SMART CITY INSTITUTE
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DIGITAL TWINS: TOOLS FOR CRISIS MANAGEMENT WITHIN TERRITORIES?

INTRODUCTORY REPORT

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CONTENTS

1. INTRODUCTION 6

2. CRISIS MANAGEMENT 8

Definition 8

Types of crises 8

Management 10

Link between crisis management and Smart Cities 12

3. DIGITAL TWIN 14

Origins and definitons 14

Digital twins in a territorial context 16

Maturity levels 18

4. DIGITAL TWINS AND CRISIS MANAGEMENT 20

Planning 21

Raising awareness and optimising resources 22

Stakeholders collaboration 23

5. LIMITS 24

Territorial complexity 24

Data 25

Governance 25

6. EXAMPLES 26

7. CONCLUSION 38

The Smart City Institute 40

References 42

01

INTRODUCTION

Crisis management is not a new challenge for local authorities. Since the dawn of time, one of humankind's urgent and immortal concerns have been the sudden arrival of a mass disaster that could threaten its existence and cause chaos and destruction within its community[1]. Crisis situations are an ancient and recurring problem in our territories, but their frequency, form and impact have evolved over the centuries[2]. Over the last decades, these crises have become more complex because of globalisation[3]. Certain megatrends, such as climate change, have also increased the frequency of disasters and related crises[4]. This was illustrated in Wallonia by the floods of July 2021.

At the same time, the use of technological innovation within territories has also developed. In this respect, the concept of the Smart City has gradually emerged as a means of ensuring sustainability by optimising and improving urban and non-urban contexts[5]. One of the technologies frequently put forward in recent years is the Digital Twin, which is commonly described as "a digital representation of a physical element or assembly using integrated simulations and service data"[6]. In an urban context, it is particularly used as a decision-support tool based on simulation and visualisation[7,8,9]. Research predicts that there will be more than 500 urban Digital Twins in the world by 2025[10].

The purpose of this introductory report is at the intersection of these two observations and asks the following question: how can Digital Twins contribute to crisis management? The aim of this report is twofold. Firstly, it aims to position crisis management from a theoretical point of view and demystify the concept of the Digital Twin. Secondly, it explores the role that this technology could play in crisis management within territories. To do this, it is structured as follows: the first section looks at the definition of crisis management, as well as the different types and characterisations of crises, and finally, the overall link between crisis management and Smart Cities. The second section explains the origins of the Digital Twin, its application to a territorial context and its different levels of integration. The third section highlights several ways in which the Digital Twin can be used in the crisis management process. The fourth section looks at the current limitations of the model, particularly in terms of data and governance. Finally, several international examples are highlighted to conclude this report.

From a methodological point of view, this report is based on a review of the scientific literature and expert reports, and on discussions with various players active in the field.

02

CRISIS MANAGEMENT

DEFINITION

A crisis can be defined as "a moment of intense difficulty or danger"[11]. Crises occur in all kinds of contexts, to varying degrees. Hence, it is simply impossible to give an exhaustive definition[12]. However, a crisis can be characterised by the following three criteria [3,12]:

1. Crises are associated with **threats** to the fundamental values defended by decision-makers, such as security, health, democracy, civil liberties, political autonomy and economic viability. A crisis inevitably has a significant impact on the survival and development of an organisation and no society, nation, organisation or individual can remain immune to the threats imposed by crises;

2. Crises involve a **high degree of unpredictability and uncertainty** about the nature of the threat and the response to it[3]. A crisis is a crisis partly because it is almost impossible to predict exactly when and where it will occur or what consequences it will have;

3. Crises lead to a sense of **urgency**. Events are perceived as evolving rapidly and the possibilities of influencing their course are limited. Consequently, they force decision-makers to take important decisions in extremely difficult circumstances.

The concept of disaster is also intrinsically linked to these notions of threat, uncertainty and urgency. A disaster can be defined as "a serious disruption in the functioning of a community, on any scale, due to hazardous events interacting with conditions of exposure, vulnerability and capacity, resulting in one or more of the following: human, material, economic and environmental losses and impacts"[13]. Because of the complex interdependence of society, infrastructure and the natural environment, the processes and outcomes of disasters are extremely difficult to predict[14].

In other words, a disaster generally leads to a crisis. However, a crisis is not always linked to a disaster, since it may be the result of a long-term process (e.g., an economic crisis). In this report, we focus on the chain reaction triggered by a disaster that quickly leads to a crisis.

TYPES OF CRISES

Disasters and the ensuing crises can be categorised based on their causes: natural or technological/human.

Natural disasters are the result of high-intensity environmental phenomena and are classified according to their origin(s): biological, geophysical, hydrological, meteorological and/or climatological. Some of these natural disasters are exacerbated by human impact and the resulting climate change[3].

Natural disasters have significant political and economic repercussions. Despite constant scientific and technological progress, it is impossible to predict disasters completely accurately[3].

TYPE	BIOLOGICAL	GEOPHYSICAL	HYDROLOGICAL	METEOROLOGICAL	CLIMATOLOGICAL
Explanation	Exposition of living organisms to a microbe or to toxic substances	Event occurring on firm ground	Event originating in water	Event caused by short-term variations in atmospheric processes	Event cause by a mid- or long-term variation in atmospheric processes
Examples	• Epidemic (viral, bacterial, parasitic, fungal) • Insect infestation • Animal panic movement	• Earthquake • Volcanic eruption • Dry land movement (landslide, avalanche, subsidence)	• Flooding (general, flash flood, coastal) • Wet ground movement (landslide, avalanche, subsidence)	• Storm • Cyclone, hurricane or typhoon	• Extreme temperatures (heat wave, cold wave, extreme winter) • Drought • Fire (forest, land)

Tab. 1 - Classification of natural catastrophes (Adapted from Below et al., 2009[15])

Technological disasters, or man-made disasters, are disasters that cannot be attributed to nature, and generally result in massive destruction and loss of life[16].

TYPE	INDUSTRIAL ACCIDENT	TRANSPORT ACCIDENT	MIXED ACCIDENT
Explanation	Any event occurring on an industrial site with serious consequences for personnel, residents or the environment	Any event with consequences for the transport user and/or its environment	Any disaster combining different sources
Examples	• Explosion • Fire • Poisoning	• Plane • Road • Train • Boat • Space	• Military accident or attack • Terrorist attack • Food poisoning • Environmental pollution • Mine accidents • Dangerous materials (gas leak, radiation)

Tab. 2 - Classification of human/technological disasters (Adapted from Below et al., 2009[15])

In terms of territorial scope, crises can extend beyond national borders and have significant economic repercussions due to the interconnected nature of the global economy and the interdependence caused by this globalisation. As the Covid 19 pandemic demonstrated, a local crisis can become a global crisis due to the spillover effect[3,12].

MANAGEMENT

As stated at the beginning of this report, crisis situations are an old and recurring problem for territories, but their frequency, form and impact have evolved over the centuries[2]. During a crisis, at the local level, public authorities are exposed to uncertainties (timing, duration, intensity), which can have a major impact on the lives of citizens[3].

Local governments therefore need to develop crisis management capabilities to deal with the complexity, novelty, ambiguity and/or uncertainty that characterise contemporary crises[3]. Crisis management is a key responsibility for decision-makers, who have a crucial role to play in strengthening the resilience of their critical infrastructure networks and their populations[3,17].

The primary aim of crisis management is to reinforce a territory's resilience. Applied to an urban context, the notion of resilience refers to "the capacity of a city to succeed as a centre of human habitation, production and cultural progress, despite the challenges posed by climate change, population growth and globalisation." Cities are resilient if they absorb shocks and can maintain their usual activity. To move towards territorial resilience, decision-makers must constantly improve their processes and capacities to prevent, reduce, manage and mitigate the consequences of crises[3,18].

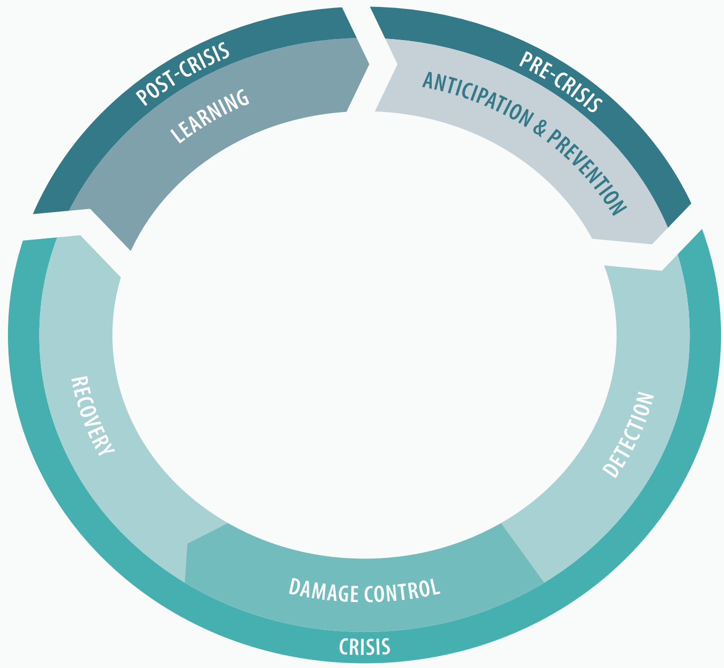


Fig. 1 - Crisis management cycle (Created based on Xue et al., 2022)

As shown in the scheme above, crisis management is made up of three main phases: pre-crisis, crisis and post-crisis, which are themselves divided into sub-phases[12].

1. **Pre-crisis**: knowledge and assessment of local risk factors (hazards, threats, vulnerabilities) are the foundations of crisis and emergency preparedness. This knowledge makes it possible to develop anticipation skills and take preventive measures such as setting up an early warning system[i] or building up stocks of goods or services.
2. **The crisis:** as soon as the crisis materialises, the response phase begins. This is divided into several stages:
   a. Detection of the crisis: identifying the signs of a potential crisis;
   b. Damage control: when damage cannot be avoided, measures are put in place to prevent it from spreading to other areas;
   c. Recovery: the effects of the crisis response are felt and a return to 'normal' takes place.

[i] An early warning system is an integrated system of risk monitoring, forecasting and control, disaster risk assessment, communication and preparedness, systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risk before dangerous events occur. (United Nations, n.d).

3. **Post-crisis**: the measures undertaken are reviewed and analysed to learn from them and improve crisis management in the future.

