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BLOSSOM: DIGITAL TWIN INTEGRATION IN BIM–GIS ENVIRONMENTS FOR CLIMATE-RESILIENT URBAN CONSTRUCTION

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Abstract

Climate change increases urban exposure to thermal stress, heatwaves and storm water flooding, and requires tools that integrate the built environment, the territory and the climate within a common framework. We present **BLOSSOM**, an **urban Digital Twin** platform based on an **interoperable BIM–GIS** architecture to support resilient planning and construction. The solution combines geometric, semantic and temporal information at different scales (building–district) and integrates static data (BIM models, cartography, digital elevation models and land use) with dynamic data (climate series, thermal observations, future scenarios and simulation results). On this basis, two modules are implemented: **urban heat island** analysis and **storm water flooding** analysis, generating thermal maps, anomaly indicators, heatwave analyses, and depth and flood extent mapping. The platform maintains traceability between data, transformations and results for use by technical staff and decision-makers, and its preliminary application in European pilot cities shows potential for identifying critical areas, comparing adaptation scenarios and prioritizing nature-based solutions.

Keywords: Digital Twin; BIM–GIS; urban resilience; nature-based solutions.

1 Introduction and industrial context

Cities are on the front line of climate change: heat stress, heatwaves and storm water flooding [1] are already affecting comfort, health, energy demand and the operational capacity of infrastructure and public spaces. However, the assessment of these risks is severely limited by fragmented workflows: BIM models, GIS information, climate data and simulation results are typically managed on separate platforms, hindering coherent multi-scale analyses and the translation of technical results into actionable decisions and solutions.

In this context, urban Digital Twins offer an ideal framework for integrating geometric, semantic and temporal information on the built environment with spatial and climate data, enabling decision-oriented analyses. BLOSSOM addresses this need as a European R&D&I project [2] in which CEMOSA is participating, developing a platform that integrates BIM, GIS and historical and projected climate data to support resilient urban planning and construction. This article describes the solution's architecture, the climate models and their preliminary application in European urban cases.

2 Technical framework, approach and objectives

The BIM–GIS integration forms the technical core of BLOSSOM. BIM (Building Information Modelling) provides detailed information on buildings, their structural elements, materials, geometry and semantic properties. GIS (Geographical Information Systems) provides the spatial context necessary to analyze the relationship between the built environment and urban variables such as topography, land use, road networks, vegetation, drainage, administrative boundaries and spatial exposure to climate risks. The combination of both approaches allows us to overcome the traditional separation between the building scale and the urban scale.

The BLOSSOM approach is based on three principles: interoperability (reusing existing information through formats and procedures compatible with real-world workflows), traceability (linking each result to its source data, transformations and modelling assumptions) and decision-making orientation (ensuring that results are not limited to representing data, but help to identify critical areas, compare scenarios and prioritize adaptation measures).

The main objectives of the work are as follows:

1. To describe a BIM–GIS architecture for an urban Digital Twin geared towards climate resilience.
2. To integrate static and dynamic data relevant to the analysis of the built environment in the face of climate risks.
3. Implement models for analyzing the urban heat island (UHI) effect and urban stormwater flooding within the digital environment.
4. Apply the approach to pilot European cities and assess their potential to support resilient urban planning.
5. Identify limitations, validation needs and next steps to evolve towards an operational system providing continuous decision-making support.

Unlike approaches focused exclusively on urban visualization, BLOSSOM aims to articulate a complete analytical workflow: data ingestion, BIM–GIS integration, climate analysis, indicator generation and presentation of results for technical users and decision-makers.

3 State of the art and the need for BIM-GIS integration for climate resilience

The digitalization of construction through BIM has improved the structuring of geometric and semantic information at the building scale, but urban climate risks depend on territorial and environmental processes that extend beyond that scale. For its part, GIS allows for the analysis of spatial phenomena at the urban and territorial scale (topography, land use, networks, environmental variables), although it typically lacks the construction-specific detail found in BIM. BIM–GIS integration addresses this gap and enables the connection of the building scale with the urban context necessary to assess exposure and vulnerability.

In the field of urban heat, it is important to distinguish between the atmospheric urban heat island (air temperature) and the surface heat island derived from surface temperature via remote sensing [3, 5]; the combination of stations/sensors, satellite data and morphological variables improves the spatial characterization of thermal stress [4, 6]. In the case of storm water flooding, current approaches combine 1D drainage models with 2D surface runoff models, which are particularly suitable in dense environments where impervious surfaces and local topography influence flooding. Integrating these results into GIS and linking them with BIM assets facilitates vulnerability analysis at the building scale.

