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The Place of Smart Occupational Health and Safety in Smart City Design

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ABSTRACT

Smart cities are a very clear example of complex systems, and their development focuses on the use of technology to transform every aspect of society and embrace the complexity of these transformations in order to promote the well-being and safety of the people who inhabit these cities. One essential, but often implicit, aspect that must be considered in the design of a smart city is occupational health and safety (OHS). After identifying a significant number of OHS issues that must be effectively addressed, a prospective analysis reveals that there is still an existing gap to be filled in the context of smart city design: an explicit guarantee of safety for workers in uncertain environments open to constant digital transformation changes. In this article, the authors present the VENTURA2020 model, an architectural capabilities-driven model that describes the main aspects to be taken into account to integrate smart OHS into smart city design.

KEYWORDS

Digital Transformation, Occupational Health and Safety, Organizational Safety Management, Safety at Work in Smart Cities, Safety Governance

INTRODUCTION AND THE CURRENT SITUATION

A sustainable smart city is "an innovative city that uses information and communications technology (ICT) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects" (MTSFB, 2016, p. ii). All smart cities'

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economic, social, and environmental facets imply people performing jobs, and their safety is a right, not a mere privilege. Related to this idea, Millard et al. (2014) define a smart city as "a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership"(p. 9) while AENOR (AENOR, 2016) points out that a smart city is "a fair and equitable city" that is citizen-centered and continuously improves "sustainability and resilience," taking advantage of the knowledge and resources, especially ICT, to improve "life, the efficiency of urban services, innovation and competitiveness." Arduin et al. (2016) and Caragliu et al. (2011) claim that a city is smart "when investments in human and social capital and traditional and modern communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance"(p. 1). Therefore, safety in citizen-centered smart cities must be addressed from a governance perspective. Some specific approaches directly emphasize the role of smartness as an essential feature of governance (Gil-Garcia et al., 2016). Furthermore, smart cities should offer people an ideal place to live where the quality of life (as a common good) can be interpreted from a multi-disciplinary perspective through perceived public value (Rodríguez Bolívar, 2019).

Although this usually goes unmentioned, all the above aspects of viable smart cities are related to the specific dimension of improving people's safety at work, usually referred to as occupational health and safety (OHS). One of the most detailed descriptions of a smart city available (Gil-Garcia et al., 2015) mentions safety, albeit in public rather than occupational safety. However, as Gil-Garcia et al. (2014) argue, regarding the importance of new technologies, "new and emergent technologies, over the last three decades, have continuously disrupted the administrative landscape of bureaucracies and the public sector around the world" (p. I2). This statement reveals that, as a responsibility of modern governments, the safety of workers is another important issue to be addressed by the most recent technologies available for developing smart cities. However, this issue has so far been overlooked, as revealed by Sappa (2022), who reports a comprehensive list of ICT applications for smart cities, limited to urban environment monitoring, intelligent mobility, waste recycling processes, computer-aided diagnosis in healthcare systems, and computer vision-based approaches for efficiency in production processes with no mention of the OHS area.

OHS in smart cities is more than just providing an ergonomic chair or a hard helmet. It systematically comprehends all risks that workers face (irrespective of the workplace), including risks derived from organizational dynamics and culture, which affect people's emotional stability and peace of mind.

Until 2019, company occupational risk prevention services steered safety at work. However, the global situation caused by COVID-19 led all humankind to stop, think and move fast to adapt and move up a notch. In the OHS sector, there has been much debate about how prepared public and private sector industries, companies, and general organizations were to globally and systemically protect people when all workers were asked to go home and start working in a *remote setting*, a situation which is now acknowledged to be here to stay. Smart cities are leaders in adopting technologies and driving people, processes, and organizations to adapt. However, no definite methodologies or strategies on how to drive OHS in emergent smart cities have been presented as yet.

Although it is not a new discussion topic, OHS is a major issue, bearing in mind that people are an organization's most important asset and that it guarantees workers' safe return to work after the lockdown. The question is, are OHS-related systems ready to provide all the guarantees for a safe return to work or to protect workers working from home as part of a smart organizational strategy? Are these systems ready to manage any emerging situation related to a health crisis? Are these systems ready to support the physical and psychological stability required to improve people's health during and after the return to work?

Note also that an organization's preparedness to manage risks and safety will depend on its capabilities to succeed. These capabilities are related to its safety culture management maturity levels. Safety culture can be defined as "the ideas and beliefs that all members of the organization share

about risk, accidents and ill health" (Confederation of British Industry, 1990). People at different organizational levels may perceive the safety culture differently (Fung et al., 2005). Therefore, it is important to think about OHS management systems implementation "to help establish a more effective prevention system and to ensure effective participation of all employees regardless of the level difference in the operating system to safety system"(Cąliş & Buÿükakinci, 2019).

Goncalves Filho et al. (2010) proposed a safety culture maturity model for petrochemical companies in Brazil, comprising a framework to measure what they call "safety culture maturity" based on the model proposed by (Hudson, 2001, 2003). This model considers the following levels of maturity: pathological (less mature), reactive, calculative, proactive, and generative (the most mature). In addition, Sha (2015) deployed a survey based on Hudson (2001, 2003), and found that surveyed companies have different stages of safety culture maturity, where most were classed as being at the "proactive" and "sustainable" stages (another level that establishes sustainability as the main driver of the most mature safety culture level).

From the perspective of a methodological implementation, Bianchini et al. (2017) proposed a methodology for measuring the implementation of an OHS management system in the European Union, focusing on its potential effectiveness. They identified a direct relationship between an organization's safety culture and the chances of an OHS management system implementation succeeding.

