sustainability

MDPI

Article

Optimizing the Sustainable Aspects of the Design Process through Building Information Modeling

Clara Vite * and Renata Morbiducci

Department of Architecture and Design, University of Genoa, Stradone S. Agostino 37, 16123 Genoa, Italy; renata.morbiducci@unige.it
* Correspondence: clara.vite@unige.it

Abstract: More than thirty years after the definition of sustainable development, the commitment to protect the planet has been renewed, and all sectors of human activity have been called to contribute to this critical challenge of our time. Therefore, the construction sector can also make an essential contribution. Designers are called upon to modify their actions to consider the environmental, social, and economic impacts during the entire life cycle of construction. The digital revolution could be a suitable opportunity for a profound renewal oriented towards sustainability. The new digital technologies and the increased computing power are useful for managing the increasing complexity in current projects and supporting collaboration between the many experts involved. The presented research analyzes the current state and identifies the signs of change and the cues to imagine possible virtuous complicity between sustainable development goals and the digital revolution's potential, which is supported by the operational features of optimization methods. Based on this in-depth analysis, an operational strategy has been defined, combining the three macro themes usually treated separately—sustainability, digitization, and optimization. This strategy can be a valuable tool to guide designers in optimizing the process of sustainable design and regenerative construction.

Keywords: sustainable architecture; sustainable design; innovation in building technologies; construction 4.0; digital revolution; Building Information Modeling; optimization; decision-making; integrated and sustainable approach

Citation: Vite, C.; Morbiducci, R. Optimizing the Sustainable Aspects of the Design Process through Building Information Modeling. *Sustainability* **2021**, *13*, 3041. https://doi.org/10.3390/su13063041

Academic Editor: Giuseppe Margani

Received: 31 December 2020
Accepted: 1 March 2021
Published: 10 March 2021

1. Introduction

More than thirty years after the definition of sustainable development [1], and the first forecasted scenarios for our future, the expected impact on the environment due to the evolution of human civilization is unchanged, if not worsened. Agenda 2030 renews the commitment to "protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations" [2].

Rising global temperatures, rising sea levels, and desertification are some of the most worrying impacts of climate change that compromise the survival of many biological systems on our planet. These must be added the inevitable effects due to the increase in world population [3] and the growth of existing urban areas or the creation of new ones [2].

Therefore, climate change mitigation is one of the most significant challenges of our time, and all sectors of human activity are called upon to make their contribution. The construction sector can make an essential contribution because its environmental, social, and economic responsibilities and implications are significant. There is a renewed call for an approach that considers environmental impacts, from the design phase to the demolition/recycling phase. Designers are called to move in a context for a resilient future where resources (energy, raw materials, economic, etc.) are limited and where we must, therefore, try to make optimal use of them.

The construction sector is facing another major challenge: Entering the age of digitization, with rapid alignment with industry 4.0 [4] principles in production, construction, and management processes. It is a challenge that involves all areas and all companies, from the smallest to the largest, offering new growth and innovation opportunities. It is an opportunity to renew a sector that has always been a protagonist of "delayed innovations" compared to other human activity fields. The need for safety, procedural checks, and specific regulations, the limited diffusion of "novelties", but above all its intrinsic inertia, due to massive and traditional connotations, have regularly characterized this sector, especially in countries like Italy so rich in history.

The situation is evolving in a new and fast way linked to two new conditions: On the one hand, there is an increasing demand for innovative "tools" that lead to design their intelligent use for buildings, districts, and entire cities; on the other hand, there is a growing need to create—or recreate—the conditions of well-being for man and to contribute to environmental quality actively.

The digitization of the construction sector is only just beginning. "Small improvements will translate into substantial benefits for companies and for society" [5], including increased productivity, management of processes with greater complexity, time optimization, increased quality, and safety, etc. Digital technologies and methodologies are multiple and apply to all phases of the construction process: From planning, design, and construction to demolition or recycling/reuse. In many contexts related to construction, the digital transformation's focus coincides with a specific "environment", BIM (building information modeling), a parametric system able to ensure the full sharing of information of the entire process and coordination between all people involved.