Although local governments have a major role to play in crisis management, the privatisation and/or decentralisation of certain services has altered their ability to take direct action to prevent or mitigate risks in key sectors such as water management or transport. Differences in perception and even conflicts of values between the various players involved in a crisis sometimes complicate decision-making[12]. Crisis management must therefore be adapted to include many stakeholders, all of whom potentially have different priorities and interests[3]. It is therefore important to develop an interdisciplinary convergence towards a unified vision[9].

Questions to Simon Riguelle, director of Wallonia's regional crisis center[19]

In your opinion, what is crisis management and how is it structured in Wallonia?

Crisis management is part of a wider process known as the risk management cycle, which comprises several stages (ndlr: see above). Hence, there is always work upstream to prevent risks and make plans to deal with residual risks, and downstream to restore the system to a stable state and improve processes.

At the Walloon level, we need to understand what falls within the competences of the Walloon Region as an institutional entity. In this respect, the decree on crisis management structures risk management around the risk cycle, provides for the establishment of a regional crisis management plan which should, in time, incorporate all the risk and crisis management procedures of the regional public services. As such, each department is responsible for identifying, preventing and managing the risks associated with the competencies it exercises. Where necessary, coordination between the various players is carried out by the Centre de Coordination des Risques et de l'Expertise (CoRTEX)[20].

The practical management of emergencies occurring in Wallonia is the responsibility of the local authorities (municipalities and provincial governors) or the national authorities (Minister of the Interior), depending on the scale of the emergency.

Who are the most relevant actors?

All links in the chain are important but crisis management often relies on key human resources, namely the various operational disciplines (D1: rescue services; D2: medical aid; D3: police; D4: defence and civil protection; D5: communications) and the emergency planning services. At the municipal level, an emergency planning officer is responsible for preparing for and responding to crises and emergencies, in support of the administrative authority.

What is the relation between the Region and municipalities?

The Walloon Region provides support and expertise to municipalities. This ranges from the mapping tools and information needed for emergency planning, to expert appraisal of the risks falling within its remit before and during a crisis. To this end, expertise units (Celex) carry out multidisciplinary analyses of the risks (forest fires, flooding, drought, etc.) and advise the local authority on the measures to be taken.

LINK BETWEEN CRISIS MANAGEMENT AND SMART CITIES

While each territory is unique, it shares similar challenges with others, such as demographic change, transport organisation, water management, security and energy sustainability[21]. Over the last few decades, the digital revolution, particularly through information and communication technologies (ICTs)[ii], has changed the way to communicate, work, produce and live together[21]. It is at the intersection of these challenges and solutions that the concept of the Smart City[2,21] has emerged.

In this respect, the use of ICTs and data can facilitate the sustainable and smart transition of territories to improve the lives of citizens. The non-exhaustive list includes:

- the Internet of Things (IoT) in the broadest sense;
- sensors;
- Big Data;
- microprocessors;
- the cloud;
- robots;
- mobile applications;
- artificial intelligence (AI), including machine learning;
- GPS (Global Positioning System);
- virtual and augmented reality and;
- drone technologies.

With crisis management in mind, the United Nations' 11th Sustainable Development Goal (SDG) states that Smart Cities must be able to prepare for and better respond to unforeseen events[17,22]. The use of ICTs can therefore be extended to the context of crises and mitigate their effects when they become unavoidable[2].

An increased access to information and better use of it can offer decisive advantages in the event of a crisis, such as smart crowd management, response coordination, emergency alert systems and emergency operations management[2,3,16,22]. In a territorial context, this access to information forms the basis of the added value of a Digital Twin in decision-making.

As a reminder, the Smart City Institute defines a Smart City as[21]:

- an ecosystem of stakeholders (governments, citizens, multinational and local companies, associations, NGOs, universities, international institutions, etc.);
- in a given (urban) area;
- engaged in a sustainable transition process (the aim is to ensure economic growth and prosperity, social well-being and respect for natural resources in this area);
- while using technology (digital technologies, engineering, hybrid technologies) as a facilitator;
- to achieve sustainability objectives and carry out the related actions.

[ii] A set of technological tools and resources for transmitting, recording, creating, sharing or exchanging information, including computers, the Internet (websites, blogs and e-mail), live (radio, television and Internet broadcasting) and recorded (podcasts, audio and video players and recording media) broadcasting technologies and devices, as well as telephony (fixed or mobile, satellite, videoconferencing, etc.) (UNESCO).

03

DIGITAL TWIN

ORIGINS AND DEFINITIONS

The first mentions of the Digital Twin can be traced back to the Apollo 13 spacecraft rescue mission in 1970. NASA had built two identical spacecraft, one of which remained on earth and was used to map the condition of the spacecraft sent into space[23]. At the time, NASA defined the Digital Twin as "an integrated multi-physics, multi-scale probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc. to reproduce the life of its flying twin"[24,25]. The concept was brought back in 2002, when Dr Michael Grieves, a researcher from the University of Michigan, proposed the Digital Twin as a simulation model for improving the life-cycle management of various industrial products.

He defined the Digital Twin as the combination of three key elements[26]:

(1) a virtual twin

(2) a physical counterpart, and

(3) a data flow cycle between the physical and virtual entities.

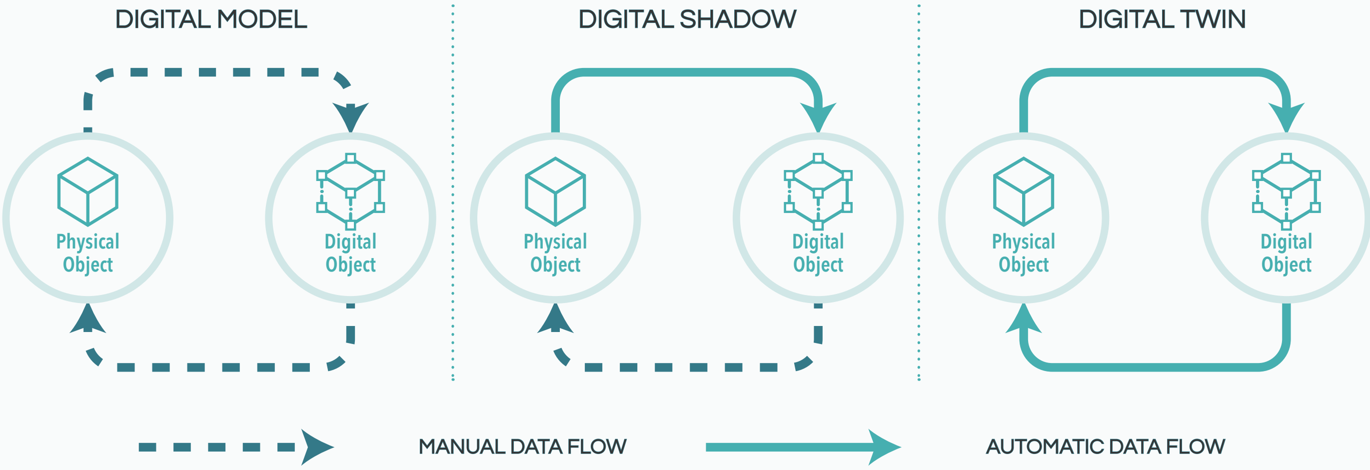
Although there is no single definition of the concept, all existing definitions agree on these three elements[27,28].

Within the framework of this report, we will complete these elements with the following definition: **"A Digital Twin is a dynamic, self-evolving virtual model or simulation of a real subject or object that represents the exact state of its physical twin at a given time through the exchange of real-time data and the preservation of historical data. The Digital Twin does not only imitate its physical twin: any change in the Digital Twin is also imitated by the physical twin"**[24].

A Digital Twin is a platform that relies on the intensive use of quantitative and qualitative data (related to material, manufacturing, process, etc.), both historical and in real time. The intensive use of this data is coupled with analysis, modelling and/or learning capabilities (e.g., artificial intelligence).

The major advantage of a Digital Twin in an industrial context is its ability to predict the future state of a system when it is tested under different conditions, on the basis of analyses and simulations based on data, under real or hypothetical conditions[26]. It enables certain decisions to be simulated on the Digital Twin rather than the physical twin. Information therefore replaces wasted physical resources, i.e., time, energy and materials[26].

Beyond the debates about what a Digital Twin is, it is important to note what it is not. Although many organisations use the term 'Digital Twin' as a synonym for a 3D model, a 3D model is only a potentially tiny part of a Digital Twin[24]. As the diagram below shows, depending on the level of data integration between the physical and digital counterparts, three sub-categories are considered: the digital model, the digital shadow and the Digital Twin.



The digital model does not automate the exchange of data between the physical model and its digital equivalent. All data flows are carried out manually. No change in the state of the physical object or its digital equivalent has any direct consequence on the other.

The digital shadow involves an automatic flow of data from the physical model to its digital equivalent. A change in the physical object can modify the digital representation, but not vice versa.

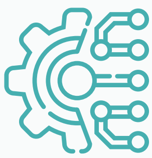
In a Digital Twin, there is a flow of data between the physical model and its digital equivalent, and vice versa. The physical twin can control the digital, but in this case the Digital Twin also impacts the physical object. It is this constant and fully integrated flow that makes a Digital Twin.

Fig. 2 - Distinction between digital model, shadow and twin (Adapted from Andrade, 2022[29])

The bi-directional exchange of data, also known as the 'data flow cycle,' and real-time self-management distinguish the Digital Twin from other digital systems[24].

A Digital Twin, in its more advanced version, is caracterised by the three following elements[25]:

CONCENTRATION

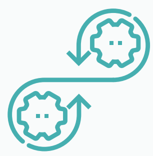


All the data in the lifecycle of a physical system is stored on a main digital line for centralised, unified management, making data transfer in both directions more efficient.

INTEGRITY

Digital Twins integrate all the components and sub-components of a system, providing the basis for high-precision modelling. Real-time monitoring of the data allows this model to be enriched and improved, enabling it to contain all the knowledge of the system.

DYNAMISM



Sensor data describing the environment or the state of the physical system can be used for dynamic object updates. Real-time interaction between the physical and Digital Twins enables models to grow and evolve throughout their lifecycle.

DIGITAL TWINS IN A TERRITORIAL CONTEXT

The rapid development and popularisation of Big Data, IoT and AI has given a strong impetus to the development and adoption of Digital Twins[12]. The Digital Twin concept has been widely used in different sectors such as manufacturing, aviation or automotive. Its application to the built environment is more recent (2017)[28,30]. One can only find a few scientific publications on this subject before 2018[31].

As explained in the section on crisis management, territories have become complex systems where social, economic, environmental and technological challenges impact and influence each other (e.g., climate change, urbanisation, loss of biodiversity)[5,25,32]. In this context, territorial management has become more complex and public systems of governance are sometimes inadequate, since the issues at stake transcend traditional organisational, institutional and sectoral boundaries[33].