Although platforms exist that integrate data for visualization, limitations persist regarding traceability, validation and the handling of uncertainty. In response, BLOSSOM proposes architecture geared towards interoperability and industrial applicability, adaptable to different levels of data availability [7, 8].

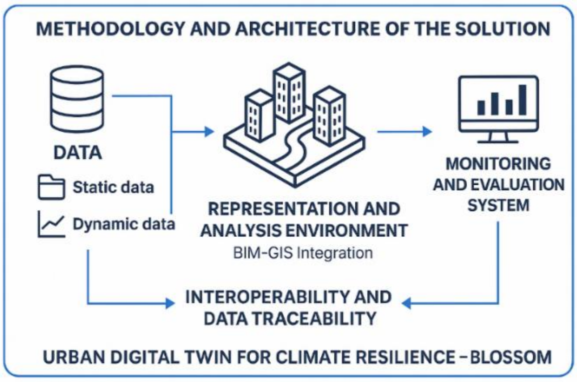


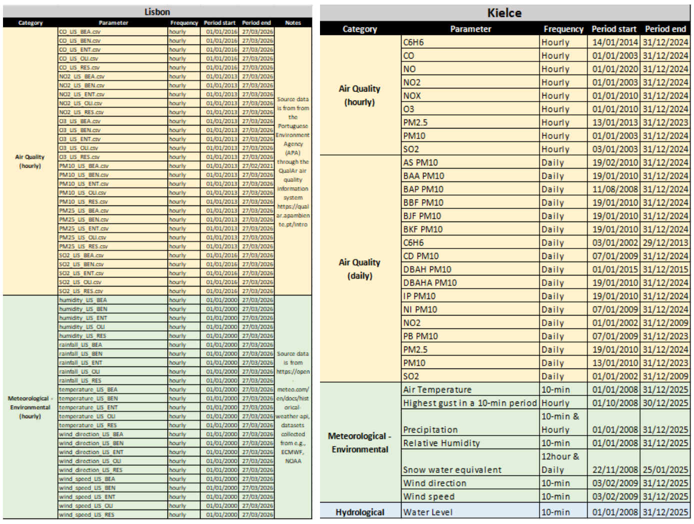
Figure 1: Architecture of the BLOSSOM Digital Twin: integration of static and dynamic data in a BIM–GIS environment for the monitoring, analysis and assessment of urban climate resilience.

4 Methodology and solution architecture

The BLOSSOM methodology combines BIM models, GIS systems and climate data to represent the built environment and assess its exposure to thermal and hydrological risks at different scales, from the building to the urban district.

4.1 First phase: the data layer

The first phase consists of collecting and organizing the information required for the analysis. The data is classified as static and dynamic. Static data includes BIM models, urban mapping, digital elevation models, land use, drainage networks, building geometry and morphological characteristics of the urban fabric. Dynamic data comprises climate series, meteorological observations, surface temperature data, sensor records, future climate scenarios and simulation results [3, 6, 8].



