A Methodological Approach to represent Climate Change Impacts on Buildings

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The main aim of the research is to propose a methodological approach to permit an assessment of the climate change impacts on buildings and their lifecycle, also by making the process computable.

Climate change is a problem that designers and professionals in the AEC sector have begun to tackle more consistently and intensively in recent years. From the perspective of building sustainability in its entire life cycle, in fact, the problem of changing conditions in which the building 'lives' cannot be ignored, since many times they can be completely different from those in which it was designed and built.

Recent research has shown how the use of BIM models, more systematic and relevant in the last few years, can be one of the best strategies for the management of new constructions and renovations in the different phases that characterise a building, from its design to its realisation and up to its renovation or change of use. That is not only due to the accurate 3D model, but especially thanks to the considerable availability of data and information related to the Building Object in question. The management of the simulation through a game engine, on the other hand, allows the user to live a direct experience in real-time.

In this research, therefore, through the use of BIM models (Autodesk Revit) as a database (DB) of building-related data and combined and enriched with those obtained from other DBs from case studies and literature, it is possible to obtain a useful database which allows, through algorithms implemented within a game engine (Unity 3D), to visualise existing problems according to the date of construction and/or renovation.

Keywords: *Climate Change, BIM, Impacts, Building, Game Engine*

INTRODUCTION

In the 1992, the UN Intergovernmental Panel on Climate Change (IPCC) has defined climate change in its reports as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer" (IPCC-AR5, 2018), while the UNFCCC (United Nations Framework Convention on Climate Change), ratified by the countries participating in the COP (conference of the parties), through Article 1, further contributes to the definition of Climate Change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". (UNFCCC, 1992)

As the IPCC declared in August 2021, "since systematic scientific assessments began in the

1970s, the influence of human activity on the warming of the climate system has evolved from theory to established fact." (IPCC-AR6, 2021)
Construction activities, regardless of whether they involve new construction or the maintenance of an existing building object, turn out to be one of the main activities in which human beings interfere and modify the environment in which they live. These activities have a significant impact caused essentially by high energy consumption and considerable greenhouse gas emissions, in particular as a result of the production, transport of building materials, and waste management. (IEA, 2018; NASA, 2020)

Considering the importance of the construction sector for climate change and, vice versa, the impact of the latter on buildings, the main aim of this research is to propose a methodological approach to evaluate the impacts of climate change on buildings and their life cycles. Moreover, by making this approach computable through simulations in the Game Engine environment and managing information obtained from databases in the literature or from BIM models, it will be able to support the various professionals involved in the AEC sector, seeking to optimise analysis times and reduce evaluation errors.

PROBLEMS AND STATE OF ART

The IPCC through its reports, specifically the one of 2014, has highlighted the main climate changes and their consequences. Although the impact due to climate change is an issue that is properly studied and analysed as a whole, it is in the construction sector, and even more specifically on buildings. In this case, the greatest impacts may be caused by certain climate changes, such as rising global temperatures, increasing heat waves, and an increase in the frequency and intensity with which extreme weather events occur, with subsequent greater temperature fluctuations. (IPCC-AR5, 2014)

The RCP8.5 scenario, also known as the "business-as-usual" scenario, is one of the Representative Concentration Pathways (RCP) developed by the IPCC. It represents a future in which greenhouse gas emissions continue to increase at the current rate, leading to a global temperature increase of 4.5°C by 2100 compared to pre-industrial levels.

Significant impacts on the environment would occur under this scenario, including sea level rise, more frequent and severe heat waves and droughts, increased frequency of extreme weather events such as hurricanes and floods, and loss of biodiversity. It is important to note that the RCP8.5 scenario is considered a worst-case scenario and is not a forecast of the future. It is used as a tool to assess the potential climate impacts of different levels of greenhouse gas emissions. (MASE, 2022)

Efforts to reduce GHG emissions and move to a low-carbon economy are critical to avoiding the worst impacts of climate change.