Building information modeling is not only technological innovation but is a new approach to the entire life cycle of construction, capable of generating a real cultural revolution in our sector. The key is the information that each person involved in the process generates, manages, and stores, and which is now collected and put into a single central database. Thanks to the renewed dynamics of collaboration and dialogue between all participants, BIM can generate multiple benefits for the entire construction chain regarding productivity, quality, and safety.

The presented research analyzed the construction sector's current state and identified the signs of change for a comprehensive sustainability-oriented renewal. The research is structured on three key topics: Sustainability, digitization, and optimization. The synergy between all these studied elements generated reflections that were then translated into an operational strategy that could be a concrete demonstration of what is proposed and offered to designers. The last part of the article reported some applicative examples of the procedure developed to show the possible uses in the case of different objectives, digital models, tools, and calculation methods.

2. Research Background

2.1. Sustainable Development

Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. This definition, developed in 1987, and the scenarios on our planet's future, elaborated in the following years by international researchers and international bodies, seem more pertinent and appropriate to the current situation. We are facing a situation where "it's clear that business as usual simply isn't good enough anymore. We must do more—much more—in areas related to mitigation, adaptation, and finance to support all this work. And we must do it quickly" [6].

The climate is changing globally, and according to the IPCC—Intergovernmental Panel on Climate Change [7], this is mainly due to greenhouse gas emissions from human activities, from the use of fossil fuels, agriculture, and various land use. Climate change has a variety of impacts on our health, ecosystems, and economy, often in interaction with other factors.

In 2018 the IPCC issued a special report [8] on the impact of global warming of 1.5 °C, request by the 21st Conference of the Parties of the United Nations (COP21) [9]. The report provides a graph showing global warming from 1960 to 2017 and then estimates the future trend up to 2100. More specifically, the study notes that human activities have caused about 1.0 °C of global warming above pre-industrial levels, with a probable range from 0.8 °C to 1.2 °C and that the 1.5 °C will almost certainly be reached between 2030 and 2050 if it continues to increase at the current rate.

In the 2019 "Emission Gap Report" [10] prepared by UNEP, similar results are reported. Greenhouse gas emissions have increased steadily over the last 30 years at a rate of 1.5% per year over the last decade. Between 2014 and 2016, there was a brief sign of stabilization, and then in 2018, the record level of 55.3 Gt-CO2e was reached. The most significant contribution is fossil CO2 emissions from energy use and industry.

All these studies outline future scenarios where it is highly likely that the situation will get worse with this trend, and impacts will become more severe in the coming decades. Hence, the need to reduce greenhouse gases globally substantially to mitigate the impacts of climate change. At the same time, there is also a need to adapt, as it is impossible to prevent all impacts.

In response to these needs, there are two main drivers. On the one hand, citizens demand evidence and proof of quality and environmental performance of the products and processes they use and buy. On the other hand, governments have reviewed—and will continue to do so for the foreseeable future—their current plans and outlining long-term strategies to promote societal growth in all sectors under the sustainability umbrella.

All sectors are called upon to play their part, including the construction sector, which can substantially contribute as its environmental, social, and economic responsibilities and implications are significant. In fact, in the 2030 Agenda, there is an objective entirely dedicated to "Sustainable Cities and Communities".

The world population will grow significantly to almost 10 billion people by 2050 [11]. Today, half of humankind, about 3.5 billion people, live in cities, and by 2030, people are expected to move from the countryside to cities, and around 60% of the world's population will live in urban areas [2]. 95% of urban expansion in the coming decades will take place in developing countries, and today, there are still more than a billion people living in slums, and the number, rather than decreasing, is continuously increasing. Therefore, it will become increasingly important to ensure access to adequate, safe, and affordable housing and essential services for all.

