ground floor through the higher floors. It should be noted herein, that this particular indicator does not reach the value of zero since there is always a storey (ground) that is deemed to be vulnerable to the flood peril. The exact same scoring approach is adopted for the coping capacity indicators. The inclusion of the COP indicators in the vulnerability assessment serves very well the ultimate scope of the developed methodology which is to form the engine behind our DSS. Hence, one by modifying the input with regards to the COP attributes, which essentially reflect the mitigation measures and actions that could be implemented in order to embrace the resilience of the city to cope with certain perils (e.g., YES:1, NO:0 for the existence of an early warning system) could instantly have an overview on what are the consequences of such decisions on the vulnerability component of the risk as well as on the risk estimates *per se*.

An exact same scoring methodology was adopted for the other two risk elements, namely the hazard and the exposure. For the hazard (H) the maximum score (1) is assigned to a high intensity event which is also very likely to occur (low return period) and vice versa for the lowest possible score (0). In those cases that the estimation of the return period of the event is not possible the methodology will be formulated on a scenario basis (“what if”). With regards to the exposure (E) element of the risk, similarly to the vulnerability component, it was discretized to indicators that account for the physical exposure and indicators that account for the social exposure. Physical exposure indicators include metrics/measures that account for the density of the building stock across the urban area of interest while social exposure indicators account for the number of people living, working and/or commuting in this area. This component essentially depicts that equally vulnerable environments subjected to the same peril intensity do not pose the same risk levels if the number of the exposed elements is different, with the environment having less exposed assets being characterized by lower risk estimates.

Owing to the above, one could combine (e.g., by computing their geometric mean) the risk elements (H, V, E) to eventually deliver spatially variable (e.g., on a building block resolution level or any higher or lower depending on the available data) risk estimates for a city network. The methodology is only briefly outlined here. It should be noted that not all indicators are of equal importance. This essentially means that, for instance, when assessing the susceptibility of the built environment we may define susceptibility attributes that do not affect the overall physical vulnerability equally. To account for this, the indicators may be assigned appropriate weights. Assigning weights to the indicators is far from trivial and constitutes the most sensitive step among those that need to be taken for the computation of the required indices [30]. Among the possible methods for estimating the weights are those that are based on statistical analysis, such as the principal component analysis, as well as methods that are based on expert judgment, such as the analytical hierarchy process. In the absence of concrete evidence, one may also use the equal weighting method. Figure 2 illustrates for a random peril how the hazard, the vulnerability, and the exposure component could vary across the different building blocks in the city of Piraeus and how these components could be convolved to deliver the pertinent spatially variable risk estimates, upon which one could work out risk-aware mitigation and preventative measures.