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Category	Parameter	Frequency	Period start	Period end	Notes
Air Quality (hourly)	CO_LIS_BEA.csv	hourly	01/01/2016	27/03/2026	Source data is from from the Portuguese Environment Agency (APA) through the QualAr air quality information system https://qualar.apambiente.pt/intro
	CO_LIS_BEN.csv	hourly	01/01/2016	27/03/2026	
	CO_LIS_ENT.csv	hourly	01/01/2016	27/03/2026	
	CO_LIS_OLI.csv	hourly	01/01/2016	27/03/2026	
	CO_LIS_RES.csv	hourly	01/01/2016	27/03/2026	
	NO2_LIS_BEA.csv	hourly	01/01/2013	27/03/2026	
	NO2_LIS_BEN.csv	hourly	01/01/2013	27/03/2026	
	NO2_LIS_ENT.csv	hourly	01/01/2013	27/03/2026	
	NO2_LIS_OLI.csv	hourly	01/01/2013	27/03/2026	
	NO2_LIS_RES.csv	hourly	01/01/2013	27/03/2026	
	O3_LIS_BEA.csv	hourly	01/01/2013	27/03/2026	
	O3_LIS_BEN.csv	hourly	01/01/2013	27/03/2026	
	O3_LIS_ENT.csv	hourly	01/01/2013	27/03/2026	
	O3_LIS_OLI.csv	hourly	01/01/2013	27/03/2026	
	O3_LIS_RES.csv	hourly	01/01/2013	27/03/2026	
	PM10_LIS_BEA.csv	hourly	01/01/2013	27/02/2021	
	PM10_LIS_BEN.csv	hourly	01/01/2013	27/03/2026	
	PM10_LIS_ENT.csv	hourly	01/01/2013	27/03/2026	
	PM10_LIS_OLI.csv	hourly	01/01/2013	27/03/2026	
	PM10_LIS_RES.csv	hourly	01/01/2013	27/03/2026	
	PM25_LIS_BEA.csv	hourly	01/01/2013	27/03/2026	
	PM25_LIS_BEN.csv	hourly	01/01/2013	27/03/2026	
	PM25_LIS_ENT.csv	hourly	01/01/2013	27/03/2026	
	PM25_LIS_OLI.csv	hourly	01/01/2013	27/03/2026	
	PM25_LIS_RES.csv	hourly	01/01/2013	27/03/2026	
	SO2_LIS_BEA.csv	hourly	01/01/2016	27/03/2026	
	SO2_LIS_BEN.csv	hourly	01/01/2016	27/03/2026	
	SO2_LIS_ENT.csv	hourly	01/01/2016	27/03/2026	
	SO2_LIS_OLI.csv	hourly	01/01/2016	27/03/2026	
	SO2_LIS_RES.csv	hourly	01/01/2016	27/03/2026	
Meteorological - Environmental (hourly)	humidity_LIS_BEA	hourly	01/01/2000	27/03/2026	Source data is from https://open-meteo.com/en/docs/historical-weather-api, datasets collected from e.g., ECMWF, NOAA
	humidity_LIS_BEN	hourly	01/01/2000	27/03/2026	
	humidity_LIS_ENT	hourly	01/01/2000	27/03/2026	
	humidity_LIS_OLI	hourly	01/01/2000	27/03/2026	
	humidity_LIS_RES	hourly	01/01/2000	27/03/2026	
	rainfall_LIS_BEA	hourly	01/01/2000	27/03/2026	
	rainfall_LIS_BEN	hourly	01/01/2000	27/03/2026	
	rainfall_LIS_ENT	hourly	01/01/2000	27/03/2026	
	rainfall_LIS_OLI	hourly	01/01/2000	27/03/2026	
	rainfall_LIS_RES	hourly	01/01/2000	27/03/2026	
	temperature_LIS_BEA	hourly	01/01/2000	27/03/2026	
	temperature_LIS_BEN	hourly	01/01/2000	27/03/2026	
	temperature_LIS_ENT	hourly	01/01/2000	27/03/2026	
	temperature_LIS_OLI	hourly	01/01/2000	27/03/2026	
	temperature_LIS_RES	hourly	01/01/2000	27/03/2026	
	wind_direction_LIS_BEA	hourly	01/01/2000	27/03/2026	
	wind_direction_LIS_BEN	hourly	01/01/2000	27/03/2026	
	wind_direction_LIS_ENT	hourly	01/01/2000	27/03/2026	
	wind_direction_LIS_OLI	hourly	01/01/2000	27/03/2026	
	wind_direction_LIS_RES	hourly	01/01/2000	27/03/2026	
	wind_speed_LIS_BEA	hourly	01/01/2000	27/03/2026	
	wind_speed_LIS_BEN	hourly	01/01/2000	27/03/2026	
	wind_speed_LIS_ENT	hourly	01/01/2000	27/03/2026	
	wind_speed_LIS_OLI	hourly	01/01/2000	27/03/2026	
	wind_speed_LIS_RES	hourly	01/01/2000	27/03/2026	