The construction sector's economic importance is based on the total annual turnover, which represents about 6% of world GDP [12]. Specifically, it accounts for 5% of total GDP in developed countries, while for developing countries, it is over 8% of total GDP. The industry is expected to grow significantly in the coming years to reach an estimated $15 trillion revenue by 2025, creating new jobs and positions. To date, it is estimated that more than 100 million people are already employed in this sector worldwide.

Finally, given the characteristics and products of this industry, it has the highest consumption of resources, raw materials, and waste production. Therefore, it has a substantial impact on the environment. It is estimated that it uses about 36% of total energy consumption with the consequent high release of CO2 [13]. About 50% of solid waste in the United States comes from construction and demolition [14]; this value in Europe is between 25 to 40% [15,16], and about 41% in Italy [17].

All these data, gathered from the most recent reports and statistics available, show that the strategies and plans outlined in past years have not led to the hoped-for improvement, and there is still much to be done. The scale and influence of the construction sector show that even small improvements in this area will substantially benefit people and the environment.

These improvements should not be 'instantaneous', but they should generate long-term effects and extend the concept of sustainability to the building's entire life cycle. Improving the whole process would reduce costs and resource consumption, improve the quality of construction and the quality of materials used, contribute to a healthier indoor environment and increase sustainability.

2.2. Digital Revolution and the Construction Industry

The radical change in society that we are experiencing, due to extraordinary technological advances, is opening a new chapter in human development. The many technological innovations emerging and will probably continue to do in the coming years have integrated and generated significant changes in our daily routine and all aspects of society and industry. This change is identified as the fourth industrial revolution. An era when the gap between the digital world and the physical one is being reduced, and they will be completed integrated.

The fourth revolution that we are experiencing today can transform every industry much faster and significantly impact than any of the previous three [18]. It is based on the connection between physical and digital systems, complex analysis through Big Data, and the use of intelligent machinery interconnected and connected to the internet in all components, products, and production equipment. Industries are transforming and moving towards a "smarter" configuration in which the traditional demand for physical space is replaced by that of digital space and virtual systems.

Another of the main peculiarities of this fourth revolution is disruptive speed. Emerging technologies and innovations are spreading much faster and on a larger scale than previous revolutions. "The spindle (the hallmark of the first industrial revolution) took almost 120 years to spread outside of Europe. By contrast, the internet permeated across the globe in less than a decade" [19].

Since the presentation in 2011 of the "Industry 4.0" concept at the "Hannover Mess" event [20], it has become a widely used definition when talking about the advent of this brand-new industrial revolution, thanks to computer-physical systems, the Internet of Things (IoT), the Smart Factory and the new generation of production systems able to exchange information autonomously through Machine to Machine (M2M) communication modes.

The development of this future scenario is guided by the four key concepts of Industry 4.0 (Figure 1). Specifically:

- Digital data, their collection, and analysis: Industry 4.0 digitizes and integrates processes vertically. All data are available in real-time, supported by augmented reality, and optimized in an integrated network. The availability of this massive amount of data, also collected with the help of smartphones, social network sensors, is an opportunity for advanced industries to develop and improve integrated solutions and products to meet end customers' growing needs.
- Automation: The possibility to use new technologies to develop autonomous and self-organizing systems opens new scenarios and communication channels between man-machine and machine-machine.
- Connectivity: Industry 4.0 explores new possibilities of connection and synchronization of activities and phases that have been distinct until now, thanks to new languages and channels of wireless and non-wireless communication.
- Digital access: Access to the Internet and internal networks is the basis and the necessary condition for implementing the previous key concepts. It allows for opening new channels of communication and access to information and collected data. The latest data available in the statistics show that until September 2020, 63.2% of the world's population has access to the network [21].