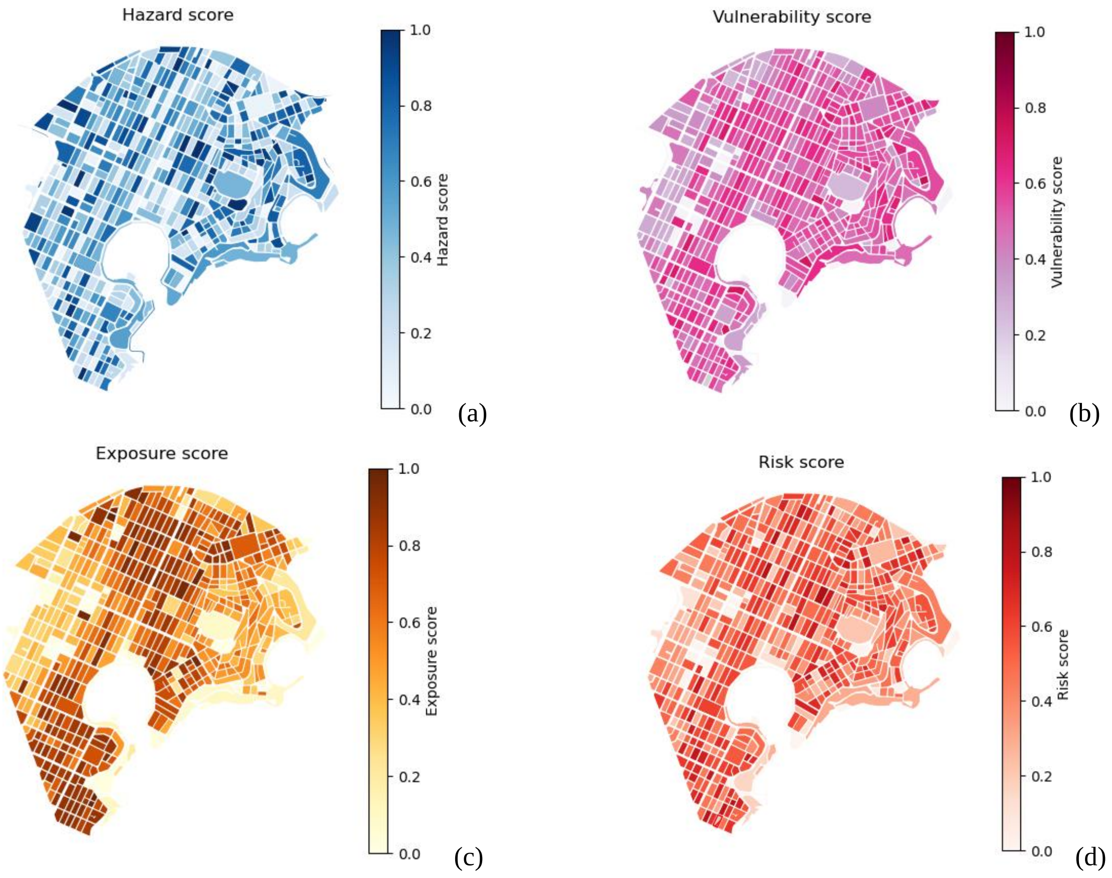


Figure 2. Spatial variation (building block level resolution) of the score estimates for: (a) hazard, (b) vulnerability, (c) exposure and (d) risk evaluated for a random peril affecting the city of Piraeus according to the indicator-based risk assessment methodology.

3.2 Data collection, integration, and evaluation; derived challenges

In order to integrate the individual European urban environments into one comprehensive urban risk assessment and adaptation methodology, a wide variety of scientific/technical knowledge and data with urban context information (e.g., environmental, socioeconomic, land cover, critical infrastructures, etc.) have been merged for each case study.

Since urban land cover maps play a crucial role in determining the intensity of several hazards, novel deep learning (DL) techniques are developed, leveraging Earth observation (EO) data in order to provide up-to-date information and for filling the potential gaps in existence datasets. For instance, DL-based methods to extract built-up area and its spatiotemporal changes from multi-source imagery (i.e., spectral and radar), acquired by the Copernicus missions Sentinel-1 and Sentinel-2[31], were developed and applied to the pilot cities[32]. Other foreseen activities are to map urban green areas, as well as urban green area changes. It should be noted that the use of EO data in combination with DL models not only offers the potential to produce more frequent updates of land cover maps than official land monitoring services provide, but it also facilitates the transferability of the methodology developed within this research project to new cities for which the required data may not be readily available by the pertinent authorities.

For the purposes of data handling, the HARMONIA Integrated Resilience Assessment Platform (IRAP), is established as a robust and scalable[33] interoperability node for the data acquisition and distribution of the HARMONIA's datasets. The urban context data collection procedure needs to follow specific principles to guarantee the reliability and correctness of the final output. In particular, the data is provided by governmental, municipal, cadastral, or statistical authorities. Regarding the geospatial data, crowdsourcing resources, such as OpenStreetMap, are approved and consequently utilized only following their cross-verification through relative sources. For the purposes of developing an easily adaptable DSS to the various urban environments, all the geospatial data have been scaled down to the building block level. Furthermore, the integration of building-level information, i.e., height, area, use, age, etc., into the implemented methodology is very important for the risk assessment analysis and the spatial resolution of the DSS's output.

3.3 Urban planning adaptive solutions

The urban planning adaptive solutions can be either human-made interventions or policies. Their efficiency varies according to the different topologies of the urban environments, increasing the necessity for a large variety of several solutions. In order to provide efficient and tangible policy-making recommendations the individual solutions must be collected, evaluated, and categorized based on their implications on the different urban aspects that will be affected, i.e., urban green, sustainable surface materials, water/blue solutions, air quality, and mobility. To this end, previous similar research activities propose a series of evaluated sustainable indicators and solutions for the adaptation of the urban environment to different hazard scenarios[34], which has proceeded to analyze thoroughly the implications of each solution. Finally, every solution is categorized in the aforementioned categories and characterized by several performance indicators, each of which specifies the weight of the implication on the urban environment (e.g., urban green, air quality, economy, citizens approval), helping in the evaluation of the alternative scenarios[35].

Therefore, the urban planning DSS is developed to optimally combine all the collected information aiming to produce useful, tangible, and reliable urban planning recommendations, through a holistic multiparametric risk assessment methodology, achieving the mitigation of future hazard-driven adverse consequences.