Urban modelling is not a new phenomenon, as urban planners have been debating its usefulness and impact since the 1960s[33]. However, Digital Twins represent a new generation of models and make it possible to overcome traditional silos by analysing the impact of decisions on different sectors and different stakeholders in the area[5,10,33].

The ability to manage and process a territory's data is essential because of the quantity and the heterogeneity of data that can be generated[30]. Digital Twins have the potential to improve interoperability across territories thanks to their ability to integrate several data models[30]. Indeed, **the main added value of Digital Twins compared to other types of information systems is their ability to interconnect these different sources of urban data using artificial intelligence and algorithms in a way that can evolve with the territory and reflect its complexity**[8,31,33,34]. Following the same logic as an industrial Digital Twin, an urban **Digital Twin therefore makes it possible to explore interdisciplinary strategic opportunities, when it is risky, complicated or expensive to experiment with this on the ground**[35].

Ultimately, the urban Digital Twin aims to improve management and operations towards sustainable urban policies and a better quality of life for citizens[7,33,36]. There are two categories of benefits associated with Digital Twin simulations[10]:

- Predictive benefits: improved planning of longer-term scenarios to inform investment decisions
- Reactive benefits: improved real-time or near-real-time intervention and smooth day-to-day operation of the city or infrastructure being analysed

The graphical interface is also a key element in facilitating the understanding of results. The Digital Twin thus becomes an urban simulation platform that displays an updated model in real time showing the queries and analysis of various areas of the city (e.g., urban spaces, infrastructures, vegetation)[30]. This display can be in 2D or 3D, depending on the needs of the project and the resources available. On the one hand, 3D vision enables more accurate modelling, particularly in the case of buildings or bridges. However, it requires important simulation capacities and a lot of time. On the other hand, 2D vision does not allow complex infrastructures to be modelled and, hence, is less accurate. However, it requires less simulation capacity and allows large spaces to be examined more easily[4].

It is important to note that, even though one talks about urban (or territorial) Digital Twins, there is no such thing as a holistic territorial system. It is in fact a virtual ecosystem, made up of the superposition of several Digital Twins (e.g., roads, energy infrastructure), in which all the elements that make up the territory, or a functionality of the territory, are represented[37]. This system of federated systems serves as a simulation and management environment and provides the missing links between existing specialised urban models[33]. To be accurate and precise, the Digital Twin technology must therefore be able to construct a global perception of the infrastructure, both static (e.g., roads, schools, hospitals) and dynamic (e.g., pedestrian flows, energy consumption, position of emergency services)[12].

Its operation is simplified in the diagram on the next page.

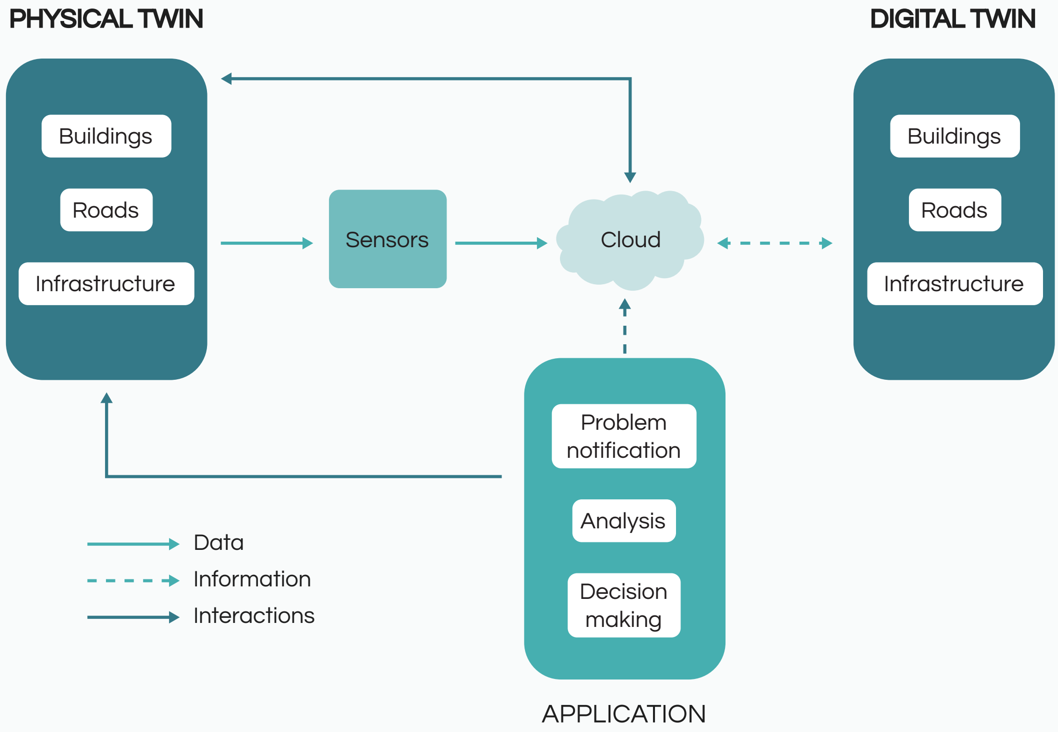


Fig. 3 - Operation of a Digital Twin in a territorial context (Dogan et al., 2021[4])

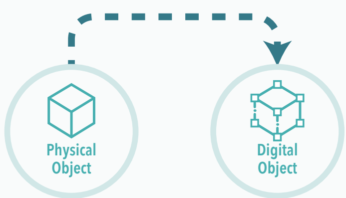
MATURITY LEVELS

There are several levels of maturity for urban Digital Twins. As already explained, the accuracy and usefulness of a Digital Twin depends on the level of detail and the exhaustiveness of the data available[34]. In addition, its ability to anticipate requires computing capabilities to operate faster than the physical activity they simulate[26]. In the table below, different levels of maturity are defined, making a clear distinction between those levels that are a digital model, a digital shadow or a real Digital Twin.

Most urban Digital Twins are currently at level 2 or 3[31]. Therefore, it is important to note once more that the term Digital Twin is commonly used when, in the strict academic sense of the term, it effectively refers to digital models and shadows.

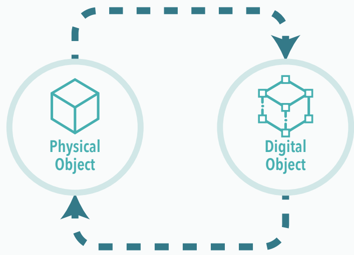
At this level, the primary objective is to model the existing physical environment. Data is collected using a variety of methods (e.g., surveys, photographs, drones, maps, plans).

Level 0
Capturing reality



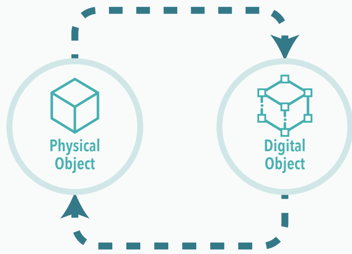
At this stage, the objects are designed and updated based on the model established at level 0. The data is historical and is encoded manually. At this level of maturity, the added value of the model lies in optimising and coordinating the design of assets, by answering questions such as: is there room to run a new power line in this location? How would the maintenance team manage this task?

Level 1
Basic 2D-3D mapping



The model is connected to up-to-date historical building data sets (e.g., design information, materials, inspection reports). Data is added, tagged and extracted from existing systems, not integrated or stored directly in the 2D/3D model. At this level, the model provides integrated multiphysics and multi-scale simulations and answers questions such as "What would happen if ...?" or "If I change X, what will be the impact on Y?". Hence, it enables engineers, planners and project managers to take better decisions faster thanks to unique encodings from which all data can be viewed and interrogated. This reduces errors, uncertainties and costs.

Level 2
Link to historical data

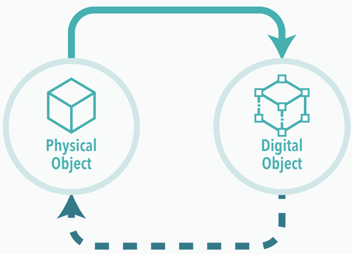


Using sensors and IoT, dynamic data is obtained and displayed in (near) real time via a one-way flow from the physical object to its digital counterpart. This data can be analysed to inform and predict the behaviour of the built asset and aid decision making.

At this stage, the tool can become a real-time simulation tool thanks to the massive use of real-time data and AI. Different models, provided by various players, can be operational within the urban Digital Twin. One model can use the results of another model, and models can be replaced by others, without hindering the operation of the urban Digital Twin as a whole.

This level of maturity represents what many technology and service providers would consider to be the starting point for a 'true' Digital Twin, even if this is not the case in the academic sense of the definition of the term. This level of maturity is the most complete/advanced currently in use.

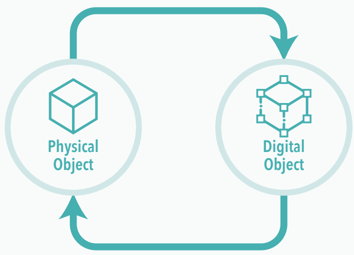
Level 3
Real time data



The defining element of this level is the bi-directional flow of data between the physical twin and its digital counterpart (their synchro-nisation)[24,27,38]. The state and condition of the physical asset can be changed through the Digital Twin, with the results being fed back and updated in the physical twin.

For example, an operator could manipulate a valve or activate a machine by triggering the action from the Digital Twin. This level of integration requires many sensors and mechanical precision in the physical twin to enable it to update itself.

Level 4
Integration and
bi-directional interactions



A final level of maturity is reached when the urban Digital Twin not only supports human decisions, but also enables automated decision-making. Attaining this level of maturity is only a utopian dream for the moment.

This two-way flow would make it possible to carry out a virtual optimisation process based on the current state of the physical entity and to implement this optimal set of virtual parameters in the physical twin[39]. The quantifiable benefits are not yet fully understood.

Level 5
Automated operation
and maintenance

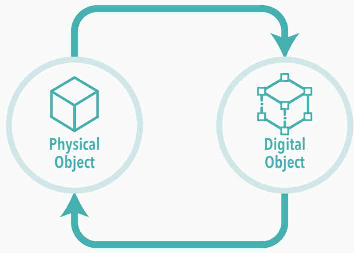


Fig. 4 - Levels of modelling and integration of the physical environment and its digital counterpart in a territorial context (Adapted from Evans et al., 2019[37])

04

DIGITAL TWINS AND CRISIS MANAGEMENT

Current technologies cannot yet predict when disasters will occur, but they can provide the means to act before and afterwards to reduce their effects on citizens and infrastructure[4]. In this respect, the Digital Twin is one of the most promising technologies, since its *raison d'être* is its ability to run simulations to determine how a physical twin would react under a wide variety of conditions and to train its users for abnormal situations they might face[12,26].