In addition to these fundamental concepts, several technologies, also called enabling technologies [5], have been revolutionizing the entire industry in recent years. The nine key technologies [22] are: Autonomous robots, simulations, integrated systems, Internet of Things (IoT), cybersecurity, cloud computing, additive manufacturing, augmented reality, and big data (Figure 1).

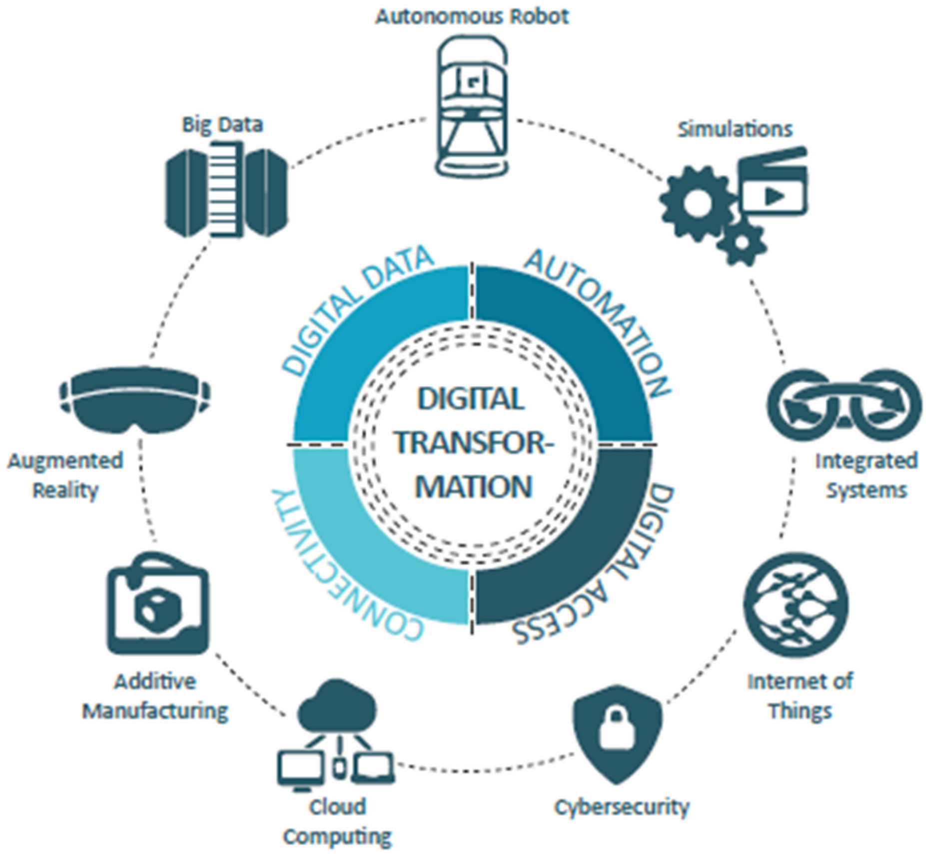

Figure 1. Industry 4.0: Key concepts and digital technologies (source: Image created by author C. Vite based on Roland Berger's image).

Most industrial sectors have experienced disruptive changes and have reaped the benefits of industry 4.0 innovations. In this global transformation, the construction sector has also been involved, but "construction is the least digitized sector in the EU" [23]. The construction industry is the one that has been most hesitant to take full advantage of the latest technological opportunities, due to its peculiar historically reluctant and slower nature, compared to other sectors, in adopting and adapting to innovations. Thus, while most other industrial sectors can benefit from the positive consequences of this new situation—improved productivity, efficiency, or sustainability—the construction sector's overall productivity has stagnated and remained almost flat over the last 50 years [24]. Therefore, the fourth industrial revolution may be an opportunity for the construction sector to reverse this trend. Entering the era of digitization and aligning with the key concepts of industry 4.0 can be seized as an opportunity for a profound renewal and overcoming of the internal barriers that hold back change.