4. NOVEL URBAN PLANNING DSS

The development of an urban-planning DSS cannot be established on the basis of a one-dimensional architecture and methodological approach. The complex urban environment of European cities generates a large variety of urban context data, requiring a cross-layer analysis for a better understanding of their morphology. In combination with the different multiparametric nature of each urban peril, an agile methodology approach is required, adaptable in any case study, tacking efficiently the several urban-hazard future scenarios and mitigating future hazard-driven adverse impacts. Moreover, the final output of the DSS workflow is crucial to showcase the "where", the "how" and the "why" of the recommended urban-planning solutions. The "where" refers to the spatial reference of the solution; the "how" describes the urban-planning innervation or policy; The "why" points out the entailed impact on the urban environment.

4.1 Urban planning DSS functionalities

Following a multiparametric methodological approach, different functionalities were developed, running either simultaneously or following a strict workflow, in order to obtain the final output of the algorithmic procedure. Tree-structured decision analysis was applied as one of the main functionalities of the urban-planning DSS to ensure the correctness of the whole procedure. In developing a spatial-based DSS, the integration of spatial management and analysis functionalities is inevitable. A large variety of spatial tools exist (e.g., GIS applications, python libraries), making multiparametric spatial analysis and spatial computations tangible, expanding significantly the spatial analysis component of the DSS. The integral part of the DSS constitutes the visualization tool, enabling the dissemination of the multiparametric and multidimensional output, in an understandable and analytical way, maximizing decision-makers' information regarding different recommended alternatives aiming at the mitigation of urban hazards impact. The developed DSS will provide the spatial, statistical, and optical aspects of the final output, for enhancing the understanding of the decision-makers by means of widely-approved, understandable, and efficient visualization methods.

4.2 Tree-structure decision analysis

For the purpose of providing reliable urban planning recommendations for each of the end-users' scenarios, while also addressing the needs of the decision-making, a multi-branched tree-structure decision analysis architecture is applied to point out the optimal solution. Our proposed tree-structure decision analysis is able to ensure that the final recommendations account for the individual input parameters and performance indicators (area of interest, date, hazard, coping capacity indicators, etc.), applied by end-users[36]. Additionally, the final output derived from a logical branch-by-branch procedure is specific and easily understandable. This constitutes a significant advantage, providing a key tool in the development and refining process of the DSS, facilitating the error detection procedure. All the urban-hazard scenario parameters, contained in the end-users' request, constitute the arguments of the decision tree conditional nodes. Driving through the conditional nodes of the decision tree, the DSS yields the final group of the recommended solutions, as it is illustrated in Figure 3. Thus, each group of the proposed urban planning solutions corresponds to a different input in the multiparametric spatial analysis component of the DSS.

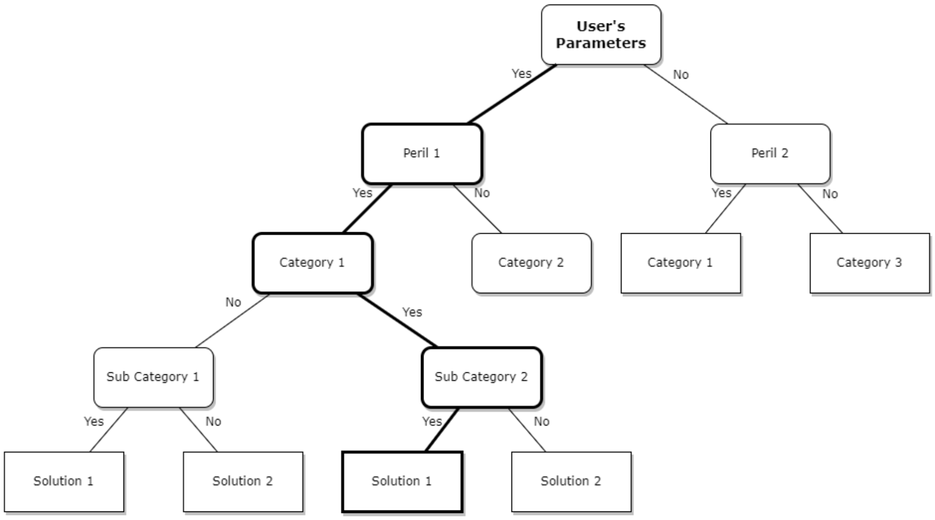


Figure 3. An illustrated example of the DSS Decision-tree analysis.