From a technical point of view, the past and present constituting elements of a territory (i.e., objects, infrastructures and information flows) can be integrated by the Digital Twin model and analysed in greater detail to better understand how they interact. The use of ICT and AI makes it possible to simulate and analyse the impacts of different scenarios to inform upstream or real-time decision-making, by combining past and present information and future scenarios[30].

In a nutshell, **Digital Twins provide a realistic, data-driven environment for decision-making, training and preparedness, enabling leaders to better understand, respond to and mitigate the effects of various crises. Consequently, they have the potential to improve situation assessment, decision making, coordination and resource allocation**[7,9,30].

This report focuses on aspects related to planning, situational awareness and intervention optimisation, as well as the role of the Digital Twin for collaboration between stakeholders. These uses are not mutually exclusive and generally even reinforce each other. As the diagrams on the next page show, these different uses cover the entire crisis management cycle.

Questions to Simon Riguelle, director of Wallonia's regional crisis center[19]

In your opinion, what is the role of technology and the use of data in crisis management?

Technology plays a central role in crisis management. The use of data and technology must improve the early detection of threats and the assessment of risks to anticipate their effects. Feedback from the field during a crisis is a second crucial element that technology should help to optimise. However, the use of technology is currently still underexplored and underexploited.

What about the Digital Twin?

As far as the Digital Twin is concerned, this could enhance the decision-making capacity of the authorities by providing them with real-time information.

What limits or obstacles do you see to the use of technology in crisis management?

The obstacles are inherent to technology. They include: their reliability and stability, even in degraded situations (deteriorated telecoms networks), their sufficient control by the players involved, the associated costs, their compatibility with other systems, and so on.

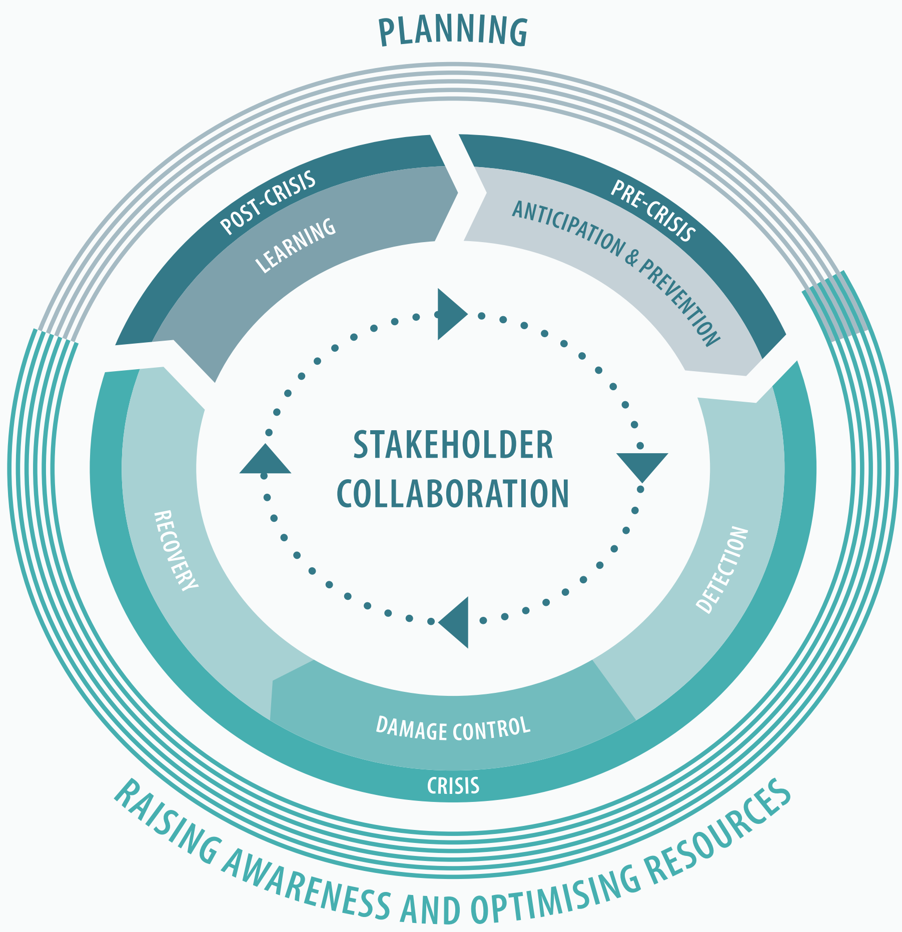


Fig. 5 - Contributions of the Digital Twin to the crisis management process

PLANNING

While it is impossible to avoid all the damage associated with a crisis, potential risks can be mitigated through proper planning. Planning involves determining what aims to be done, how something should be done and what means and resources are needed to achieve this[3]. The goal of emergency planning is to ensure that the various players in the area have sufficient capacity to improvise and innovate[3]. Whatever the type of crisis, planning involves a number of actions, such as[3]:

- Identifying particularly vulnerable locations;
- Understanding the problem(s) and need(s);
- Identifying the possibilities, opportunities and resources available;
- Determining the actions to be taken using existing means and resources to improve crisis response capacities;
- Listing the players and equipment needed to implement these actions (e.g., install IoT devices in buildings and in critical infrastructures such as transport, telecommunications, electricity and natural gas networks).

As already explained, contemporary crises require more agile response capabilities than in the past[3]. Territories need reliable planning models able to mimic real-life experiences, to reproduce past events, but also to predict the future[39].

In this respect, Digital Twins can play a key role in a real anticipation and training approach. They make it easier to assess the risks and dangers likely to cause a disaster, to prevent them or to mitigate their possible effects[16,26]. They enable simulations to be carried out in situations that are extremely rare but that can have disastrous consequences[34].

By setting up 'what if' scenarios and measuring the effects of interventions, Digital Twins can be used to visualise complex and perhaps abstract cause-effect relationships[7,39]. For example, it is possible to identify several scenarios (best, worst and intermediate) from the information available[3,7]. These simulations enable decision-makers to understand the consequences of different strategies and to develop effective intervention plans.

By organising simulations, the various players involved in crisis management can also train and refine their response strategies in a simulated environment to react more effectively and efficiently to real emergency situations[16].

To sum up, from a planning perspective, simulations on a Digital Twin therefore make it possible to:

- **Support decision-making processes and promote alternative policy scenarios**[30,38]**;**
- **Identify the main stakeholders, threats and opportunities linked to the crisis**[3]**;**
- **Ensure that all stakeholders are prepared for disasters through training and exercises**[16,36]**;**
- **Anticipate as far as possible the prioritisation of resources to be deployed during a crisis;**
- **Minimise losses by responding in a timely, rapid and effective manner**[16]**;**
- **Develop solutions that enable a balanced and measured response**[3]**.**

Planning is possible at any level of maturity, but the more mature the Digital Twin is, the more precise and accurate it will be.

For example, planning and designing for flooding means putting the right interventions in the right places. In a Digital Twin, water level data can be dynamically modified, highlighting the areas that would be first affected by a river flood or heavy rainfall. The Digital Twin can be used to test several scenarios depending on the type, the speed, the velocity, the extent and the flow of flooding. These simulations can therein be useful to urban authorities in planning their response capacity to these phenomena (e.g., deciding where to deploy sandbags and which areas of the city to evacuate first)[34].

In the longer term, simulations can be used to put in place appropriate public policies to prevent or mitigate the effects of a disaster. For instance, streets can be reconfigured to improve water drainage in the event of flooding[40].

RAISING AWARENESS AND OPTIMISING RESOURCES

When a crisis begins, one of the most fundamental and difficult tasks for managers is to understand what is happening and to get an idea of how the situation is developing so that they can take effective and fair decisions[3]. Managers can ask these questions:

- What happened?
- How many people are or could be affected?
- What assets and interests are at stake?
- How could the crisis evolve?
- What capacities are available from an operational point of view?

At the start of a crisis, the information gathered by the Digital Twin can be used in emergency alert systems (EASs). EASs are systems used for different purposes to warn the community and reduce the damage caused before, during and/or after many disasters[16]. Although they have been around for decades, these systems are now benefiting from significant improvements in risk detection and monitoring in recent years thanks to ICTs. These systems also use artificial intelligence tools to deduce, learn, store, plan and analyse data[3].

During the damage control phase, decisions often must be taken as the situation evolves, even when consequences cannot always properly assessed[3]. **The Digital Twin provides a better understanding of the current situation to optimise the deployment and management of resources (human, financial and material)**[5,9]**. The Digital Twin can also be used to monitor and track the state of critical infrastructures and resources in real time**[3]**.** Using AI (maturity levels two and three), authorities can visualise the activities and damage caused, the most vulnerable places and people, and anticipate the next steps to be taken[9,30]. Consequently, the Digital Twin **makes it possible to anticipate potential bottlenecks and identify the most effective response strategies, which leads to a better management of potentially limited resources to ensure that the situation is restored as quickly as possible**[3,26].

For example, in the event of a severe thunderstorm, heavy rainfall can cause flooding, leading to road closures or water and electricity cuts[9]. Thanks to the Digital Twin, emergency services (ambulances, fire brigades, rescue services and police) can benefit from access to weather and traffic data in near real time to coordinate several services, for instance to reassess a route on the transport network affected by flooding or road incidents[9].

STAKEHOLDER COLLABORATION

Crisis response capabilities are shared between a multitude of public, private and voluntary players, at different territorial levels. These include emergency management agencies, civil protection departments, health services, fire brigades, police forces, the emergency units of transport, energy and communications operators as well as civil society. All these players can and should contribute to crisis response capabilities, depending on the nature of the crisis, their institutional structure and their mandate. However, these players generally have different perceptions of the definition of the problem, the possible solutions and the paths to follow to implement them[3].

The often-chaotic context of a crisis requires the ability to build and share multidisciplinary expertise under intense pressure. Effective crisis management depends on networked coordination and collective decision-making between the various players[9]. However, this is no easy task, as the information held by these players is rarely pooled.

Even if all the players have access to the same basic information, interpretations and priorities are likely to diverge considerably because each of them tends to analyse and interpret events from its own point of view, focusing on a specific aspect of the situation: the one that concerns its *raison d'être*[3].

Digital Twins can manage all kinds of information in a unified way, allowing different players to access and add data at any time[25]. The use of Digital Twins can solve problems of information asymmetry through a single information channel, establish a link between several players, plan in an orderly fashion, distribute tasks reasonably and provide constant feedback[41]. The visualisation aspect also helps to build a common understanding. In other words, Digital Twins have the potential to improve communication and collaboration between different stakeholders, ensuring that they have access to the same information and are working towards a common goal[3,42].