The digitization of the construction sector is only just beginning, but there are signs that the situation is changing, and the "Construction 4.0" idea is emerging. Several new technologies are already available in the Construction 4.0 panorama and applicable to all phases of the construction process, such as augmented reality, drones, 3D scanning and printing, building information modeling (BIM), autonomous machines and equipment, and advanced building materials. However, which among all these technologies is the one that more than the others allow the entire construction sector to innovate by challenging its traditional processes?

BIM seems to be the answer to this question [24]. It could be the keystone of the "revolution" of Construction 4.0, supporting the entire building process throughout the life cycle and connecting and accommodating all the data and innovations of other new digital technologies.

Among the many available definitions, one of the most widespread is the one given in the English standards, which form the basis of the ISO 19650 currently in force: "Building Information Modeling (BIM)[*sic*] is a collaborative way of working underpinned by digital technologies, which allow for more efficient methods of designing, delivering and maintaining physical built assets throughout their entire lifecycle. Greater efficiencies can be realized, due to significant pre-planning during the design and construction phases, providing comprehensive information at handover stage" [25,26].

BIM covers all aspects, technologies, and people involved in the construction sector. It can be defined as a catalyst element, which has resulted in a rethinking of the way construction design conduction of the built environment [27].

A key element of BIM is the "I" of the acronym, i.e., information and data. It is a mechanism that allows the creation, storage, and sharing of information in a new way, one might say "revolutionary" and far superior to all other systems currently in use [28,29]. BIM can integrate, in a unique and shared model, the set of processes and information used for design, implementation, and management, through models created by all participants in the building process, at different times and also for purposes not equal to each other to ensure quality and efficiency throughout the life cycle of the product.

These revolutionary features and characteristics for the construction sector are the results of a long process of evolution that has transformed both the tools and techniques and the process itself.

Nowadays, it is possible to talk about different levels of BIM uses, levels of maturity, and the degree of interoperability achieved [30]. The evolution of BIM has also led to an increase in the number of aspects considered and included. These aspects are commonly defined as BIM's "dimensions" BIM—2D, 3D, 4D, 5D, 6D, and 7D—and each of them corresponds to a specific aspect of the building process. The 2D and 3D dimensions correspond to the geometric aspects of the project; BIM 4D allows for the integration of time aspects; BIM 5D allows managing costs; the possibility provided by BIM to store any information allows this tool to have enormous potential in the Facility Management (FM) phase, enclosed in BIM 6D; BIM 7D, finally, concerns aspects related to project sustainability. While there are already many aspects included, the dimensions described are not exhaustive, and this list may soon be expanded with new "Ds".

Therefore, BIM is a new approach and a new tool common to all actors in the construction process that will allow us to use virtual modeling and collect all the information needed to design and manage any aspect of the construction life, including those related to sustainability. The potential of this innovation as the heart on which to graft the whole construction process and the scale of the benefits it would bring to our industry are widely described and noted. The theory is still a long way from practice, and the possibility of managing all aspects of construction in BIM is not yet really feasible. The technical difficulties associated with the hardware available to professionals and the public administration, the cost of software licenses, etc., are just some of the problems hindering the "BIM revolution" and still require research activities to improve and disseminate it.

Finally, focusing on sustainability aspects, it must be stressed that although all construction experts are aware that they have to modify their actions to consider environmental, social, and economic impacts throughout the construction life cycle, there is still potential for significant improvements. A substantial transformation of the "mentality" is therefore necessary. The digital revolution could represent a suitable opportunity for a profound renewal oriented towards sustainability.

2.3. Optimization in Design Process

The selection of the best alternative is the optimization phase of the project. In the field of construction, this is undoubtedly an important choice—which, in addition to being complex, also brings multiple responsibilities, since other people will use the building or will be conditioned by the designed space. Many projects also have a long life, and there are also different scale projects. Although they have different societal influences and resource demands, the underlying design principles are common in all projects.