Even though several approaches to OHS we have identified management systems, most focus on the organizational level from a *people management* perspective. Maturity levels are defined in terms of how safety culture implementation is perceived, but it provided no architectural levels to identify the needs or problems to understand maturity. If smart cities are to efficiently embrace OHS at all levels, it is important to identify the digital transformation needs and their related dimensions in this sector. This is the ultimate motivation for this research. In 2020, we developed a cross-disciplinary and methodology-driven study to analyze the situation of prevention at the current time. A formal methodology was followed to design a value map that considers key stakeholders' actual needs and priorities to propose a system of interconnected solutions that, as a whole, constitutes an efficient idealized prevention system for the 2020s. The main results were published in Sánchez-Segura et al. (2021), where the sources of information (mostly formally recognized international experts) and the methodological foundations for the study (Osterwalder et al., 2014) were described in Table 1, listing the intervening stakeholders, alongside characteristics related to their experience. All the tables, including Table 1, are our own and were generated exclusively based on information from previously reported sources (Sánchez-Segura et al., 2021). These working groups applied some ideas Osterwalder et al. (2014) developed about the value proposition design method. We illustrate the description of this process in Figure 1.

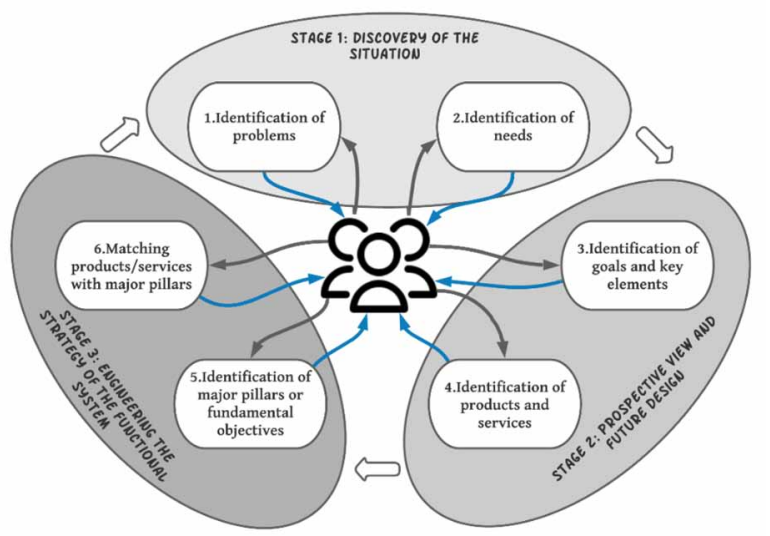
As a product of the enacted process, they identified the following problems in the OHS field:

1. There is a clear lack of preventive culture among workers.
2. There is a heavy workload due to the authorized enterprises registry (Registro de empresas autorizadas - REA).
3. The motivation for training is very weak.
4. Business activities certificate (*Certificado de actividades empresariales* CAE) causes a heavy administrative workload.
5. There is a lack of company prevention culture.
6. Business activities certificate (*Certificado de actividades empresariales* CAE) requirements are not useful for job performance.
7. Working time is low.
8. They cannot use the health and safety plan on building sites.
9. There is a general lack of control tools.
10. There is a general lack of support for integrating prevention.
11. General malpractice among competitors.

Table 1. Ventura2020 Value Proposition Model Creation Participants

Working group created	Mission	Number of people by gender	Affiliation	Experience
1	Value map creation representative of OHS technician needs and wishes	3 women/2 men	IRSST	Ten years of experience in the OHS field
2	Value map creation representative of OHS in-house prevention service needs and wishes	1 woman/ 3 men	ELECNOR	Ten years of experience in the OHS field as directors, managers, and technicians
3	Value map creation representative of OHS external prevention service needs and wishes	1 man	QUIRON PREVENCION	20 years of experience in the OHS field, as director, manager, and technician

Figure 1. Stages of Osterwalder's Methodology Followed by Sánchez-Segura et al. (2021)



12. Lack of tools for the detection of needs.
13. Lack of integration of prevention within companies.
14. Lack of integration of prevention across the different institutions of Madrid's Regional Government (*Comunidad Autónoma de Madrid*).

Some technological artifacts (digital products) were identified apart from problems and needs. A detailed list is available in Sánchez-Segura et al. (2021) that opened the avenue toward the concept of smart OHS as a key aspect to consider in designing future smart cities.

According to Millard et al. (2014) and AENOR (2015), there are several aspects of the standards specifically referring to security dimensions, including infrastructure security, information system security, service access security, personal data, and sensitive information security. However, the only

reference to the security dimension regarding people care is that existing standards can also be applied to improving the resilience of smart cities, considering the safety and security of citizens, with no specific mention of people's responsibilities as workers within a smart ecosystem.

The Framework on Smart Cities Standardisation in relation to Information and Communications Aspects guidelines (MTSFB, 2016) states that the "Management & Assessment Standards," "Services Standards," "ICT Standards," and "Physical Infrastructure Standards" frameworks are key sectors of smart cities (ITU, 2016). However, none of these standards explicitly refers to the safety dimension regarding workers' activities. All the smart city sectors covered by these standards (around 26 specific sectors) involve people doing jobs, and, by definition, all these activities may involve risks to be considered, prevented, and avoided. Therefore, OHS can be regarded not as a specific sector to be included in one of these standards, but as a transversal sector correlated to all the specific smart city sectors.

Likewise, some key smart city sectors have been proposed (AENOR, 2016; Millard et al., 2014). Proposals include a set of smart city attribute groups that must be accounted for: smart economy, smart governance, smart environment, smart mobility, smart society, and smart living. The smart economy domain groups attributes related to the city's employment, economic and financial growth prospects. The smart governance area groups attributes related to the capacity to efficiently manage resources, execute policies and adequately combine the interests of citizens, social organizations, companies, and administrations. The smart environment area groups attributes related to the natural environment, physical energy, water and urban planning structures, and their current and future operational sustainability. The smart mobility domain groups attributes related to transportation and logistics. The smart society domain groups attributes related to the city's human capital, education, social inclusion, and citizen collaboration. Finally, the smart living area groups attribute related to improving the citizens' quality of life and lifestyle in terms of physical and material aspects (health, safety, housing, and income) and social aspects (culture, family, associations, personal development) in order to promote innovation, education, social cohesion, and citizen collaboration.