The first agreement that introduced the first legally binding emission reduction targets for developed countries was the Kyoto Protocol in 1997. The Paris Agreement, signed by 196 countries in 2015, has the goal of limiting global warming to well below 2°C compared to pre-industrial levels and continuing efforts to limit temperature rise to 1.5°C. (European Council, 2022)

In Italy, as well as in the rest of the world, man's primary need to occupy land with new buildings has been overtaken, for several years now, by the renovation and reuse of existing buildings in favour of a more sustainable architecture, whose ultimate goal is to improve the performance and comfort within these buildings.

In Italy, the residential building stock requiring renovation is over 50%, with a difference between the north and south of almost 10 percentage points; in the north, it is about 48%, while in the south, it is about 57%. (IEE Project EPISCOPE, 2006)

Analysing solely the hospital building sector, on the other hand, the percentages rise to over 80%. This is due to the fact that the operating theatres in these facilities—almost 90 percent of the hospitals were built before 1910—are substandard compared to the minimum requirements of current regulations. (Moscato et al., 2007)

In recent years, within the construction sector, sustainability and climate change have increasingly become binomials that are almost impossible to treat separately. (Pelsmaker et al., 2022; Zhai, Helman, 2019; Andrić Koc, Al-Ghamdi 2019)

To realise buildings that can be qualified as sustainable, climate change issues cannot be excluded. For this reason, in 2022 the European Commission, "committed to supporting the integration of climate resilience considerations in the construction and renovation of buildings", in collaboration with Ramboll and CE Deft, respectively a Danish consultancy company and a Dutch research and consultancy centre, launched "a study to collect and synthesise existing methods, specifications, best practices, and guidelines for climate resilient buildings". The final purpose of this collaboration is the realisation of the EU-level technical guidance on adapting buildings to climate change, whose main objective is to define and mitigate the priority risks that may affect buildings due to climate change, in order to achieve an in-depth review of vulnerability and climate risk assessment methodologies (see figure 1, elaboration from the original RAMBOLL infographic), taking into consideration "any variation needed for different scales of buildings, from the individual to the whole block, providing comments on the impact, user-friendliness, and synergies/conflicts of the methodologies". (CE, Ramboll, 2022)

In 2013, several European universities, through the European Union's Intelligent Energy Europe Programme (IEE), started to tackle the issue of building sustainability in the management of the existing building stock. In particular, the main objective of the TABULA project was to "make transparent and efficient energy redevelopment processes in the European housing sector" by classifying the different building types present in the main European cities, developing "building stock models to evaluate renovation processes and predict future energy consumption" (see figure 2).
The efforts of these researchers have successfully led to the definition of specific indicators that can be used to promote a significant improvement in the quality of renovations, especially with regard to the energy aspects of buildings, from compliance with regulations to the monitoring and management of the energy-saving and upgrading processes. The effects of climate change have an impact on the

Figure 1
Priority hazards affecting buildings

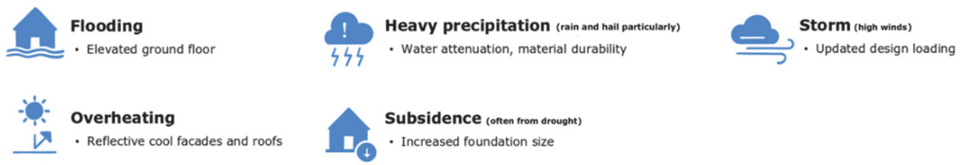


Figure 2
Building stock models from Tabula Project

	DESCRIPTION	IMAGE	HIGHEST SPREAD PERIOD		U [W/m²K]
	Concrete masonry (30 cm)		1955	1975	2,80
	Hollow-core masonry with bricks (30 cm), low level of insulation		1976	1990	0,78
	Hollow-core masonry with bricks (40 cm), low level of insulation		1976	1990	0,76
	Hollow brick masonry (25 cm), low level of insulation		1976	1990	0,80

materials used to construct buildings. For example, when analysing the Italian situation before 1970, there is no evidence of the use of insulating materials inside or on the surface of external walls. (IEE Project EPISCOPE, 2006)