Designers have the task of making important design decisions, and any mistakes made generally have a significant impact on the result.

The design process can be described in many ways, but there are some aspects in the process that each description must contain: An acknowledgment of need, an act of creativity, and the selection of alternatives. Correctly, the following stages of the process can be identified:

- recognition of the need or objective;
- identification of the problem;
- creation of one or more physical configurations;
- study of the performance of the individual configurations;
- selection of the best alternative;
- testing of the prototype made.

The decision-making process is intuitive when considering problems related to individual criteria, since the decision-maker is only called upon to choose the alternative with the highest rating. However, when, on the other hand, the decision-maker has to evaluate alternatives with multiple criteria, many problems, such as the weighting of criteria, dependence on preferences, and conflicts between criteria, the decision-making process is more complicated and can be tackled with more sophisticated methods.

To address problems related to decision making, the steps to be taken are [31,32]:

- identify the problem: Understand how many attributes or criteria exist in the problem;
- build preferences: Collect appropriate data or information about the decision maker's preferences and how they can be taken into account when solving the problem;
- evaluate alternatives: Identify a range of possible alternatives or strategies to ensure that the objective will be achieved;
- find and determine the best alternative: Select an appropriate method to assess and exceed our level of expertise and enable us to find possible alternatives or strategies.

There are many rigorous scientific approaches, but the best known and used for the decision-making process in architectural design is Multi-Criteria Decision Making (MCDM) [33]. In the broad field of MCDM, problems can be classified into two main categories [34]: Multi-attribute decision-making (MADM) and multi-objective decision-making (MODM), according to different purposes and different types of data.

Multi-attribute decision methods (MADM) are usually used to identify the optimal decision between a finite number of predetermined alternatives and discrete preference classifications. The MODM is especially suitable for the design/planning facet, which aims to achieve the optimum, considering the various interactions within the data constraints. In this way, infinite alternatives can be obtained to pursue the goal as much as possible, but without knowing what is and if there is the ideal optimum solution.

The use of computers and some of the techniques used to help the decision-making process, although not to solve the problem, where many factors must be considered as in a building project. The evolution of computers and the development of new techniques to help decision-makers have led to widespread optimization in the construction sector. To date, it is a field that is still in a complete state of development and remains little explored concerning specific aspects, such as those related to sustainability.

2.4. BIM and Sustainability Aspects

The first element to emphasize when talking about sustainability and BIM is the very association of sustainability with a specific BIM dimension. A brief search online or in contributions on the topic shows that there is some confusion about this. Together with Facility Management (FM), sustainability is one of the last aspects included in BIM. Depending on the contexts, they are associated with different dimensions: In Italy, it is associated with Italian BIM-7D, while in other countries, it is exchanged with BIM-6D. This fact highlights even more how this level has not yet been reached, and this information is not yet fully managed in the building process in the BIM environment.

For the research presented here and developed in Italy, we have chosen to report the Italian UNI standard definition that associates sustainability with 7D.

The seventh dimension of BIM is defined in the Italian standard UNI 11337-1 as: Simulation of the work or its elements according to the sustainability (economic, environmental, energy, etc.) of the intervention, as well as space, time, and production costs [34].

Building information modeling, thanks to its intrinsic characteristics and potential to generate a model updated continuously and increasingly faithful to reality, can, therefore, also be able to manage all aspects related to sustainability. Using BIM tools, it is possible to perform simulations and analysis of the performance of the sustainability of the building or even just some of its elements can be carried out: For example, it is possible to study multiple aspects, such as orientation, shape, daylighting, energy profile, materials, etc.

Although the 7D dimension of BIM is included in the standard and the literature, the reality is different. Considering, for example, the applications available to professionals, it possible to see that as the size increases, the number of applications available decreases (Figure 2).