4.3 Multidimensional spatial data analysis

In an attempt to optimize the processing time and the reliability of the outputs, the urban planning DSS has been developed to efficiently manage, process, and make spatial computations on multidimensional data, structured in datacubes format. Moreover, established open Python libraries such as rasterio, gdal, numpy, etc., have been integrated into the DSS computational component to enhance its geospatial data management capabilities.

Through intergrading end-users' multiparametric approach into the decision analysis process, the DSS is factionalized to understand the individual spatial parameters and thresholds in conjunction with a variety of performance indicators for mitigation solutions' implications, applying logical conditions (e.g., hazard-intensity>0.80, built-volume<2000m^3, population-density>0.05person/m^2), pointing out the most suitable areas for urban planning adaptive solutions, aiming to mitigate the hazard-driven impacts. Receiving an on-the-fly hard-structured object/message derived from the end-user interface, DSS is developed to divide it into parts and trigger individual python scripts activating the data collection process through the IRAP. Through applying this approach, the final outputs of the DSS differ each time, based on the selected key DSS's inputs/parameters, such as the hazard selection procedure and/or the preferable mitigation actions (e.g., focus on green measures, air quality, urban mobility). Consequently, individual data layers are structured in a datacube format, establishing the input to the cross-layer spatial analysis procedure, as demonstrated in Figure 4. The output datacube becomes the input to the next stage of the DSS procedure. The execution of the next stage is based on the initial user input. In case the user has specified a particular urban-planning solution category for the final recommendation, the DSS executes the decision-tree algorithm to find out the most suitable among the solutions available in this category. Alternatively, the final output may be based only on the user's scenario. The only way to address this case was the extra functionalization of the DSS to provide an overall and adaptable recommendation to the decision-makers, taking into account the whole case study area and the entire spectrum of urban-planning solutions.

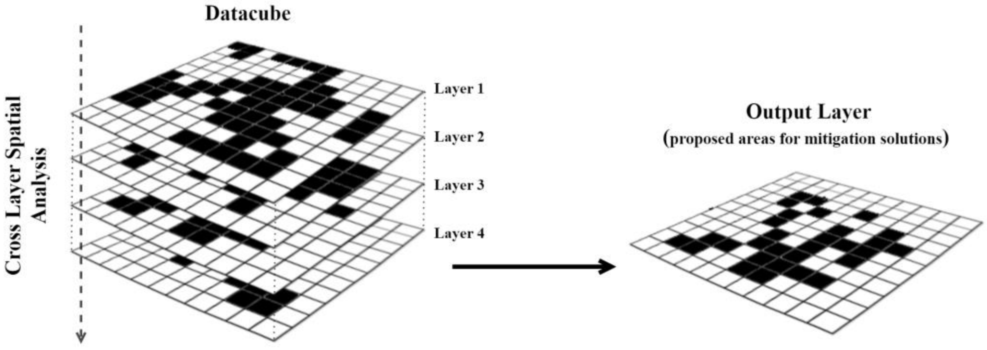


Figure 4. Datacubes cross-layer spatial analysis.

4.4 Web-based visualization tool

The web-based visualization tool is deemed to be the interaction link between the end-user and the urban planning DSS. A user-friendly interface with geospatial and diagrammatical visualization capabilities is the key for achieving the optimal understanding of the current state of the city and for illustrating the individual or a combination of proposed scenarios. The multidimensional nature of the urban context data requires advanced tools to efficiently handle and visualize geospatial information. Applying the Software-as-a-Service (SaaS) architecture[37] a web-based, user-friendly, and spatial-oriented interface has been developed, in alpha version. To overpass the security issues stemming from the integration of sensitive data, a robust end-user authentication system is required and will be reevaluated accordingly during the operational phase of the system. Three different levels of authorized access have been taken into consideration in the main architecture of the interface: "Citizens", "Researchers" and "Municipality". Each one of them provides diverse authorized access rights to the pre-specified groups on data and functionalities.