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Category	Parameter	Frequency	Period start	Period end
Air Quality (hourly)	C6H6	Hourly	14/01/2014	31/12/2024
	CO	Hourly	01/01/2003	31/12/2024
	NO	Hourly	01/01/2020	31/12/2024
	NO2	Hourly	01/01/2003	31/12/2024
	NOX	Hourly	01/01/2010	31/12/2024
	O3	Hourly	01/01/2010	31/12/2024
	PM2.5	Hourly	13/01/2013	31/12/2023
	PM10	Hourly	01/01/2003	31/12/2024
	SO2	Hourly	03/01/2003	31/12/2024
Air Quality (daily)	AS PM10	Daily	19/02/2010	31/12/2024
	BAA PM10	Daily	19/01/2010	31/12/2024
	BAP PM10	Daily	11/08/2008	31/12/2024
	BBF PM10	Daily	19/01/2010	31/12/2024
	BJF PM10	Daily	19/01/2010	31/12/2024
	BKF PM10	Daily	19/01/2010	31/12/2024
	C6H6	Daily	03/01/2002	29/12/2013
	CD PM10	Daily	07/01/2009	31/12/2024
	DBAH PM10	Daily	01/01/2015	31/12/2015
	DBAHA PM10	Daily	19/01/2010	31/12/2024
	IP PM10	Daily	19/01/2010	31/12/2024
	NI PM10	Daily	07/01/2009	31/12/2024
	NO2	Daily	01/01/2002	31/12/2009
	PB PM10	Daily	07/01/2009	31/12/2023
	PM2.5	Daily	19/01/2010	31/12/2024
	PM10	Daily	13/01/2010	31/12/2023
	SO2	Daily	01/01/2002	31/12/2009
Meteorological - Environmental	Air Temperature	10-min	01/01/2008	31/12/2025
	Highest gust in a 10-min period	Hourly	01/10/2008	30/12/2025
	Precipitation	10-min & Hourly	01/01/2008	31/12/2025
	Relative Humidity	10-min	01/01/2008	31/12/2025
	Snow water equivalent	12hour & Daily	22/11/2008	25/01/2025
	Wind direction	10-min	03/02/2009	31/12/2025
	Wind speed	10-min	03/02/2009	31/12/2025
Hydrological	Water Level	10-min	01/01/2008	31/12/2025

Figure 2. Data layers: static vs dynamic and illustration of the data.

4.2 Second phase: BIM–GIS integration

The second phase concerns the BIM–GIS integration environment, which enables construction data from BIM models to be linked with the spatial context provided by GIS systems. This integration is achieved through georeferencing, geometric harmonization and semantic enrichment, so that urban elements can be related to climatic variables and modelling results. The integrated information is managed in a common spatial repository, maintaining traceability between the source data, the transformation processes and the generated results.

4.3 Third phase: the analytical and climate modelling layer

The third phase involves the implementation of the climate models integrated into BLOSSOM. This work considers two main modules: the analysis of the urban heat island (UHI) effect and the mapping of storm water flooding. The first combines satellite data, GIS information and, where available, in situ measurements to assess thermal anomalies, urban-rural differentials and episodes of heat stress during heatwaves [3, 4, 5, 6]. The second uses topographic information, land use, precipitation and drainage network data to generate maps of flood depth, velocity and extent using a hydrological and hydraulic modelling approach [7, 8].

4.4 Fourth phase: visualization and decision-making support

The results obtained are represented through georeferenced maps, climate indicators and outputs that are comparable across scenarios, facilitating the identification of critical areas and the preliminary assessment of urban adaptation measures. Thus, BLOSSOM enables the transformation of heterogeneous urban and climate information into results useful for decision-making, whilst maintaining compatibility with real-world industrial and administrative workflows.

5 Climate Resilience Models integrated into the BLOSSOM Digital Twin

5.1 Urban Heat Island (UHI) effect analysis model

5.1.1 General description and formulation of the model

The BLOSSOM UHI module integrates satellite remote sensing, GIS information, meteorological data and, where available, in-situ urban sensors to characterize urban thermal patterns and their temporal evolution, explicitly distinguishing between surface heat islands (based on land surface temperature) and atmospheric urban heat islands [3, 5, 6] (based on air temperature). This distinction avoids interpreting surface temperature as a direct equivalent of air temperature and allows for the analysis of the relationship between thermal response, urban morphology and land cover within the Digital Twin.

The intensity of the phenomenon is defined as an urban-rural differential:

$$\Delta T_{UHI} = T_{urban} - T_{rural} \tag{1}$$

To assess anomalies against reference climatology, the following formula is used:

$$A(m, y) = T(m, y) - \overline{T}(m) \tag{2}$$

where$T(m, y)$ represents the average temperature for month m in the year y, and$\overline{T}(m)$ is the climatological average for the same month in the reference period.

During heatwave episodes, the excess urban intensity is calculated by comparing the urban-rural differential during the event with the average differential under normal conditions:

$$\Delta UHI_{excess} = UHI_{heatwave} - UHI_{normal} \tag{3}$$

This indicator allows us to assess whether the urban environment locally amplifies heat stress during extreme episodes.