This multidisciplinary expertise must be organised before, during and after the crisis[33]:

- Before and after the crisis: the Digital Twin can serve as a collaborative environment for the various stakeholders to agree on the complexity of the territory and the interdependencies between its constituting elements (i.e., human beings, infrastructures and technologies) and decision-making in the context of different disaster scenarios.
- During a crisis, a Digital Twin can also improve cooperation between all stakeholders, particularly within public authorities, both horizontally between different departments and vertically between different levels of government.

It is particularly important to communicate with citizens. Traditional crisis communication consists of transmitting messages on the state of a crisis, its impact and the actions and measures that have been deployed. It is generally aimed at feeding the media with facts and demonstrating to citizens that the public authorities are keeping the incident under control[3]. Digital Twin technology can improve citizen engagement by enabling them to participate in crisis management (e.g., a Digital Twin of a city can provide residents with real-time updates on emergency situations, enabling them to take appropriate action to protect themselves and their families)[33].

05

LIMITS

Although the Digital Twin technology is promising, the development of territorial Digital Twins around the world is generally only at stage 2 or 3 of maturity. Furthermore, the use of Digital Twins in crisis management remains relatively isolated[4]. There are still several obstacles and limitations, including the difficulty of reflecting the complexity of territories, the maturity of the technology and the governance of the model.

TERRITORIAL COMPLEXITY

The first step in setting up territorial Digital Twins is the modeling of the various territory's infrastructures. Given their complexity as geographical entities and living spaces, building these models can be difficult. Critics have emphasized the high degree of simplification of the processes required to simulate them. However, this reductionism does not make it possible to understand and assess the major interconnections between the various elements that make up the territory[33].

Hence, the first challenge is to understand the different layers of infrastructure that are interconnected and act on each other in a non-linear dynamic[32]. Beyond the infrastructure, **a territory is made up of neighbourhoods that are defined as much by their urban planning as by their interactions, which are difficult to quantify**[30,32]. This means that the ways in which Digital Twins operate often overlook the importance of **social interactions and norms, laws, culture, history or political dynamics**[10]. In a crisis context, the interdependence between the physical infrastructure and these aspects makes it difficult to quantify citizens' reactions.

It is impossible to make sense of what is happening in the real world without a solid understanding of the relationships between contextual reality and the choices made by people in the area. Data is an instrument, not a goal, and it does not speak for itself[39]. The territory is not an automated system that can be easily understood and predicted, but rather a living system that is constantly evolving through the variations and developments of its physical constructs, its economic and political activities, and its social and cultural frameworks[8,25,36]. Some critics even go so far as to say that digital universalism is a 'myth,' placing particular emphasis on the dangers and risks involved in its intention to achieve complete representation and knowledge of a phenomena[10].

In the future, it will be vital to be able to incorporate a behavioural variable to analyse and critically evaluate the social, political, economic and technical impact of Digital Twins on an area[33].

DATA

Apart from the difficulty to grasp the complexity of a territory, a Digital Twin requires massive quantities of data as well as the technical capacity to integrate them, as of the start of the project[26, 27, 41].

The **availability and quality of the data** used is a major challenge[12,18]. It is impossible to build a local Digital Twin without a solid database and without Big Data, as crisis management requires real-time data on the state of multiple, diverse and simultaneously connected infrastructure[27,38]. However, projects involving Big Data are likely to fail due to a lack of proper data governance and management to address challenges such as identifying and accessing data, transforming data from different sources or poor data quality[24,43]. Acquiring data is not easy since some of it is not publicly accessible. The players who own them have certain prerogatives and this can potentially lead to conflicts of interest between large companies, which have a monopoly on data, and the public authorities[10].

Then, during a crisis, it is particularly difficult to have access to all the necessary data in real time, not least because there is a **risk that the infrastructure (e.g,. sensors) could be damaged** by a major climatic event[3]. Information gathered by citizens is often put forward to mitigate this risk, but it is not always sufficient for effective decision-making[44].

Moreover, it is not enough to have real-time data for the Digital Twin to work. This **data must also be loaded automatically**[26,43]. For example, there is a tendency not to use available data sources automatically because of their heterogeneity (various sources, different formats). The standardisation of data formats and their interoperability, which enable better integration, are therefore a major challenge[32, 45].

Finally, most Digital Twins can currently be used for short-term predictions only when a stable relationship between causes and effects can be assumed. However, this is not the case when they are used for long-term planning and decisions[39,44]. In addition, **current simulation technology still cannot capture the intricate details of infrastructure materials and dimensions, or describe complex external environmental factors**[45]. Better integration of Digital Twin data with associated digital technologies is therefore required[10,46].

GOVERNANCE

The adoption of Digital Twins goes beyond the maturity of the technology itself and requires particular attention to governance aspects.

First and foremost, decision-makers need to understand what their ultimate challenges are in managing a Digital Twin, and what their decision-making processes look like. When this is not clear, it is difficult to convince end-users that the Digital Twin can be useful to them. Hence, the first step is to map out the most important management decisions that the twin will need to support[47].

Then, to be able to transform the data into useful and impactful information, it is vital **to share the information appropriately and present it in the most accessible way possible**[42]. In 2002, Dr Grieves, founder of the Digital Twin, already said: "*We believe that the technology needed to solve these problems will be available much sooner than the cultural changes required to adopt and make full use of the technology*"[48].

In this context, **transparency** is also challenging. The lack of transparency towards citizens and stakeholders sometimes positions data and modelling as a 'black box.' This creates uncertainty as to data's democratic value[33].

At the same time, citizens tend to worry about the security problems caused by leaks of personal data, particularly in the case of GPS data[41]. The introduction of Digital Twins involves the systemic recording of the physical world in their digital 'double' would guarantee absolute transparency, which could to some extent cause panic among citizens[41]. This would mean that these data could potentially be consulted and used by actors whose objectives are contrary to the initial aim of the project[3].

If it is not carefully managed, Digital Twin technology can therefore be associated with various forms of vulnerability and pose a serious threat to privacy, civil liberties and democratic processes[3,36].

06

EXAMPLES

Across the world, many regions are deploying (quasi) Digital Twin solutions to improve their crisis management, whether before (planning, anticipation), during (awareness, damage control) or after the crisis (learning).

GRAND DUCHY OF LUXEMBOURG: NATIONAL RESILIENCE[49,50,51]

The Grand Duchy of Luxembourg (± 640,000 inhabitants) aims to create the first nationwide Digital Twin. The project is being led by the Luxembourg Institute of Science and Technology (LIST), the University of Luxembourg and the Luxembourg Institute of Socio-Economic Research (LISER).

The initiative can be traced back to three major climatic events, all of which occurred on 9 August 2019: a tornado that caused serious damage in southern Luxembourg, a major blackout that deprived one million people of electricity in the United Kingdom, and a fuelling system malfunction that stranded many aircraft at Amsterdam-Schiphol airport. These three events, although completely different, were totally unexpected and had serious consequences for society.

The Digital Twin therefore appeared to LIST as an opportunity to build a more resilient digital society, capable of mitigating this type of event on the scale of Luxembourg. Hence, the overall aim of this Digital Twin is to gain a better understanding of the country as a whole and to predict the behaviour of the infrastructure and its inhabitants during future crises.

The first uses envisaged were urban planning, resource management and mobility. However, the emergence of the COVID-19 pandemic changed priorities. The researchers quickly set up dashboards to understand the impact of political decisions (e.g., closing schools, reopening restaurants, keeping borders open) on the expected number of infections and hospitalisations, as well as on various socio-economic variables. The numerical model has since been extended to other policy aspects, such as how to make the electricity network safer and more resilient.

The project is currently funded by the National Research Fund's INITIATE programme. It supports the launch and development of strategic research and innovation project ideas that contribute to making Luxembourg competitive at international level.

BACTON: ANTICIPATING COASTAL EROSION[52,53]

The Digital Beach Twin (DBT) is a virtual mirror of the coastal development project at Bacton (UK, ± 1,200 inhabitants) due to coastal erosion. As an integral part of a planning approach, this coastal protection project will make it possible to anticipate risks and ensure the future protection of the existing gas terminal, as well as putting in place adaptation plans for neighbouring villages.

This virtual mirror means that decisions can be taken at the right time:

- Neither too late (which could lead to catastrophic impacts in terms of erosion and flooding);
- Nor too early (which could lead to inefficient or even pointless investment).

End-users (companies operating in the harbour and North Norfolk County Council) can interact with the DBT via the online user interface, enabling them to make informed decisions about future investment in the management of this coastline.

In practice, stakeholders have access to a map with geospatial data (representing the past and present state of the beach), a graph with beach profiles and the results of modelling and the triggering of potential interventions. They also have access to a graph showing when and where intervention, and consequently reinvestment, should be required. The predictive models are regularly recalibrated using the latest monitoring data.

Royal HaskoningDHV, the engineering company in charge of managing the project, highlighted the following elements to ensure the success of a Digital Twin:

- The importance of direct and intensive collaboration between end users, which is a key factor in the success or failure of a Digital Twin.
- An effective synergy between a digital solution and the knowledge of those involved on the ground.

KUMAMOTO: FLOOD PREDICTIONS[54,55]

Japan is naturally prone to climatic disasters (typhoons, earthquakes and floods). In 2016, two major earthquakes struck the Kumamoto prefecture, in the south of the country, less than 28 hours apart. These magnitude 7+ earthquakes caused the collapse of more than 8,000 buildings and significantly damaged 35,000 others.

Since 2018, the city of Kumamoto (± 740,000 inhabitants) has been collaborating with the company One Concern on a Digital Twin that aims to measure river overflows (external flooding), rainfall that exceeds the drainage capacity of urban areas (internal flooding) and flooding caused by storm surges in coastal areas.

As shown in the diagram below, the global model is based on a set of predictive models specific to each type of flood. In practice, the system is based on weather forecast data. The system also monitors meteorological information provided periodically by Weathernews, a local organisation, and sets thresholds for river water levels, coastal tide levels and rainfall. If the necessary data is available for major rivers, the system can also forecast their water levels for the next 72 hours and display the locations where water overflow may occur.

Floods are also strongly influenced by specific local factors. Therefore, these models are based on data from the natural environment, such as altitude and land use. However, these data are not sufficient to make accurate forecasts. AI and machine learning technology are therefore combined with available public data to extrapolate the missing information. The model is calibrated using past data on river flows and water levels, data on tide levels and data on the extent and depth of flooding when it occurs.