Despite the definition of areas and the clearly stated need for health and safety in the smart living domain, we cannot say there are direct instructions on guaranteeing workers' health and safety. Instead, references to health and safety are rather vague, leaving decision-makers to interpret the terms as they see fit and design the strategies to achieve such fuzzy health and safety goals. From a critical viewpoint, and without berating the overall contribution of this corpus, note that aspects related to workers' health and safety have not been prioritized. Therefore, in their current form, the standards need to be extended with a complementary definition of guidelines or strategies leading to the design of the smart prevention of risks in future cities (Sánchez-Segura et al., 2021). As expected, a review of the best-known general standards guiding smart cities' design and creation cannot identify the importance of caring for workers from a governance perspective. Therefore, there is an urgent need to formally address this issue. The research reported here is extremely relevant in this respect.

The digital transformation of OHS into smart OHS implies integrating smart OHS into the design of smart cities. This article proposes the VENTURA2020 model. VENTURA2020 is a compendium of capabilities that any smart OHS digital system should include, which should be considered in smart city design to leverage smart technologies in urban or regional OHS governance. This way, OHS can be digitally connected and permanently interact with all the other smart city digital components. The extension of the smart concept to the OHS field must be addressed through the digital transformation of this sector. By extension, smart OHS should be part of the design of any smart city.

Identifying what needs must be covered to digitally transform the OHS field is necessary. We have identified a set of capabilities modeled by VENTURA2020 that shows how any digital prevention platform meets smart OHS needs. Also, we address how public administration should govern smart OHS, helping any organization to self-assess its prevention platform/system against VENTURA2020 model specifications. The identified architectural elements embrace capabilities enabling smart city design to support smart digital OHS.

The following section summarizes the main architectural elements of the smart prevention ecosystem that are regarded as the minimum occupational health and safety elements capable of adapting and supporting the design and creation of a safe, smart city.

SMART OHS AND ITS PLACE IN SMART CITY DESIGN

According to several sources, including (AENOR, 2016; Millard et al., 2014), ICTs play a very important role in addressing the social challenge of assuring the quality of life of city dwellers today and in the future. According to AENOR estimates (2016), 70% of the world's population will live in cities by 2050. Therefore, it is entirely conceivable that these cities guarantee city dwellers ready access to services and good quality of life. Against this backdrop, the concept of a smart city emerged. Based on the definition of smart cities, six domains emerged and were identified as aspects or domains that needed to evolve smartly to fulfill the purpose of smart cities: smart economy, smart governance, smart environment, smart mobility, smart society, and smart well-being. In addition, some smart city requirements were identified as levers to be used by key performance indicators to measure how cities developed in terms of the domains identified above. The indicators suggested so far all fit into one of the following categories of smart city requirements and transversally affected all identified smart city domains:

- Information and communications technologies
- Environmental sustainability
- Productivity
- Quality of life
- Equality and social inclusion
- Physical infrastructure

Despite the wide coverage of the identified domains and critical requirements reported by Sánchez-Segura et al. (2021), one area of critical importance that is not being explicitly considered is occupational health and safety (OHS). This article argues that because the different smart city industry job sectors are dynamic and continuously changing, with new jobs constantly emerging and others disappearing, the domain of smart occupational health and safety (smart OHS) must be added to the formal design of smart cities. Furthermore, in this environment of uncertainty surrounding the jobs of the future, where the only thing that can be taken for granted is that many roles and jobs will appear and disappear under smart city needs, it is also necessary to have an intelligent framework to tolerate, assimilate and manage the change in jobs, ensuring that workers' health and safety remains invulnerable.

Figure 2 includes the concept of smart OHS in the current view of smart city domains and requirements. The smart OHS domain is also affected by the same critical requirements as all the other currently identified smart city domains. The present-day culture in the OHS field is 5Z (5Z Culture, 2022), meaning zero accidents, zero diseases, zero waste, zero inequality, and zero unawareness. The 5Z culture maps to the requirements affecting the smart OHS domains as follows:

- **Information and communications technologies requirements:** Underpin the 5Z culture with the smart OHS vision.
- **Environmental sustainability requirements:** Cover zero waste.
- **Productivity requirements:** Underpin the improvement of the 5Z culture with the smart OHS vision.
- **Quality of life requirements:** Cover zero accidents and zero diseases.
- **Equality and social inclusion requirements:** Cover zero inequality.
- **Physical Infrastructure requirements:** Set up sensors and other mechanisms in physical smart city infrastructures to gather information to be used later to support the 5Z culture with the smart OHS vision.

Figure 2 shows how the smart OHS domain is a critical aspect that must be considered in smart city design and is explicitly related to the previously identified requirements. This is the idea behind the Ventura2020 model, an intelligent model to address workers' health and safety. The Ventura2020 model is a superstructure supporting comprehensive prevention at all ecosystem levels where workers are located. The Ventura2020 model integrates existing systems and current operations and focuses on ensuring interoperability. Therefore, the information flows between the distinct elements of the ecosystem are guaranteed. Figure 3 illustrates the general architecture of the Ventura2020 model.

The elements of the Ventura2020 model are all interconnected and constantly interact. At the model's core is the set of actors participating in the execution of all the activities. Actors are to interact with or put forward the model's architectural elements, endowed with capabilities that must fulfill some specific requirements described by the architectural elements. Implementing technological artifacts enables the model capabilities. Technological artifacts are the change-elements that use technology to enable the entire system to meet the requirements related to digitalizing OHS. A brief description of the core elements of the Ventura2020 model follows:

Figure 2. Smart City Aspects/Domains and Requirements Considering Smart OHS

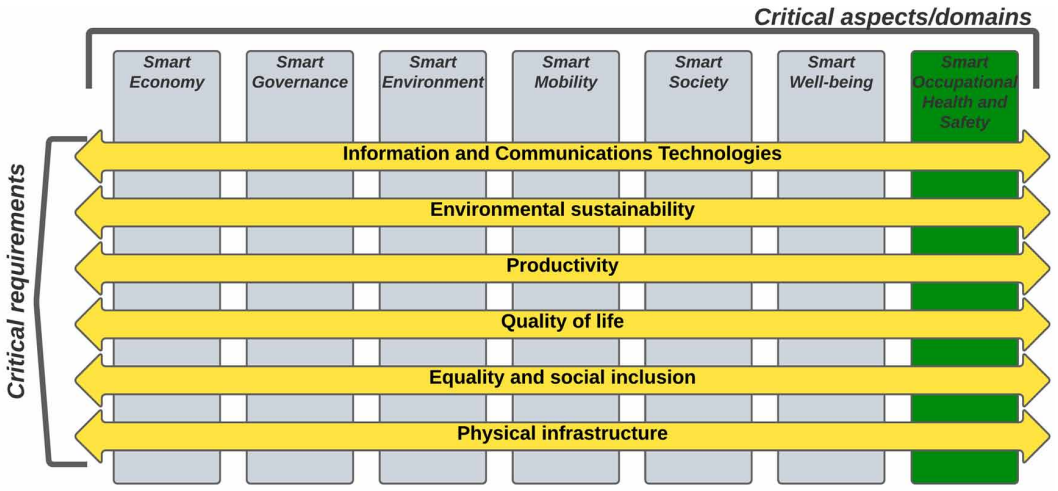
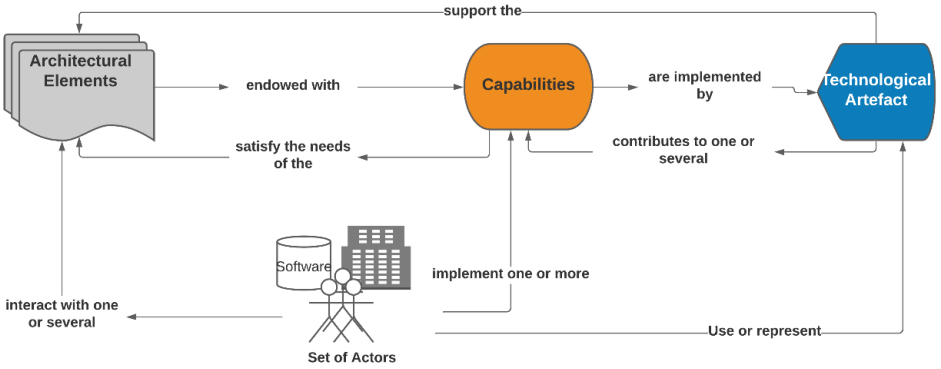


Figure 3. Elements of the VENTURA2020 Model



- **Architectural element:** Architectural elements are the puzzle pieces that fit together to conform to the smart city prevention ecosystem. Each architectural element (AE) is described in terms of the objectives that satisfy its needs, capabilities contributing to the smart OHS system operations, and the actors that implement those capabilities. The key architectural elements at the core of the Ventura2020 model are:
  - Digitalized prevention plan;
  - Digitalized risk assessment;
  - Preventive measures;
  - Integrated preventive planning.

The Ventura2020 model's architectural elements are illustrated in Figure 4. All the elements, with their capabilities and technological artifacts, conform to a strategy for implementing OHS digitalization, enabling smart OHS in smart cities:

- **Capabilities:** The capabilities describe the quality or state of being able to achieve a goal regarding a specific aspect. Ventura2020 capabilities represent how the smart city prevention ecosystem can guarantee workers' safety by using and implementing the technological tools required to do so. Capabilities are valued on a scale of 0 to 5, depending on the extent each capability is accounted for by the organization's in-house and external prevention services. The maturity of each architectural element depends on the coverage level of each element's capabilities. The following rules in Table 14 can rate each capability.
- **Actors:** The stakeholders interacting with the architectural elements to protect the prevention ecosystem's capabilities. The actors may be persons, institutions, or smart entities holding a particular stake in assuring that smart OHS stay healthy and alive.
- **Technological artifact:** Technological artifacts are the key enablers that implement specific technologies to strengthen capabilities. These technologies must support the effective incorporation of smart OHS into smart city design.

Figure 4. Architectural Elements of the VENTURA 2020 Model

They conceived the Ventura2020 model to fill the existing gap in smart city design: the lack of competencies focused on guaranteeing the safety of workers. In addition, the Ventura2020 model is an enabler that supports the smart OHS domain as a key aspect of being considered in smart cities.

The objectives, needs, capabilities, and actors for each architectural element of the Ventura2020 model are defined below.

AE: DIGITALIZED PREVENTION PLAN

In the Ventura2020 model, they integrate occupational risk prevention into the general management system of modern smart city organizations through the digitalized prevention plan. This plan must consider the different activities carried out within the organization and its hierarchical levels. Therefore, the digitalized prevention plan must include the organizational structure, responsibilities, functions, practices, procedures, processes, and resources necessary to enact risk prevention at the company. Risk assessment and prevention planning are essential instruments for managing and implementing the digitalized prevention plan. These architectural elements are presented later. We can consider the definition of the contents of the digitalized prevention plan as a way of configuring the preventive system to carry out a risk assessment and preventive planning. Therefore, the information should be added to the digitalized prevention plan before carrying out the risk assessments.

We grouped the information elements included in the digitalized prevention plan under the following headings:

- Company preventive policies and objectives.
- Company organizational structure.
- Occupational risk prevention (ORP) positions.
- Practices and procedures.
- Workforce management:
  - Worker information that is not submitted for approval;
  - Worker information that is submitted for approval without consultation and participation of workers' representatives;
  - Worker information submitted for approval with consultation and participation of workers' representatives;
  - Information on social contributions paid to the worker by the company (Enterprise Prevention Plan (EPP), training, etc.).
- In-house workplace.
- External workplace.
- Inventories (e.g., equipment and chemical products).
- Configuration of ORP indicators.

Most of the information managed under the digitalized prevention plan headings is first approved and then disseminated.

We mapped the digitalized prevention plan architectural elements to smart cities by linking the smart city design strategy with the effective incorporation of policies related to prevention ecosystem implementation as part of the smart city. In particular, the digitalized prevention plan provides essential information on the ICTs required to support safety in critical areas, such as smart well-being, mobility, environment, and governance. Besides, the digitalized prevention plan provides strategic information that nurtures specifications regarding three critical smart city requirements. First, quality of life, as people's well-being is the priority of smart cities. Second, environmental sustainability, as a preventive culture is a key part of environmental protection policies. Third, productivity, as the effect of effective prevention implementation is expected to impact worker satisfaction and commitment and the measurement of productivity indicators.