5.1.2 Temporal evolution of the UHI (2000–2025)

This subsection analyses urban temperature trends between 2000 and 2025 using monthly anomalies relative to the reference period and a 12-month moving average to reduce monthly variability and highlight potential trends. **Figure 4** summarizes the evolution of the average urban temperature (top panel) and the UHI (bottom panel), including confidence intervals and the 12-month moving average (MM12m), which allows us to identify the shift towards warmer urban values and a progressive change in the urban-rural temperature difference.

The results described indicate a shift towards more persistent positive anomalies in recent years and a relative intensification of the urban-rural contrast from 2016 onwards; however, the causal interpretation must be reinforced with additional statistical analyses and specific information on land-use changes and morphological evolution of the study area.

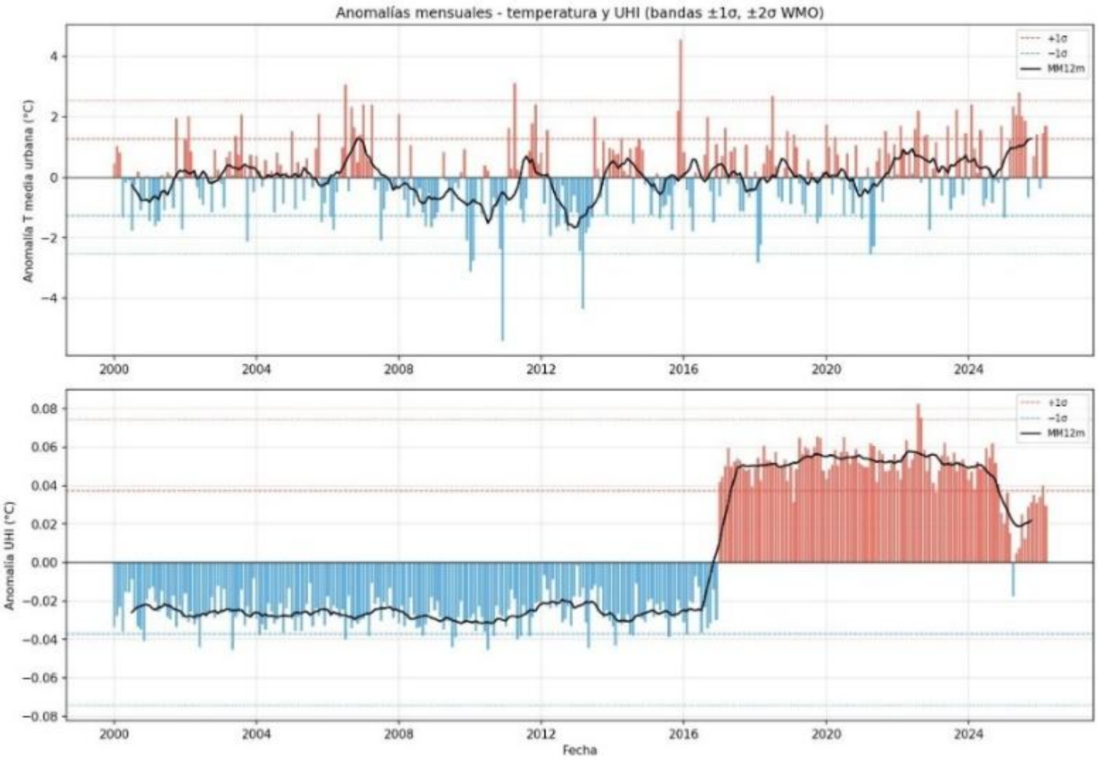

Figure 4. Monthly anomalies in mean urban temperature (top panel) and the UHI (bottom panel), with ±1σ and ±2σ bands according to the WMO methodology and a 12-month moving average (period 2000–2025).

5.1.3 Heatwaves and urban amplification of heat stress

This section evaluates UHI behavior during extreme episodes by comparing the urban-rural differential on normal days versus heatwave days, considering the duration of the event and urban heat excess to detect situations of local amplification. **Figure 5** summarizes the **114 heatwaves** detected (2000–2025), relating duration and UHI excess, and includes a comparison of distributions of the daily average UHI on normal days versus heatwave days.