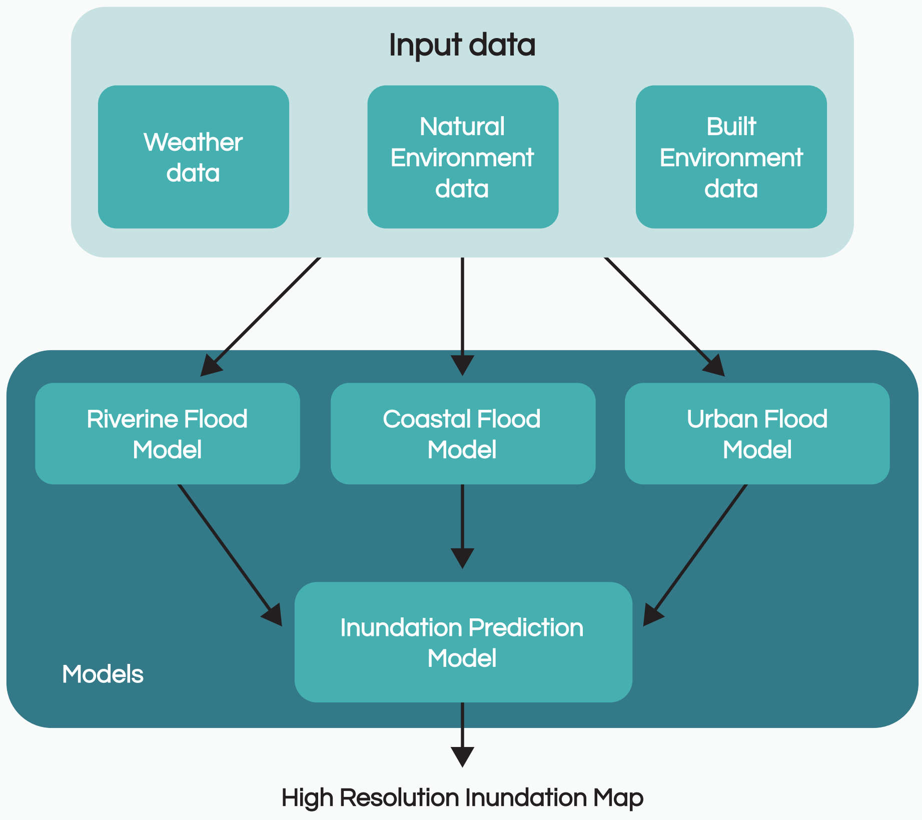


Fig. 6 - Kumamoto's Digital Twin working environment (Adapted from OneConcern, 2021)

Decision-makers can consider worst-case scenarios and plan alternative evacuation and emergency response measures. In August 2021, during dangerous rainfall, the Digital Twin correctly predicted that the river would not flood and the observed river levels closely matched the predictions.

Fig. 7 - Screenshot of the Kumamoto Digital Twin platform
(Captured from One Concern, 2021)

ANGERS: FLOOD SIMULATION AND FORECASTING[56]

Like many cities located near large bodies of water, the French city of Angers (± 151,000 inhabitants) faces the constant threat of flooding as it is situated along the Loire River.

To effectively manage these challenges and reduce risks, the city's leaders turned to the use of Digital Twins, in collaboration with the company Siradel. Siradel's tool enables town planners and emergency services to obtain data-driven information through:

- Historical insights: floods over the past 20 years have been modelled and visualised to understand their impact on vital infrastructure - such as street lighting, roads and bridges - particularly in vulnerable areas of the city.
- Realistic simulations: by simulating potential flooding scenarios (e.g., a two cm rise in the river level), the city was able to identify high-risk areas and critical infrastructure likely to be impacted.
- Forecasts: by integrating real-time data and flood forecasts, it is possible to anticipate incidents, enabling the city's management and emergency services to take preventive measures.
- Detailed impact assessment: beyond traditional flood zones, Siradel's solution has enabled the city to assess the impact on specific sites, such as educational establishments, medical facilities, campsites and even electrical cabinets supplying street lighting.

Angers' adoption of Digital Twin technology has brought a range of benefits:

- Efficiency: city officials can now make informed decisions quickly, optimising resource allocation and response strategies during floods.
- Resilience: the city has strengthened its resilience to flooding by identifying vulnerable areas and implementing targeted mitigation measures.
- Sustainability: by improving flood risk management, Angers is contributing to its long-term sustainability, safeguarding both its heritage and its inhabitants.

HOF: IMPACT OF FLOODING ON INFRASTRUCTURE[57,58]

Digital Twin projects do not just apply to big cities. In 2022, the Bavarian district of Hof, and more specifically the municipalities of Hof (± 47,000 inhabitants), Selbitz (± 5,000 inhabitants) and Köditz (± 3,000 inhabitants) were affected by violent storms and flooding.

To improve the resilience of the area, the Hof district authorities, in partnership with the Dutch engineering firm Nelen & Schuurmans and the company Virtual City Systems, are developing a Digital Twin capable of simulating an emerging flood and its impact on buildings and infrastructure such as roads, bridges and the electricity network. The development of this Digital Twin is funded by the KfW bank and the Federal Ministry of the Interior through its Smart Cities programme.

The Digital Twin consists of two main components:

1. Digital modelling of the physical environment: data is collected using an aircraft and advanced camera systems capable of capturing buildings from several angles. The dataset collected reflects the floors and heights of the buildings and photorealistic textures of the buildings are added.
2. Numerical modelling of potential flooding: the company Nelen & Schuurmans has developed a hydrodynamic simulation platform capable of simulating the movement of water in processes such as rainfall runoff, infiltration, surface runoff, wastewater runoff, runoff in rivers and around obstacles, and ultimately simulating flooding. The model's rainfall data comes from the precipitation forecasts of the German Meteorological Service's model. To correctly simulate flooding, the datasets are edited to incorporate obstacles into the terrain model, such as building footprints, bridges and riverbeds.

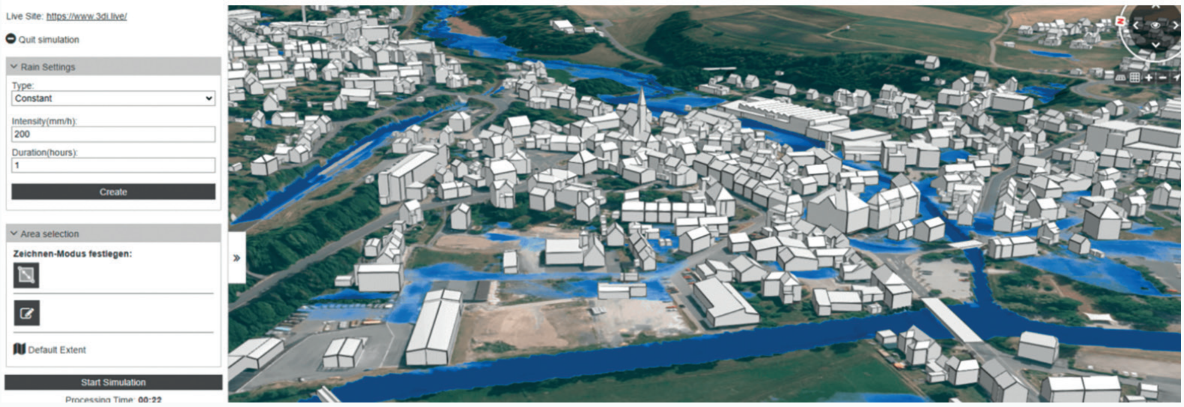


Fig. 8 - Screenshot of the Hof district Digital Twin project (Captured from Nelen & Schuurmans, 2022)

AUSTIN: IMPACT OF FIRES ON PUBLIC HEALTH[59,60]

The University of Texas in Austin (UT Austin), in collaboration with the City of Austin, recently developed FireCOM, a Digital Twin designed for real-time monitoring and forecasting of active fires and the impact of smoke fallout on the urban environment.

During a fire, 80-90% of deaths can be attributed to smoke inhalation. In addition to the risks associated with the flames and heat of a fire, the effects of its smoke have dangerous consequences for health, due to the atmospheric pollutants that result, such as asbestos, pesticides and cyanide. These become airborne and are transported to the surrounding area.

By serving as an early warning system, FireCOM aims to improve health conditions and bring about a more effective response to urban fires. Its main users are citizens, emergency services and decision-makers involved in fires and public health management.

In practice, FireCOM collects and combines different data sources in real time to accurately predict smoke dispersion within one, two and three hours of a fire. Real-time data mainly consist of:

- fire location: real-time location data is obtained from the Austin Fire Department;
- weather: meteorological data is obtained from the National Weather Service, the national agency that provides meteorological, hydrological and climate forecasts and warnings for the United States. Weather service data is extremely important, as wind direction and strength largely determine the area of impact. Weather conditions are perhaps the most important factor in determining the spatial progression of smoke;
- air quality: air quality data is provided by nearby outdoor air quality sensors, supplied by low-cost WiFi-connected laser particle sensors.

This real-time data is combined with static data such as infrastructure, including the classification of buildings and streets such as schools, hospitals and speed limits. Austin's topographic data comes from OpenTopography[61], an open-access, high-resolution topographic data platform. The 3D urban structures were taken from OpenStreetMap[62] to create the base map for the Digital Twin.

Moreover, for simulations to be useful outside a scientific audience, visualization is essential. Therefore, the researchers have therefore combined the visualization of real-time information flows with a 3D city through a suite of open-source 3D creations. More information on how these different elements work together can be found in the diagram below.