We list the strategic objectives of the digitalized prevention plan below, followed by a description of the needs and capabilities required to enact the digitalized prevention plan operation.

AE: Digitalized Prevention Plan - Objectives

- The distinction of target populations for unique elements of preventive information.
- Categorization of preventive information elements according to target populations.
- Identification of the agents/actors involved in the flow of each information element.
- The importance of the chain of access and traceability of information elements.
- Identification of actions to be taken in the event of bottlenecks in the chain of access to information elements.
- Prioritization of information elements.

AE: Digitalized Prevention Plan – Needs

Table 2 contains the needs of the prevention ecosystem related to the digitalized prevention plan, and the minimum Ventura2020 model requirements that must be met to support the prevention ecosystem.

AE: Digitalized Prevention Plan – Capabilities

Table 3 lists the identified capabilities required to support digitalized prevention plan implementation.

AE: Digitalized Prevention Plan – Actors

Table 4 lists the actors involved in digitalized prevention plan implementation and the specific capability affected by the actor. Some actors are listed repeatedly to illustrate the connection between actors and capabilities.

Now that the digitalized prevention plan, which is the most cohesive architectural element of the Ventura2020 Model, has been presented, we can describe the other architectural elements: risk assessment (RA), preventive measures (PM), and integrated preventive planning (PrevPlan).

Table 2. Identified Needs for the Digitalized Prevention Plan Architectural Element

Need ID	Description
N1	Access to the companys' organizational structure
N2	Identification of the responsibilities for prevention execution within the company (high-level - supervision)
N3	Identification of the functions of each actor in charge of prevention implementation within the company (low level - implementation)
N4	Access to process descriptions, step-by-step and execution flow of each preventive action within the company
N5	Access to the list of company resources needed to implement the execution of prevention measures
N6	Knowledge of ORP job positions
N7	Importing of company definition of practices and procedures
N8	Access to ORP indicators
N9	Evaluation of the status of the company's digitalized prevention plan
N10	Knowledge of the approval status of the digitalized prevention plan

Table 3. Identified Capabilities for the Digitalized Prevention Plan Architectural Element

Capability	Description
PP-CAP1	Access to systems of different platforms containing company ORP information
PP-CAP2	Access to company digitalized prevention plan documents
PP-CAP3	Extraction of specific information from digitalized prevention plan documents
PP-CAP4	Establishment of direct communication with the people in charge of the digitalized prevention plan
PP-CAP5	Evaluation of the effectiveness of a company's digitalized prevention plan
PP-CAP6	Generation of alerts for early expiration of company digitalized prevention plan
PP-CAP7	Generation of reports on the responsibilities of the actors in charge of the digitalized prevention plan
PP-CAP8	Identification of company ORP indicators

Table 4. Identified Actors for the Digitalized Prevention Plan Architectural Element

Capability	Actor
PP-CAP1	Prevention Services, Company, Ventura2020 Autonomous System
PP-CAP2	Ventura2020 Autonomous System
PP-CAP3	Ventura2020 Autonomous System
PP-CAP4	Ventura2020 Autonomous System
PP-CAP5	Prevention services
PP-CAP6	Ventura2020 Autonomous System
PP-CAP7	Company
PP-CAP8	Prevention services

AE: RISK ASSESSMENT (RA)

Smart city organizations must have an updated risk assessment to ensure worker health and safety. As it provides information regarding the safety status, this assessment must consider the type of activities carried out, the characteristics of jobs, and the workers performing these jobs. In addition, work equipment, chemical substances, and workplace conditioning must also be considered.

For each identified risk, the risk assessment must include preventive measures to eliminate, reduce, and control the risk. Likewise, the identified preventive measures must be planned, specifying the person in charge, the deadline, and the human and material resources necessary for its execution. The following section addresses preventive measures.

Risk assessment is generally conducted by a prevention service, such as a worker or employer who assumes responsibility for prevention could also carry it out. The company must accept the risk assessment content, plan the implementation of preventive measures, and ensure their effective execution. To avoid possible inefficiencies due to the separation between risk assessors (prevention services) and preventive measure planners and implementers (organizations, institutions, companies), preventive measure management must be integrated into all areas at all levels of the organizations, and this integration must be guaranteed through smart city interconnectivity.

The focus of the Ventura2020 model is on the processes that ensure this integration: risk assessment approval by the company, including the mandatory consultation and participation of

workers' representatives; dissemination of the approved occupational risk prevention information to the workers concerned, and planning and implementation of preventive measures.

We should integrate smart city information systems with the Ventura2020 model. This integration would make it easier for prevention technicians to prepare risk assessments. However, a scenario where risk assessments are prepared outside (albeit connected with) the Ventura2020 model should also be considered.

To give all organizations and prevention services access to a complete occupational safety management platform, the Ventura2020 model should include a module for preparing effective risk assessments. This risk assessment directly affects smart city design, and specifically the areas of i) governance, since a strategic view is necessary to include risk prevention in planning and future design, ii) well-being, since it is people that are most affected by insufficient risk prevention management, and iii) mobility, which is a critical aspect of any smart city with obvious risks regarding the safety of current and future workers of as yet unidentified mobility jobs.

Since any smart city aspect has inherent risks, there will foreseeably be many connections with smart city requirements, such as tech-driven risk management (ICTs), the risk entailed by jobs guaranteeing sustainability and effective residual waste management (environmental sustainability), the minimization of hazardous activities to improve people's well-being (quality of life), among others.

AE: Risk Assessment – Objectives

The strategic objectives of the risk assessment architectural element are as follows:

- Identification of the different groups of agents targeted for risk assessment.
- Identification of the risks inherent to each group of agents or persons exposed to occupational hazards.
- Categorization and prioritization of risks according to the impact they may have on the prevention ecosystem.
- Identify the key players and subsystems of the preventive ecosystem that can mitigate the identified risks.