A building constructed in an area characterised by a Mediterranean climate did not need insulating materials to protect it from high-temperature fluctuations or extreme temperature rises. Building in this way might have been fine 50 years ago, but today, with a progressive desertification process underway in the southern regions of Italy, it absolutely must be reconsidered. The same can be materials used to construct buildings. For example, when analysing the Italian situation before 1970, there is no evidence of the use of insulating materials inside or on the surface of external walls. (IEE Project EPISCOPE, 2006)said for northern Italy, where the effects of this process, on the one hand, have increased the number of hot days but, at the same time, have also increased the thermal variation. Italy has suffered numerous floods in recent years, many of them as a consequence of climate change. Taking into consideration the year of the building's construction, some of the building materials used to build it need to be renewed as they have completed their entire life cycle. The other building materials, which theoretically would not yet have completed their life cycle but were also chosen at the design stage to respond to specific climatic conditions no longer found there, could turn out to be incorrect, i.e., no longer able to guarantee adequate thermal comfort to its occupants, or even damaging and harmful to the building itself and its occupants (e.g., creation of humidity and condensation with related deterioration and/or creation of mould). (Tuomi et al., 2000; Kon, Caner, 2022)

For several years, research has been directed toward an increasingly complete integration of BIM models and the information therein with simulation environments developed through Game Engine software. (Coraglia, 2022; Yan et al., 2011) Among the reasons why researchers have ventured into this field is the desire to support the various professionals involved (e.g., architects, engineers, managers, educators) through 360-degree interactive and immersive experiences directly in the model, within which it has been possible to include, for example, accessibility and pathway testing, and simulations of fire evacuation drills. (Linehan, Andress, 2013; Rajendran, Pathrose Gomez, 2012)

The increasing widespread use of BIM technology by students and professionals has simplified both the management of ongoing maintenance and renovation activities of complex structures (e.g., hospitals, airports) through better

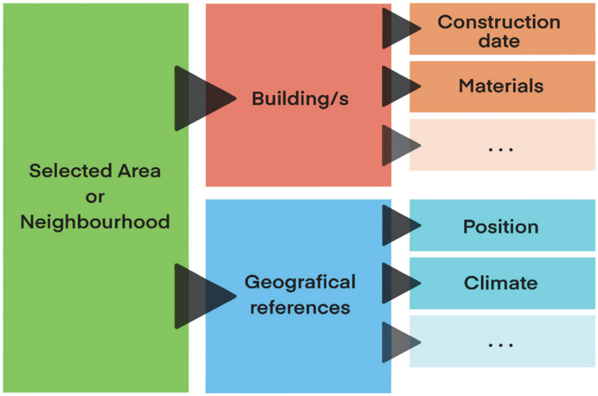


Figure 3
Breakdown of the problem into variables

cost management and related time reduction. (Doumbouya, Gao, Guan, 2016; Ma et al., 2018; Alizadehsalehi, Hadavi, Huang, 2020)

Following the analysis of the state of the art and of the main problems related to the impact of climate change on the AEC sector, this research aims to propose a methodological approach that involves both the data present in the literature, including those obtained from the collected BIM models, and the simulations in the Game Engine environment, so as to be able to support the various professionals involved through the improvement and reduction of the time and errors that may occur during the phases of identification and evaluation of the aforementioned impacts on buildings and the materials that compose them.

METHODOLOGY

The aim of this Research is to support professionals in evaluating and choosing the best renovation strategies to be implemented according to the climatic changes experienced by the affected buildings. Reducing costs and possible assessment errors due to the amount of data to be analysed, as well as reducing the timing of intervention in the design of renovation activities for buildings of different periods, turns out to be a key objective.

Knowledge base

The methodology chosen for this research involves, as a first step, breaking down the problem into variables so that each part can be analysed in more detail and the different data collected can be managed more effectively and specifically.

Although our final goal is focused on the building and its materials, it is necessary to "zoom out" and examine the area/neighbourhood in which the building object is located. This step, on the one hand, allows us to acquire geographical references (e.g., location, temperature, humidity) and, on the other hand, data on the different buildings, in which case the usefulness becomes greater in the case of renovations involving several building objects. The data that we can obtain on the building and in which we are interested is mainly the date of construction and the list of construction elements used to build it, such as the type of windows, external masonry (further subdivided into the external finish, bricks, and insulation material), balconies, railings, and roof finish. Of course, a building does not only consist of these elements, but for our research, having to deal mainly with problems due to climate change, we focused our analysis on those components that, exposed to external environmental conditions, can be most affected by climate impacts. Figure 3 shows the variable breakdown obtained.