The development of a lightweight, agile, and powerful user interface with augmented cartographic interaction requires a novel combination of cutting-edge technologies. Mapbox GL JS based on web technologies such as WebGL and Canvas enhances users' experience (UX) via a significantly less, compared to other alternatives, network bandwidth[38], as well as a large variety of 3D visualization capabilities (e.g., 3D map navigation, thematic basemaps, feature styling and extraction, heatmaps). JavaScript spatial libraries such as Turf.js offer useful geospatial-based functionalities for supportively spatial analysis directly on the front-end, expanding users' interactivity. In the case of visualization of numeric data and indicators i.e., DSS recommendations performance indicators and citizens-based data analytics, interactive and dynamic charts are designed with the use of a lightweight JavaScript library, named Chart.js, contributing to the optimal illustration of that kind of information. For embodying all the abovementioned technologies and tools, React JS is considered being the best solution, on account that is among the most widely known JavaScript frameworks, providing numerous benefits at the development stages, maintenance, and update (speed, flexibility, performance, etc.)[39]. The communication between the user interface (front-end), the urban-planning DSS, and the kernel platform, where all the data of the entire project are hosted, is enabled via the back-end component. The back-end is developed in Python 3 with the use of a fast and lightweight web application framework named Flask. Flask provides useful functionalities for the quick handling of HTTP requests and responses, being the cornerstone of overall successful communication. Outlining the abovementioned, Figure 5 depicts the overall conceptual architecture of the urban-planning DSS.

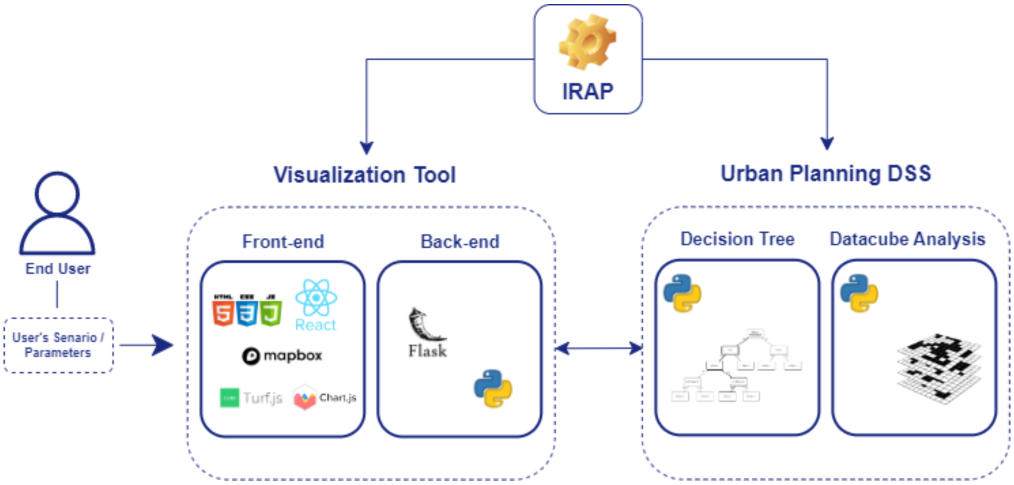


Figure 5. The overall conceptual architecture of Urban-Planning DSS.

5. CONCLUSION

The current status of the European urban environment along with the high likelihood of extreme natural-driven and anthropogenic phenomena such as flash floodings, UHI, geohazards, air pollution, and urban fires, stress significantly important issues for the sustainability of urban environments as well as for the safety and well-being of their citizens. A comprehensive multiparametric risk assessment methodology approach has been more crucial than ever in order to efficiently mitigate the diverse hazard-driven adverse impacts. Spatial urban planning DSS, functionalized to provide reliable and tangible policy-making recommendations, can be a key tool for the transformation of European cities into more resilient urban environments.

This paper introduces the outline an urban-planning DSS, developed to provide urban planning recommendations to policy-makers, that is founded upon a multiple hazard risk assessment methodology to eventually enable the transition to more resilient and sustainable urban environments. In order to understand the multidimensional topology of the urban environment and efficiently develop the DSS, a big amount of verified urban context and EO data have been collected, organized, and integrated for the purposes of our proposed workflow. Furthermore, for ensuring the reliability of the urban-planning recommendations, a big variety of tangible urban interventions and policies have been collected, categorized, and evaluated. A multi-branch decision tree is structured to point out the most efficient and adaptable individual or combined solutions. Acting in conjunction, the spatial analysis component of the DSS is functionalized to fetch the individual datasets and structure them into spatial datacubes, activating subsequently a cross-layer spatial analysis, aiming to provide a final spatial layer that includes the recommended areas and their corresponding urban-planning solutions. The interaction of the end-users with the DSS will take place via the web-based visualization tool, able to efficiently handle and visualize multidimensional (4D) geospatial information.

The finalization of both the risk assessment methodology and the urban-planning DSS is a recurrent procedure. End-users' feedback, i.e., policy-makers, municipalities, researchers, and citizens, are anticipated to provide crucial information for refining and optimally adjusting the different DSS components. Despite the diverse urban environments of the four considered pilot cities, further adaptation to the special needs and topologies of additional cases is inevitable, in order to develop a reliable and cutting-edge urban-planning DSS.

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