A trend is observed in recent episodes towards longer duration and more pronounced amplification of the urban-rural contrast, which reinforces the usefulness of the indicator:

$$\Delta UHI_{excess} = UHI_{heatwave} - UHI_{normal} \qquad \text{(see Eq. 3)}$$

to identify periods of greater urban heat stress and guide adaptation strategies (urban vegetation, green roofs, cool pavements and nature-based solutions).

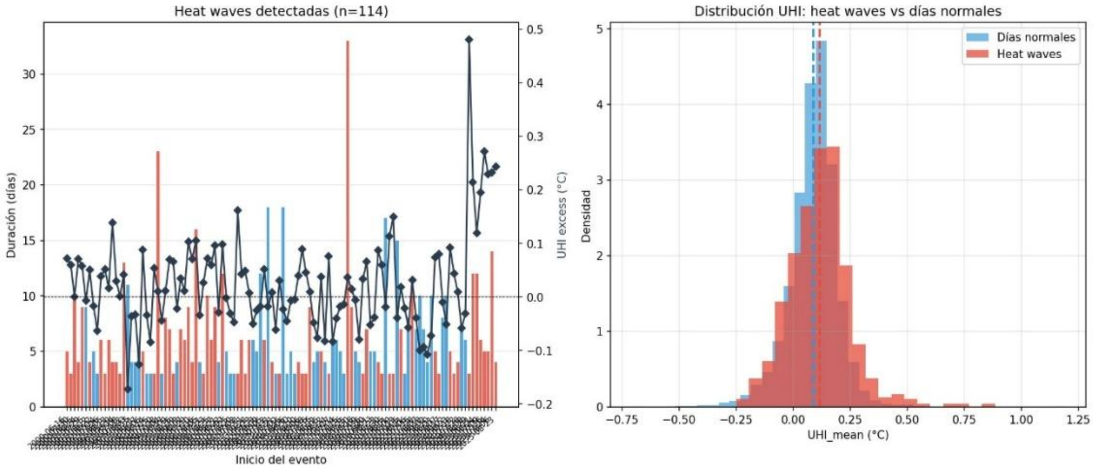

Figure 5. Left: duration in days and UHI excess of the 114 heatwaves detected (red bars: UHIexcess > 0; blue: UHIexcess < 0). Right: density distribution of average UHI on normal days (blue) versus heatwaves (red).

5.1.4 Measurement system and presentation of results

BLOSSOM combines in situ measurement and remote sensing to simultaneously cover the urban area and its peri-urban/rural reference environment. In urban areas, meteorological stations, IoT sensors, surface temperature sensors, thermal imaging cameras or mobile campaigns can be integrated; for the rural/peri-urban reference, reference stations and thermal transects are used to estimate the urban-rural differential, in accordance with equation (1).

The satellite module processes land surface temperature (e.g., Landsat/Sentinel) and uses land cover indices such as **NDVI**, **NDBI** and **MNDWI** to relate thermal response to physical characteristics [3, 6]. The results are returned as georeferenced maps (hotspots, UHI/SUHI mapping), temporal profiles and aggregations by neighborhood/block/land cover type/asset, facilitating their technical interpretation and use in planning.

5.2 Urban flooding mapping model

5.2.1 Overview of the model

The BLOSSOM flood module analyses vulnerability to storm water flooding at the urban and asset levels by combining urban data with high-resolution simulation. It integrates digital elevation models, study area boundaries, precipitation, land use and drainage network geometry (pipes and inspection chambers) to generate cartographic outputs in GIS formats [7, 8].

As a result, the system produces maps of flood **depth, velocity and extent** that enable the identification of exposed critical buildings and infrastructure and the prioritization of adaptation measures, particularly green and blue-green solutions aimed at water retention, runoff reduction and risk mitigation in urban environments [1, 7, 8].

5.2.2 Climate change and precipitation scenarios

This subsection justifies the incorporation of design storms based on climate scenarios, given that urbanization increases risk by expanding impervious surfaces and relying on drainage systems not designed for current intensities, and climate change is expected to intensify extreme precipitation. The scenarios are obtained using a bias-corrected climate projection tool that processes NetCDF files from CORDEX-EUR, comparing the historical model (1970–2005) with observations to quantify the bias and correct future projections (2006–2100), using 1970–1990 as the correction reference.

The tool generates **IDF curves** and hydrographs for time windows (2021–2050, 2041–2070 and 2071–2100) under RCP trajectories, enabling the assessment of rain-induced flood risk throughout the century under different emissions scenarios.