AE: Risk Assessment – Needs

The needs of the ideal prevention system enabled by the Ventura2020 Model are listed in Table 5. For simplification, Risk Assessment is pointed as RA.

AE: Risk Assessment – Capabilities

To satisfy all identified system needs, we must endow the Ventura2020 model with the specific capabilities listed in Table 6.

AE: Risk Assessment – Responsible Actors / Capabilities

A stakeholder is responsible for every capability. Therefore, Table 7 summarizes the previously identified actors in charge of the capabilities according to the proposed Ventura2020 model.

AE: PREVENTIVE MEASURES (PM)

Once the risks have been identified, it is necessary to think strategically about mitigating and controlling them. The prevention technician oversees the selection of one or more preventive measures for a risk. For this purpose, this technician resorts to the following information supplied by the smart city prevention ecosystem:

- A list of the measures that are associated with a risk in the risk catalog.
- A general list of the measures formally included in the catalogs and standardized platforms.

Table 5. Identified Needs for the Risk Assessment Architectural Element

Need ID	Description
N1	Determination of the status of the updated risk assessment to ensure company worker health and safety
N2	Determination of the risks identified at companies
N3	For each risk, retrieval of the preventive measures that mitigate the risk
N4	Determination of the type of activities performed, the characteristics of the jobs, and the workers who perform the jobs.
N5	Access to information on the people in charge, deadlines, and human and material resources necessary for preventive measure execution.
N6	Reception of information on the risk assessment performed by a prevention technician or similar.
N7	Establishment of responsibilities for implementing preventive measures and how they map to the risk assessment
N8	Evaluation of implementing preventive measures based on indicators of integration between responsible actors and assigned responsibilities
N9	Monitoring of and reporting on the risk assessment status, identifying different statuses: approved, received by workers, assertively disseminated, confirmed implementation
N10	Generation of alerts in the event of bottlenecks in the execution flow of preventive measures
N11	Integration with existing information systems in current prevention services
N12	Interoperability to connect with different risk assessment information on different platforms
N13	Guarantee of seamless two-way information sharing regarding risk assessments
N14	Provision of an online risk assessment model that can be used by external prevention services, aligned and coordinated with Ventura2020.
N15	Ventura2020 can process company information on different company workplaces from the viewpoint of occupational risk prevention
N16	Ventura2020 is able to identify the different jobs in the company
N17	Ventura2020 is able to process the information that the company has about enacted procedures
N18	Ventura2020 must be able to access chemical and equipment inventory information
N19	Ventura2020 must be able to identify and catalog the risks of a RA
N20	For each risk, Ventura2020 must identify the key workers, stakeholders, and responsible parties for the mitigation and prevention strategy
N21	If required, Ventura2020 should be able to guide to assist prevention technicians in the identification of positions and risk managers
N22	Identification of the different risk assessments of each company worker
N23	Ventura2020 must be able to identify the risk information elements
N24	Ventura2020 must be able to identify the preventive measures information elements
N25	Ventura2020 must be able to provide technicians with a catalog of risks and preventive measures for their use and reference
N26	For each risk, the system must be able to store the type, catalog, name, description, and related preventive measures
N27	The system must, for each position, process information regarding job tasks, roles, and responsibilities, work equipment used, chemicals used, facilities used

continued on following page

Table 5. Continued

Need ID	Description
N28	For each ORP position, the following information must be able to be edited and/or added using the system: risk, risk assessment, safety, the origin of risk identification
N29	The risk assessment of each company site must be accessible and be able to be edited using the system
N30	The system must be fully compatible with the CAE (coordination of business activities) and be able to access the ORP information of an external company.
N31	The system will transfer blocks of information from an external company's RA to the company's own RA.
N32	The prevention technician will input the emergency plan risks and measures into the system in the same way as described for the RA in specific positions.
N33	The system must allow direct access to the emergency plan of a company site.
N34	The system will transfer blocks of information from the external company to the in-house emergency measures.
N35	The prevention technician will use the system to access information on the work equipment available at the company.
N36	The system must be able to access previously entered information on the chemicals available at the company.
N37	The system must be able to retrieve, add or edit information regarding the risks of special workers: pregnant women, minors, people with disabilities, etc.
N38	The system must be able to visualize and generate a report on the specific RA of a company worker and the risks associated with his or her job.
N39	The system must be able to create a prioritized and catalogued risk map for a company's plant.
N40	The system must be able to generate a RA approval tracking report.
N41	The system must be able to generate alerts regarding the approval process.

Table 6. Identified Capabilities for the Risk Assessment Architectural Element

Capability	Description
RA-CAP1	Creation of information elements: risks
RA-CAP2	Creation/updating/deletion of risk information elements
RA-CAP3	Interoperability for accessing enterprise risk assessment information
RA-CAP4	Identification, cataloguing, and prioritization of risks
RA-CAP5	Text processing for the extraction of risk-related information
RA-CAP6	Smart mapping between risks and key people or roles for risk mitigation
RA-CAP7	Intelligent measurement of a company's risk assessment maturity
RA-CAP8	Intelligent generation of preventive alerts on the status of risk assessments
RA-CAP9	Generation of a standardized model based on multi-platform risk assessment information
RA-CAP10	Tracking and reporting on the flow of risk assessment approvals
RA-CAP11	Generation of customized guides for the use of Ventura2020 and integrating external information into Ventura2020

Table 7. Identified Actors for the risk Assessment Architectural Element

Capability	Responsible Actor
RA-CAP1	Ventura2020 Autonomous System
RA-CAP2	Ventura2020 Autonomous System
RA-CAP3	Ventura2020 Autonomous System
RA-CAP4	Prevention services
RA-CAP5	Ventura2020 Autonomous System
RA-CAP6	Company
RA-CAP7	Prevention services
RA-CAP8	Ventura2020 Autonomous System
RA-CAP9	Ventura2020 Autonomous System, Company, Prevention Services
RA-CAP10	Ventura2020 Autonomous System, Prevention Services
RA-CAP11	Prevention services

- The possibility of editing a new preventive measure.
- Priority of a preventive measure.
- Implementation deadline (expressed in days).
- (Person/stakeholder) responsible for implementation.