Breaking down the problem into an integrated system of variables makes it possible, on the one hand, to better understand the set of parameters representing them and the mutual interferences between them, and on the other, to address them through the use of artificial intelligence technologies, modelling and simulation. Once the problem has been broken down into variables, each of these must be analysed more in depth through the collection and management of relevant data that allows specific solutions to be identified that can then be integrated into the overall solution to the problem.

Data collection is therefore a fundamental step in the development of the knowledge base required to implement and execute subsequent simulations. In our specific case, data collection is divided into three areas of interest:

1. Building data
2. Climate data
3. Pathogenesis data

Building data.

The building data has been obtained from various sources:

- *BIM models*, which allow the knowledge of data concerning material schedules, geometries, and, when available, construction/reconstruction dates of both the entire building and/or individual construction elements. NB: In our case, it was possible to implement a database using the data and models collected during the internship at the international integrated engineering company 3TI Progetti Srl. (3TI Progetti Srl, n.d.)

- *Literature and/or third-party databases*, which provide different information depending on the type of data processed. For example, among the data managed and made available by the official website of the city of Vienna, it is possible to obtain the date of construction of each building and its geometry. (Wien Stadt-klima, n.d.)
- *Databases from Research Projects*, also in this situation the data available depends on the type of analysis carried out by the researchers. In this specific case, the data were obtained from research projects conducted by researchers from the Department of Architecture of the Alma Mater Studiorum-University of Bologna, who had access to the SUE (one-stop shop for construction) databases of the Municipality of Bologna. This database made it possible to collect data on the date of construction and geometry of some areas of the capital of the Emilia Romagna region. (Costantino, Benedetti, Gulli, 2022; Benedetti, Costantino, Gulli, Predari, 2022)

Climate data.

The data collected from literature and from databases of other research projects, where necessary, can be expanded and enriched by means of the TABULA/EPISCOPE Project tables (IEE Project EPISCOPE, 2006), which, for example, allow the masonry type to be deduced from the data concerning the building type and the relative decade of construction (see Figure 2).

As far as climate data is concerned, on the other hand, databases of national research institutions or municipal databases are the primary sources from which they are extrapolated.

For Italy, the databases of the Institute of Atmospheric Sciences and Climate of the CNR (National Research Council) (ISAC-CNR, n.d.) and data held by ISPRA (Italian Institute for Environmental Protection and Research) were queried. In both cases, the data related to the time period from 1961 to the present and concerned, e.g., average temperature (day, month, and year), heat waves (in days), and temperature history. For the city of Vienna, meanwhile, the data are available on the city's official website thanks to the data collections made available by GeoSphere Austria, which since January 2023 has brought together the databases of the former Central Institute of Meteorology and Geodynamics (ZAMG) and the Federal Institute of Geology (GBA), with a total of 344 years of experience in the field of meteorological and geophysical data management. (Wien Stadt-Wetter, n.d.; Geosphere, n.d.)

Pathogenesis data.

The third area of interest is focused on data concerning possible pathogenesis and deterioration of construction elements and materials during their entire life cycle.

As stipulated in European Regulation 305/2011, every construction material and product must be CE marked. This procedure does not give a real expiration date to the building product or material but obliges manufacturers of building materials to provide detailed information on the performance of their products, including durability and resistance performance. (CE Marking, n.d.; EU Lex 305, 2011)

The data sheets compiled by the Tabula project made it possible to obtain useful data to form databases on the types of deterioration and pathogenesis that can affect the materials and elements used in buildings. In order to optimise the analyses, it was decided to restrict the period of interest to the decades from 1940 to 1970 (expanding where necessary to the extremities 1930 and 1980), as these decades are characterised by well-defined types of buildings and building materials compared to those used until the beginning or end of the 20th century. (IEE Project EPISCOPE, 2006)

Simulation

The second phase is Simulation, within which two distinct phases take place:

- Data entry phase, all data that has contributed to the knowledge base is implemented within the game engine.
- Computing phase, through specific algorithms, the received data and their interactions are handled and processed within the game engine environment.