5.2.3 Flood modelling approach

The approach is based on a **1D–2D** coupling: the 1D component simulates the pipe network (including pressurized flow and full pipes) to detect overloads and bottlenecks, whilst the 2D component solves surface flow along streets and open spaces using a shallow water solver. The bidirectional coupling allows the onset of surface flooding to be captured when drainage capacity is exceeded, a critical process in urban rainfall events.

The scope is limited to **storm water flooding** (heavy rainfall that is not absorbed or drained away quickly enough), as this is the dominant mechanism in densely urbanized and impervious areas; river flooding is excluded from the analysis as it depends on river boundary conditions.

5.2.4 Results of the flood maps and their relevance to vulnerability analysis

The main added value of the 1D–2D coupling is the production of flood maps with higher spatial resolution than is typically available at the municipal level: **depth, velocity and extent** maps in GIS formats that enable the quantification of vulnerability and the identification of assets at the building scale. **Figure 6** presents an example of simulated depths for the study area, illustrating an output that can be used directly to delineate affected zones and support the prioritization of investments and adaptation measures.

The integration of these results into the BIM–GIS repository facilitates their subsequent use for exposure indicators (e.g., affected assets) and to guide retention and drainage strategies that help reduce stormwater runoff and the risk of flash flooding in the urban center [1, 7, 8].

Figure 6. Simulated surface water depth across the entire study area.

6 Use cases and application of climate models

To assess the applicability of the BLOSSOM approach in real urban contexts, use cases are organized into Front Runner Cities (FRCs) and Follower Cities (FLCs). The former act as lead pilots for the deployment of climate models integrated into the Urban Digital Twin, whilst the FLCs allow for the analysis of the system's replicability in cities with different scales, climatic conditions, data availability and urban constraints.

Table 1. BLOSSOM pilot cities (FRC and FLC): urban-climate context and main application of resilience models.

Type	**City**	**Focus in BLOSSOM**
FRC	Birmingham (United Kingdom)	Heat and rainfall stress; green-blue infrastructure.
FRC	Kielce (Poland)	Urban morphology, land sealing and surface runoff.
FRC	Lisbon (Portugal)	Extreme heat/precipitation scenarios and urban adaptation.
FLC	Newham (United Kingdom)	Transferability of UHI/flooding models from Birmingham.
FLC	Aarhus (Denmark)	Hydrological risk; urban retention and drainage (strategies).
FLC	Parma (Italy) + Alentejo–Évora (Portugal)	BIM–GIS flexibility in contexts with heritage/regulatory constraints.

This structure allows climate models to be applied in pilot cities with greater data availability and, subsequently, to analyze their transferability to other European urban environments. Taken together, the use cases provide the operational framework for evaluating BLOSSOM's performance as a tool to support climate-resilient urban planning and construction.

7 Implementation and preliminary results

The preliminary implementation of BLOSSOM has demonstrated the feasibility of integrating BIM, GIS and climate data within a common environment geared towards urban resilience. The results obtained should be interpreted as an initial functional validation of the approach, not as a definitive validation of all climate models.

7.1 UHI model results

Preliminary results from the UHI model show a gradual widening of the urban-rural temperature gap in recent years, particularly since 2016. The temporal evolution of temperature anomalies makes it possible to identify periods of prolonged warm conditions and to detect extreme events associated with heatwaves. Furthermore, the analysis of heatwaves indicates that recent episodes tend to be longer in duration and exhibit greater urban heat amplification. This information is useful for identifying areas where thermal adaptation strategies can yield the greatest benefits, particularly in areas with high urban density, low vegetation cover or a vulnerable population [4, 5, 6].