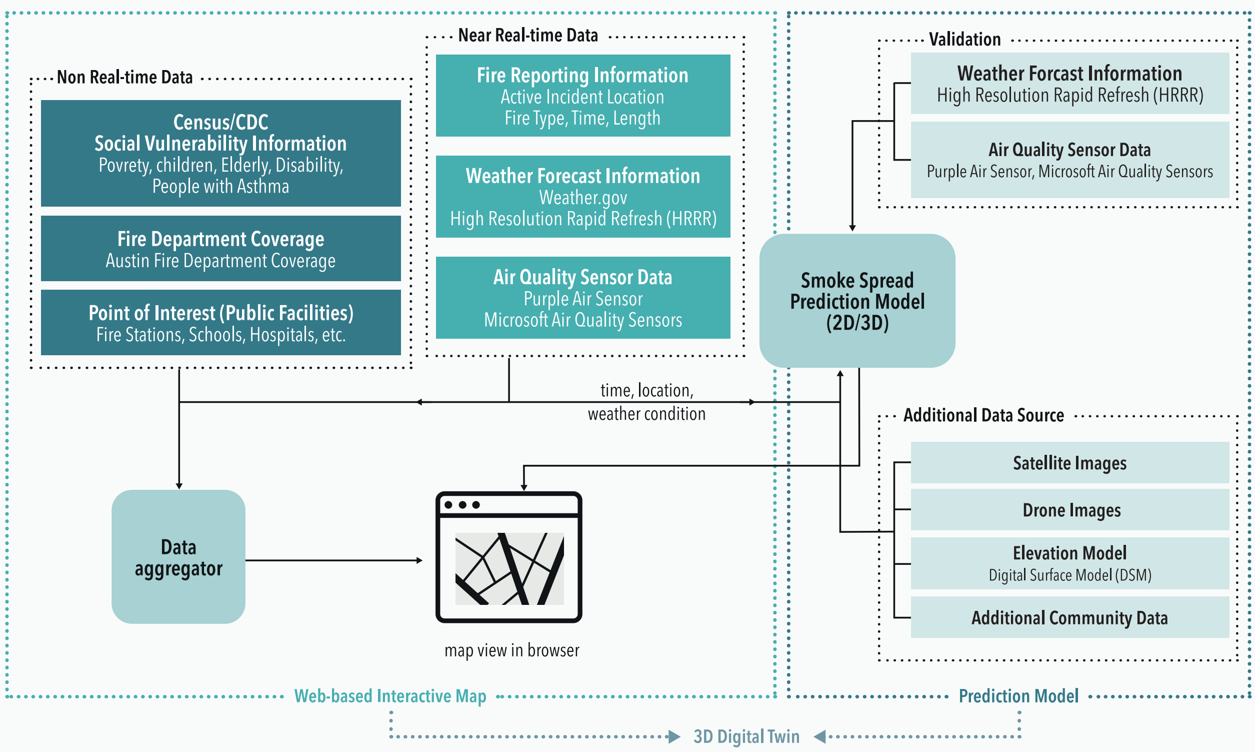


Fig. 9 - Building blocks of the FireCOM project (Adapted from Jiao et al., 2023)

On-demand simulations of urban fire smoke trajectories have never been attempted before, due to the complexity of such measurements. Without a Digital Twin, fire detection and monitoring are generally carried out using satellite data (i.e., from anomalous heat signatures and bright spots on the Earth's surface). However, these signals for urban fires are weak and often indistinguishable from other thermal signatures (e.g., sunlight reflections), making detection difficult. The Digital Twin is therefore a real planning and anticipation asset for local authorities.

In 2022, more than 20,000 fires occurred in Austin alone. Analysis of this data revealed several trends, including that most fires occur in the afternoon, typically between five and 10 pm. By cross-referencing the data received for each fire with a map of Austin, the researchers created a 'fire risk' analysis map where orange represents normal fire risk, while yellow and red represent below- and above-average risk, respectively.

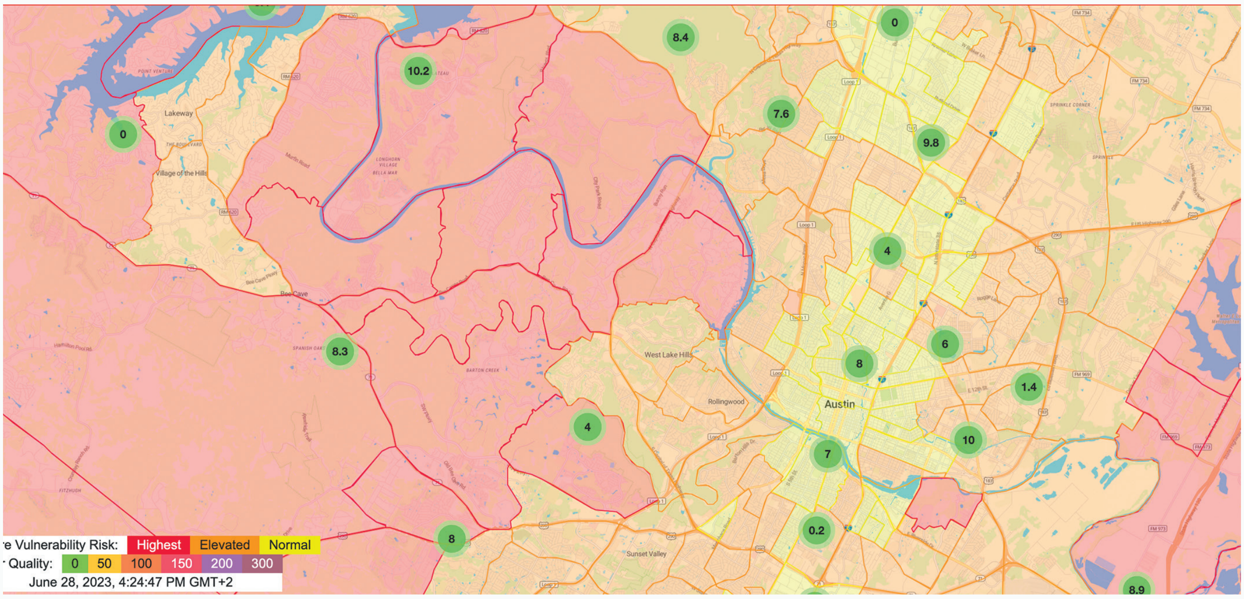


Fig. 10 - Screenshot of the platform in real time (Captured from UT Austin, n.d.)

Although the project is promising, its designers have encountered or are encountering certain limitations:

- While they give very realistic results, air fluid dynamics simulations are expensive;
- The city lacks air quality sensors. As Austin's territory is very large, air quality sensors are generally positioned at least one kilometer from the fire;
- Beyond data access, the project managers were impacted by the lack of uniformity in fire data. Hence, they created a unified schema containing only the necessary information, i.e., incident name, date, longitude and latitude coordinates, address and reporting department.
- In a comprehensive urban Digital Twin model, the current data would constitute only a marginal list of the necessary information. In a comprehensive twin, one should take advantage of traffic conditions in a right or left lane to indicate which side of the road a car on fire is on, or even make estimates based on the total aggregation of telephone signals in an area to determine the number of people potentially affected by smoke fallout.

DUBLIN: EMERGENCY DECISION-MAKING[63]

The city of Dublin (± 550,000 inhabitants) is using a Digital Twin project for emergency response operations carried out by the city's fire department. The project is led by a consortium composed of the fire department, Dublin University, Smart Dublin and Bentley Solutions as solution provider.

The diagram below shows the key stages in data management for the planning and development aspects of this Digital Twin.

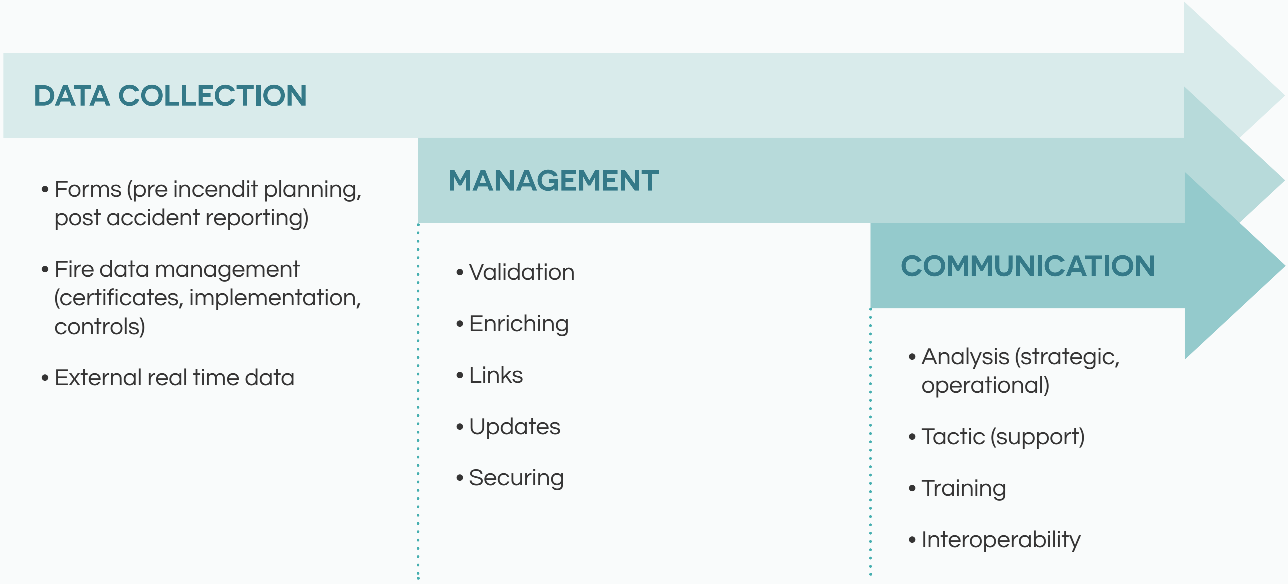


Fig. 11 - Data management steps for the implementation of the Digital Twin (Adapted from OpenCities Planner, 2023)

The communication aspect of the available data is particularly useful. The Digital Twin is available via a web browser, enabling rapid access via a tablet during an incident. In the event of a fire, firefighters have access to:

- The fire scene: a 360° view based on available sensors and real-time information from drones;
- Buildings: an overview of the layout, shape, height and arrangement of buildings, both from the air (e.g., roof details) and from the street (frequently updated historical data);
- The quantity of water available in the system in the vicinity of the fire;
- The flame exposure of surrounding buildings and streets;
- Real-time information on the location of fire-fighting equipment (e.g., fire trucks).

Rapid access to this information saves precious minutes, particularly in terms of saving lives or avoiding building collapse.

In the future, project managers would like to improve the Digital Twin by:

- Enhancing the user experience of the online platform;
- Incorporating it into an overall city Digital Twin that would bring together other functions such as transportation;
- Including more data on building interiors (e.g., alarm systems, real-time occupancy rates).