They will implement the preventive measures in all critical smart city domains where worker risks are identified, and preventive measures are needed. There are jobs involving risks in all sectors, including information technology (IT) and office workers (economy and governance), operators and drivers (mobility and society), workers focused on improving people's smart city experience (such as trainers, therapists, and coaches related to well-being, and the environment).

The preventive measures related to the above aspects, such as ICT, physical infrastructure, or sustainability, must be included in the requirements part of the smart city specifications, leaving room for new specifications that may emerge in specific smart cities (which are not necessarily homogeneous), and flexibility in this respect is essential.

AE: Preventive Measures - Objectives

The objectives of the preventive measure architectural element of the Ventura2020 model are:

- Implement specific prevention actions.
- Monitor the execution of prevention actions.
- Assess the status of prevention implementation based on evaluating preventive measures affecting each agent.

AE Preventive Measures - Needs

Table 8 lists the system's needs regarding preventive measures.

AE: Preventive Measures - Capabilities

Table 9 lists the model's capabilities to satisfy the identified needs.

Table 8. Identified Needs for the Preventive Measures in the Architectural Element

ID-Nec	Description
N1	The system must allow creating preventive measure information elements.
N2	Prevention technicians must be able to generate risk assessments and identify preventive measures to mitigate the identified risks.
N3	For each identified risk, Ventura2020 can assertively display information to workers and stakeholders interested in a specific risk.
N4	Ventura2020 must support training through a technological platform to provide instructions on different aspects: risks, measures, updates, etc.
N5	Ventura2020 must be able to provide information on the suitability or otherwise of different EPP for different jobs in each industry and information on the equipment approval.
N6	Ventura2020 must enable prevention technicians to process non-standardized preventive measures that arise from the particularities of each specific job.
N7	Ventura2020 must be able to identify, for each preventive measure, the material and human resources, budget implementation, start and execution dates, as well as estimated resource consumption.
N8	Ventura2020 must be able to monitor the execution of a preventive measure and generate reports on execution.

Table 9. Identified Capabilities for the Preventive Measures Architectural Element

Capability	Description
PM-CAP1	Creation of information elements: preventive measures
PM-CAP2	Creation/updating/deletion of preventive action information elements
PM-CAP3	Identification of the EPP related to each workstation
PM-CAP4	Training in implementing preventive measures
PM-CAP5	Processing and detailed description of specific preventive measures
PM-CAP6	Monitoring of preventive measures

AE: Preventive Measures - Responsible Actors / Capabilities

Table 10 lists the stakeholders in charge of implementing the preventive measures capabilities.

AE: INTEGRATED PREVENTIVE PLANNING (PREVPLAN)

Once the general prevention plan, the related risks, and the measures to mitigate or control these risks have been identified, it is necessary to secure the correct implementation of measures to guarantee the safety of smart city workers in terms of time, pre-conditions, post-conditions, and any related restrictions. Another part of the Ventura2020 model performs this.

In coordination with the prevention services, organization managers complete the integrated preventive planning strategy, and all related documentation for each preventive measure, including the following concepts: priority, human and material resources, the person responsible for the execution of the measure, budget, and date of application (start and end).

Integrated preventive planning comprises the logical execution, according to a timeline, of the activities necessary to ensure that smart cities implement the preventive measures on time and strategically sustainably. As mentioned above, there are risks inherent to practically all critical smart

Table 10. Identified Actors for the Preventive Measures Architectural Element

Capability	Responsible Actor
PM-CAP1	Prevention Services, Ventura2020 Autonomous System
PM-CAP2	Ventura2020 Autonomous System
PM-CAP3	Ventura2020 Autonomous System
PM-CAP4	Ventura2020 Autonomous System
PM-CAP5	Ventura2020 Autonomous System
PM-CAP6	Ventura2020 Autonomous System

city domains, and, therefore, they will all include preventive measures. However, their implementation must be planned by addressing specific activities. Their timely execution for all sectors (economy, governance, environment, mobility, society, well-being), and the planning must, in all cases, be correlated to specific requirements: ICT (as a means of implementation of technological enablers or tools, as suggested by Sánchez-Segura et al. (2021)); sustainability (which is a critical aspect of being managed from a proactive, rather than a reactive, perspective), productivity (as it is important to generate quantifiable information on the effect of prevention), quality of life (as workers' perceptions are key to evaluating the impact and people's views of smart cities), special inclusion (as a smart city must be a safe place for all without discrimination) and physical infrastructure (as a smart city makes up the environmental space in which people live and work, and risk prevention measures must be implemented in all applicable physical sectors).

We list the objectives of the Ventura2020 model regarding integrated preventive planning below.

AE: Integrated Preventive Planning - Objectives

- Be able to envisage possible scenarios for implementing preventive measures regarding each agent involved in the prevention ecosystem.
- Be able to optimize resources in the sequencing of preventive measure enactment.
- Be able to visualize possible preventive scenarios for each agent involved in the preventive ecosystem in real-time to provide for the comparison of alternative enactment options and real-time access to alternative strategies in the event of ecosystem failures.

AE: Integrated Preventive Planning – Needs

The specific needs related to integrated preventive planning are listed in Table 11.

AE: Integrated Preventive Planning - Capabilities

Table 12 lists the capabilities required to satisfy all system needs regarding integrated preventive planning.

AE: Integrated Preventive Planning: Responsible Actors / Capabilities

Table 13 lists the responsible stakeholders for each identified capability.