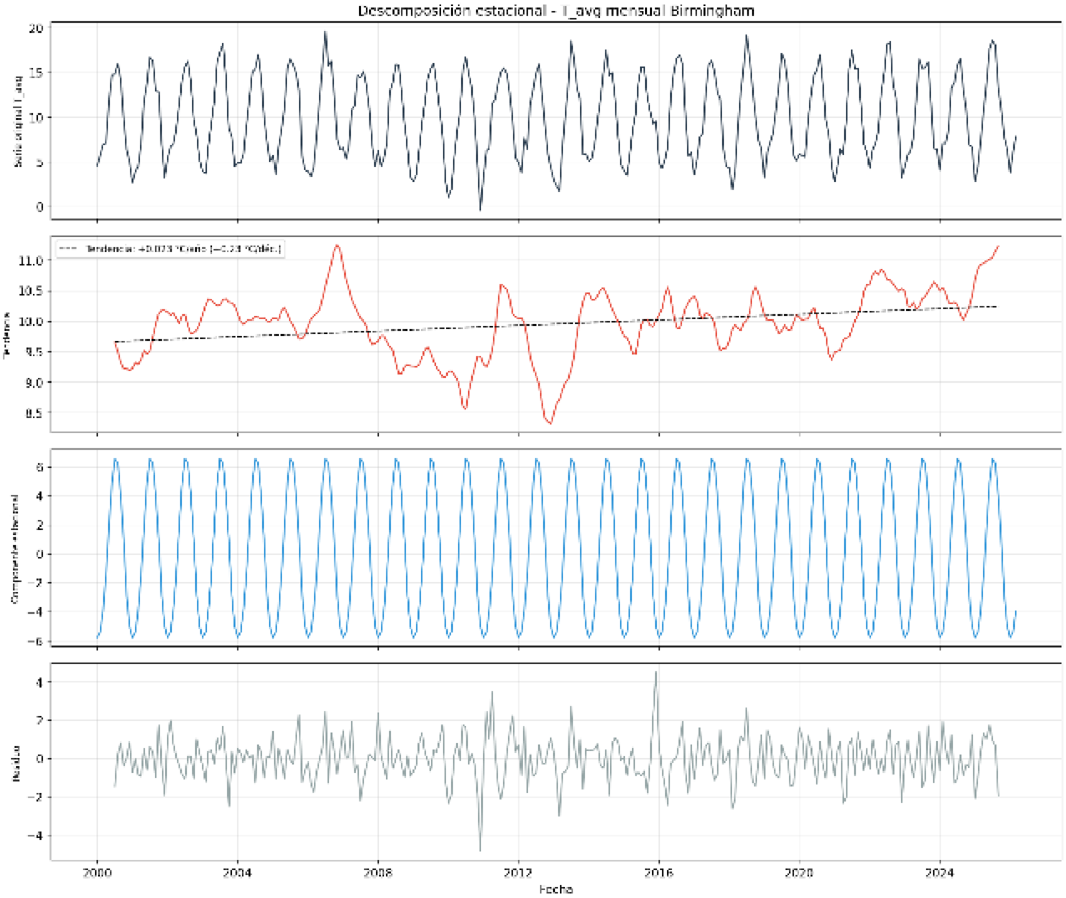

Figure 7. UHI intensity and evolution of urban temperature anomalies (2000–2025) in the pilot city of Birmingham.

7.2 Flood modelling results

The storm water flooding model enables the generation of maps showing flood depth, velocity and extent with sufficient resolution for urban analysis. These results improve the identification of exposed buildings and infrastructure and provide a basis for prioritizing adaptation measures.

The integration of flood mapping with the BIM–GIS repository enables the calculation of exposure indicators at the asset level, such as the number of affected buildings, maximum depth per building, area of flooded public space, or the proximity of critical infrastructure to areas of water accumulation [1, 7, 8].

7.3 Preliminary assessment of BLOSSOM’s added value

The preliminary results confirm the viability of the approach: BLOSSOM enables the integration of heterogeneous data into a coherent architecture and facilitates the joint analysis of thermal and hydrological risks, which are usually addressed independently. The results are spatially explicit and directly interpretable by technicians, public authorities and stakeholders involved in urban planning.

However, the system must continue to evolve to incorporate continuous validation, data automation, model calibration, uncertainty analysis and systematic comparison of adaptation scenarios.

8 Conclusions and next steps

This paper presents BLOSSOM, an urban Digital Twin platform designed to integrate BIM, GIS and climate models to support climate-resilient planning and construction. The proposed architecture enables the connection of the building scale with the urban scale, combining information on the built environment, spatial data and climate variables within a common analytical framework.

Preliminary results demonstrate BLOSSOM’s potential to identify critical areas, evaluate scenarios and prioritize adaptation strategies. In particular, the urban heat island analysis enables the detection of thermal anomalies and the amplification of stress during heatwaves, whilst the storm water flooding model allows for the mapping of depth, extent and exposure of urban assets.

Future work includes extending model validation, incorporating new case studies, improving data automation, and including uncertainty metrics and indicators that are comparable across cities. BLOSSOM aims to become a tool for real-world use: transforming urban and climate data into concrete information for those who design, plan and build the cities of the future.

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