Visualisation

Through a graphic interface, the user can visualise, in real-time, the results obtained from the simulation phase. In this case, the game engine will bring to the user's attention, by highlighting with the colour red to recall the alert situation, the building or series of buildings affected by materials or building elements affected by pathogenesis and deterioration due to the natural end of their life cycle or to the impact generated by climate change.

Figure 4 shows the conceptual framework supporting this research.

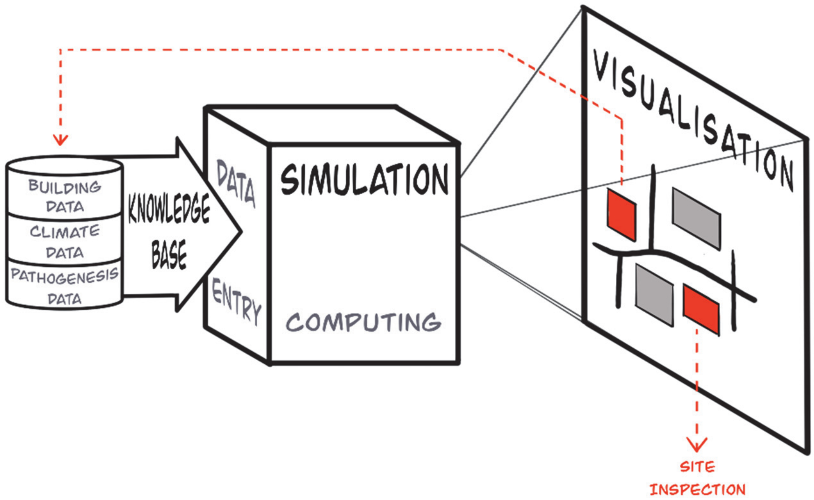
APPLICATION SCENARIOS

The described methodological approach will be validated through simulations of different case studies. These will be defined and selected from the models and data provided by the databases that contributed to the definition of the knowledge base, specifically:

1. Case study on buildings exposed to a Mediterranean climate in Rome
2. Case study on buildings exposed to a Continental climate in Bologna
3. Case study on buildings exposed to a mixed Oceanic-Continental climate in Vienna

These simulations have the aim of supporting the various AEC professionals, especially those involved in renovation and maintenance activities, in identifying buildings whose materials and/or building elements have reached the end of their life cycle or are subject to pathogenesis caused by the impacts of climate change.

Figure 4
Conceptual Framework



CONCLUSIONS AND FUTURE DEVELOPMENTS

The main aim of this research is to develop a methodological approach useful to support professionals in the construction sector involved in renovation and/or retrofitting activities by highlighting the impacts of climate change on the buildings under analysis. Through the user-friendly graphic interface developed in the game engine environment, the professional will be able to verify at a qualitative level the current state of preservation of the building(s) in relation to the natural conclusion of their life cycle or the impacts due to climate change.

As illustrated in red in Figure 4, based on the data entered in the game engine, the user will be able to verify the presence of any deterioration through visual alarms useful for highlighting buildings requiring further inspection, which will be possible by (re)linking to the building's BIM model or related data, where present. In the event of a lack of useful data, the graphical interface will advise the user to carry out an on-site inspection.

Among future developments, some of which are already in progress, the main one is certainly the inclusion within the game engine environment of the predictive layer for the management of climate change simulations. On the one hand, through the application of Monte Carlo models, it will be possible to simulate and predict in real-time the evolution of impacts caused by climate change over time. On the other hand, we planned to evaluate the effectiveness of any proposed solutions through the use of the sandbox method, which, within the simulation environment of the game engine, will allow this evaluation based on different future scenarios.

In addition, we are considering increasing the knowledge base through the inclusion of a database containing data on the urban scenarios hosting the buildings under analysis (e.g., the presence of tree-lined avenues, building orientation) in order to make the simulation more detailed.

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