DISCUSSION

This article described Ventura2020 in detail. Ventura2020 is an architectural model specifically designed to incorporate smart OHS into the smart city design. Sánchez-Segura et al. (2021) previously discussed this need and described the methodological process underpinning the collection of

Table 11. Identified Needs for the Integrated Preventive Planning Architectural Element

Nec ID	Description
N1	Ventura2020 must be able to facilitate the assignment of responsibility for implementing preventive measures.
N2	Provision of access to resource information for planning the implementation of a preventive measure
N3	Reassignment or scaling up of responsibilities when a preventive measure so requires
N4	Follow-up of the delivery of information elements relevant to the measure to workers and/or interested persons
N5	Differentiation between different preventive measures depending on how important or urgent their enactment is
N6	Report on the execution of a previously planned preventive measure
N7	Rescheduling of preventive measure enactment because of variations in resources and/or time constraints associated with the preventive measure

Table 12. Identified Capabilities for the Integrated Preventive Planning Architectural Element

Capability	Description
PrevPlan-CAP1	Assertively relate preventive measures to risks.
PrevPlan-CAP2	Eliminate relationships between preventive measures and risks, if appropriate.
PrevPlan-CAP3	Assign preventive measures to responsible persons in the company.
PrevPlan-CAP4	List and identify the resources available for the execution of preventive measures.
PrevPlan-CAP5	Reassign and scale up responsibilities for the execution of preventive measures.
PrevPlan-CAP6	Generate reports (or dashboard) on the execution of planned preventive measures.
PrevPlan-CAP7	Type of preventive measures.
PrevPlan-CAP8	Assertively disclose the implementation of planned preventive measures.
PrevPlan-CAP9	Reschedule preventive measures and realign resources.

Table 13. Identified Actors for the Integrated Preventive Planning Architectural Element

Capability	Responsible Actor
PrevPlan-CAP1	Prevention Services, Ventura2020 Autonomous System
PrevPlan-CAP2	Prevention Services, Ventura2020 Autonomous System
PrevPlan-CAP3	Company, Prevention Technician
PrevPlan-CAP4	Ventura2020 Autonomous System
PrevPlan-CAP5	Ventura2020 Autonomous System, Company
PrevPlan-CAP6	Ventura2020 Autonomous System
PrevPlan-CAP7	Ventura2020 Autonomous System
PrevPlan-CAP8	Ventura2020 Autonomous System
PrevPlan-CAP9	Prevention Services, Ventura2020 Autonomous System

Table 14. Rules to Rate Capabilities

	Is this capability being considered in any way by in-house and external prevention services?	Is there an instrument that supports this capability?	Is this instrument managed digitally?	And is this digitally managed instrument known throughout the company?
No -0	No	No	No	No
Unacceptably-1	Yes	No	No	No
Poorly-2	Yes	Under development	No	No
Acceptably-3	Yes	Yes	No	
Well-4	Yes	Yes	Yes	No
Excellently-5	Yes	Yes	Yes	Yes

information (Osterwalder et al., 2014), the identification of needs and capabilities, and the proposal of technological artifacts to support the model. However, a formal model focusing on a practical method for effective implementation was still missing. This gap was the primary reason for developing the Ventura2020 model. Ventura2020 is a conceptual proposal promoted by the Regional Institute of Occupational Health and Safety of Madrid (IRSST) in close contact with both in-house and external prevention services, such as ELECNOR and Quironprevencion, and with technological companies, such as Quentic GmbH, to implement organizational prevention. The Ventura2020 model is a compendium of capabilities whose maturity, measured on a scale from 0 to 5, as explained above, determines the extent to which each prevention service has attained the digital capabilities proposed by Ventura2020. These digital capabilities bridge the link between smart OHS and smart city design.

At the time of writing, the adoption of the proposed model is being considered at a local level, and information is being transferred to the local government agencies in charge of redesigning Madrid's smart city features. Therefore, it will take a long time to assess the impact of this proposal. However, based on its acceptance as a conceptual model, we can say that they have laid the first foundation stones to build a smart OHS framework at the Madrid city level. Furthermore, support for developing the proposed technological artifacts is forthcoming, and interim project progress has received public recognition.

CONCLUSION AND FUTURE WORK

The occupational health and safety sector is important in smart and sustainable city design. Workers' safety must take pride of place in any digital transformation leading processes like smart city design. Therefore, OHS is critical and must be considered by decision-makers as it affects all sectors. After an in-depth analysis of the areas considered by the smart city standardization framework (MTSFB, 2016), we found, surprisingly, that the traditional concept of OHS is not explicitly considered, revealing an existing and increasingly important gap, as demonstrated by the COVID-19 situation.

The "smart" concept can be extended to the OHS field by digitally transforming this sector and, by extension, including smart OHS in the design of any smart city. To do this, we first identified what needs the OHS field has to cover with a view of digital transformation. Next, we identified a set of capabilities specified as VENTURA2020 model. These capabilities show the extent to which any prevention digital platform covers smart OHS needs. We then developed an instrument that any local government administration can handle to govern smart OHS and help any organization to self-assess whether its prevention platform/system complies with the VENTURA2020 model.

This article studies the importance and relevance of the concept of smart OHS. As OHS affects all workers performing jobs in smart cities, the finding that emerged was that they should include it as a key aspect of smart city standards, such as (AENOR, 2016; MTSFB, 2016). The definition of smart OHS must explicitly fill this gap. Then, this new smart city aspect must be incorporated into existing and future standards to consider the digital side of OHS in the smart city landscape.

The key benefits of explicitly considering OHS in smart city design are that:

- It facilitates prevention management by interconnecting environments and improving work quality for prevention workers.
- It considerably reduces the number of unnecessary repetitive bureaucratic tasks.
- It provides an agile and efficient information flow, which is assertively communicated to workers, prevention enactors, and supervisors.
- It considerably reduces prevention plan design, redesign, and updating time.
- The information generated by occupational risk and safety audits is more reliable.

We want to highlight the relevance of this proposal, which is built upon a previous formal problem and needs an identification process in the prevention ecosystems and safety culture field. By engaging the respective public administration (Madrid's Regional Institute for Health and Safety) and prevention services (such as Elecnor and Quironprevencion) and also considering expert opinions, we could gain an overview of the status of prevention and the capabilities gap to be filled in order to develop towards a safety culture that meets smart city requirements. This article summarized the lessons learned from this debate and deliberation process and provides a well-founded opinion and path to follow in explicitly considering the inclusion of OHS as a key driver to complement the design of future smart cities. By the end of 2022, we expect this model to be in the public domain as an assessment at http://catedrairsst.uc3m.es. Then any company can check the digital maturity of its prevention service against the capabilities conforming to Ventura2020.

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CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

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