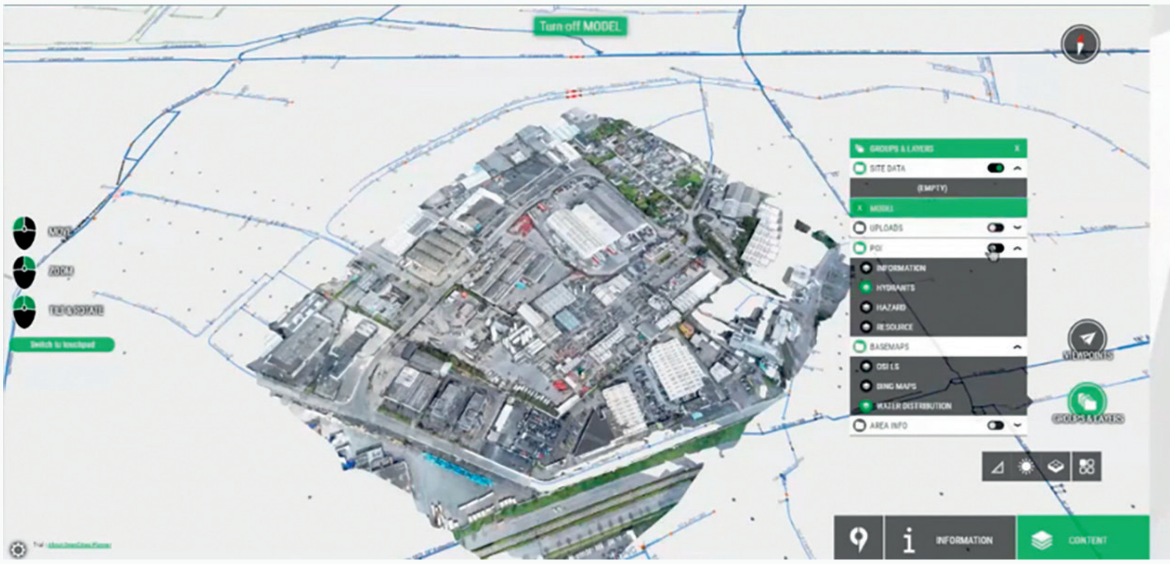


Fig. 12 - Screenshots of the Digital Twin of Dublin's fire department (Captured from OpenCities Planner, 2023)

CAUAYAN: RESPONDING TO TYPHOONS[64,65,66]

Since 2020, the Philippine city of Cauayan (± 144,00 inhabitants) has been using a Digital Twin to improve its resistance to typhoons and related flooding. It is collaborating with the company Graffiquo.

In practice, the Digital Twin platform converts drone and cloud images into a 3D model of the city, then uses AI to calculate the extent of damage to houses, crops and livestock in the event of a typhoon. Interestingly, the city's disaster management teams were trained remotely, via Zoom calls, to capture images using drones.

In November 2020, the tool was particularly useful after Typhoon Ulysses caused the territory's worst flooding in 40 years. Before this technology, it would have taken days, even months, to assess the damage caused to properties and crops. Here, however, the software quickly calculated that the typhoon had destroyed crops worth an estimated 22 million pesos (around 360,000 euros). Damage to infrastructure amounted to 550 million pesos (around 9 million euros).

The algorithms also identified 7,724 families in need of evacuation, as well as the number of neighborhoods fully or partially submerged. Thanks to the data collected, the authorities were able to immediately distribute a total of 36,844 relief packages.

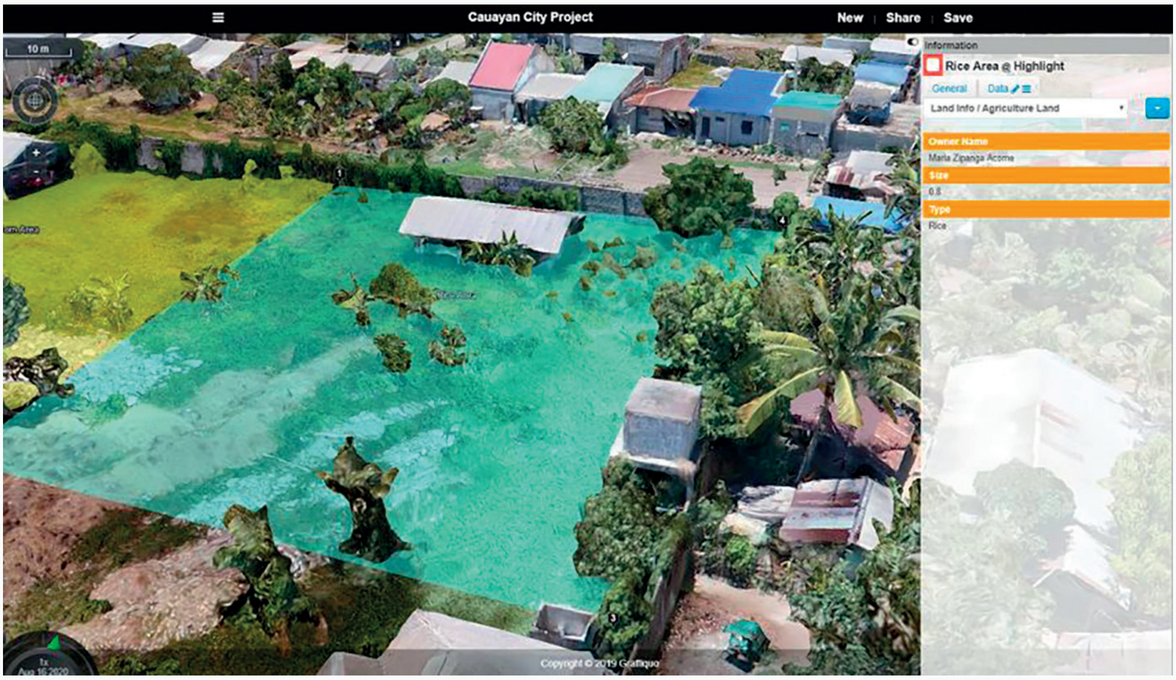


Fig. 13 - Screenshot from Cauyan's Digital Twin (Govinsider, 2021)

CHERNIHIV: POST-WAR RECONSTRUCTION[67,68]

The Ukrainian city of Chernihiv (± 280,000 inhabitants), located 100 km north of Kiev, has been the target of numerous ground and air attacks since February 2022. The city is currently working on a Digital Twin for its reconstruction.

The project comprises two phases:

1. A collaborative analysis of reconstruction costs: the aim of this analysis of satellite data is to automatically detect and highlight impacted areas. It will be completed by field inspections to validate the calculations and prioritization strategy.

2. Virtual reconstruction of the city of Chernihiv for strategic planning: a detailed and accurate digital replica of Chernihiv will be developed for optimizing the city's reconstruction, including the design of new buildings and the organization of urban transport, infrastructure and other services. Planners will be able to simulate all kinds of scenarios in the city before it is physically rebuilt.

The aim of this Digital Twin is not to rebuild the city identically, but to build a more resilient and sustainable city to serve its inhabitants. As a result, different stakeholders will collaborate to test the Digital Twin in different contexts, such as:

- The assessment of existing infrastructure (i.e., water supply and sewage disposal systems);
- The definition of transportation and accessibility requirements;
- The definition of new flood risk mitigation and climate change adaptation measures.

To carry out this work, the Ukrainian government has appointed three French companies: Dassault Systèmes, Egis and B4, which specialize in 3D virtual technologies, construction and engineering respectively.

07

CONCLUSION

Although crises have always existed, today's crises are more complex and variable than in the past. Hence, their management requires greater flexibility from decision-makers before, during and after crises.

The development of the Smart City concept, and in particular the use of IoT and AI to achieve sustainability, has enhanced this flexibility and mitigated the complexity of these emergency situations. An approach based on the harvesting and sharing of data contributes to the planning/preparation, damage control and adaptation of a territory in the face of such crises.

In this context, the Digital Twin has gained in popularity over the last decade. Initially developed in an industrial environment, this technology has now been extended to the context of land use planning and management. The continuous flow of data between a physical twin and its digital counterpart offers both predictive (planning) and reactive (more relevant interventions) benefits. However, the popularity of the term has also led to confusion with other concepts such as the digital model or the digital shadow.

Digital Twin technology has the potential to improve crisis management within territories by providing territorial managers with simulation capabilities and real-time data, enabling them to react quickly and effectively, but also to strengthen stakeholder collaboration.

However, certain limitations remain. First, relevant and useful crisis management within a territory requires a gigantic amount of data to ensure its operation in real time. However, a territory is a complex ecosystem, made up of certain socio-cultural elements that are difficult to quantify. Secondly, the technology of territorial Digital Twins is still in its early stages. Hence, further development is needed to ensure that it becomes operational, particularly in terms of the integration and interoperability of available data. Finally, there is also a real governance challenge. In the future, a subtle balance between the need for transparency in a democratic context and fears about data protection must be found.

In conclusion, Digital Twins certainly have interesting potential in crisis management, and more generally, in the governance of a territory. However, they should not be seen as an ultimate quest, but rather as one option among others, perhaps less data-intensive, to achieve territorial resilience objectives.

SMART CITY INSTITUTE

THE SMART CITY INSTITUTE

The Smart City Institute is an academic institute dedicated to the theme of sustainable and smart territories. It is based on an original partnership between a University (ULiège) and its School of Management (HEC Liège), companies and Wallonia, within the framework of the Marshall Plan 4.0 and Digital Wallonia.

This academic institute is made up of:

- University professors, researchers and project managers;
- Partners:
  - Wallonia actively supports the institute as part of its Smart Région program, an integral part of its Digital Wallonia strategy;
  - The institute is a stakeholder in the Wal-e-Cities/REACT project (European ERDF funding), which aims to support the development of Smart City initiatives across Wallonia;
  - Companies, working alongside cities, research centers and technology start-ups to develop innovative solutions that meet the needs of future generations;
  - The institute is involved in the BOLSTER project (Horizon Europe funding), which focuses on just transition and how to include marginalized communities in this process.
- Experts (in technology, real estate, infrastructure, financial services, energy, project management, etc.) in the development of sustainable, and smart territories.

The Smart City Institute approaches the theme of sustainable and smart territories from a managerial angle (and not just a technical and technological one). Its activities are built around three complementary pillars: research, teaching and support for innovation. These are supported by cross-functional awareness-raising activities.

In concrete terms, the Smart City Institute:

- Publishes scientific articles and research reports on the theme of sustainable and smart territories;
- Studies the Smart City dynamic in Belgium and Wallonia, and its evolution through barometers;
- Develops didactic tools to motivate (Belgian) municipalities to take part in the Smart City dynamic. Among these tools: a collection of Practical Guides and notebooks, templates or even didactic video capsules to guide them step by step in their steps;
- Organizes training activities (e.g., thematic workshops, continuing education) that address the essential managerial issues of the Smart City;
- Organizes an annual event at which academics and practitioners are brought together to discuss and exchange views on the sustainable and intelligent transition of territories;
- Organizes a seminar for 2nd Master students at HEC Liège, in "Sustainability and Smart Territories";
- Supports innovation in the field of Smart Cities.

With regard to its geographical scope, as an academic referent, the Smart City Institute actively contributes to the Smart City and Smart Region dynamic in Wallonia, but it also regularly carries out projects with a national and international vocation.

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