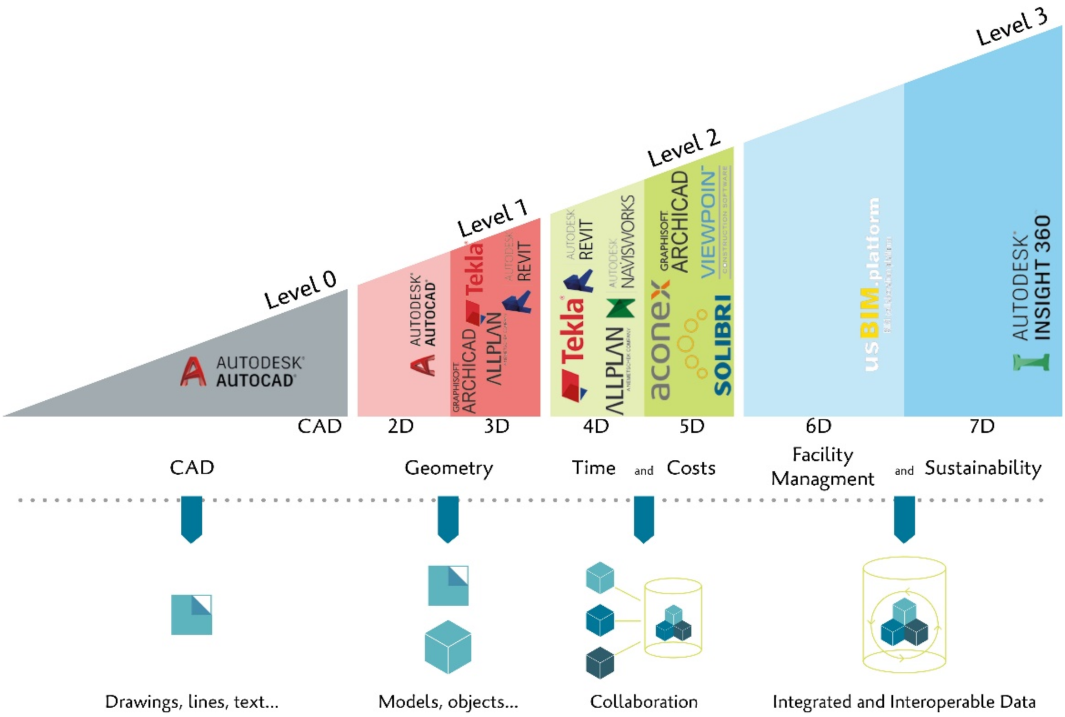

Figure 2. Most common tools available and used for each building information modeling (BIM) levels and dimensions (source: Image created by author C. Vite based on GenieBelt's image).

In level 0 and for 2D, the most widespread tool is AutoCAD [35]. Although there are also other similar and opensource tools, this is the most used by architects, project managers, engineers, designers, graphic designers, urban planners, and other professionals.

The most common tools for 3D geometric modeling, corresponding to a BIM Level 1, and certified by buildingSMART [36] are: Archicad [37], Revit [38], Tekla [39], and Allplan [40].

In Level 2, there are several tools to manage relatively new aspects of BIM. The list is continuously updated. However, those that are more widespread and consolidated in professional firms for collaboration, coordination, and model-check using BIM are Navisworks [37], Solibri [41], and BIMcollab [42]. Synchro [43] and Assemble System [44] are more specific for 4D and 5D dimensions.

For BIM 6D and 7D Level 3, software like Green Building Studio [45] or the Italian usBIM platform [46] could be mentioned, but due to their limited flexibility or the extremely recent development, they cannot yet be considered tools with a wide range of diffusion and use among professionals.

Many elements influence the achievement of sustainability goals in a building project. One surprising thing that emerged is that the fundamental problem related to sustainability is "time". The process is usually a kind of cascade process: Usually, the designers start the design process, once something of the priorities of the users has been solved, then a kind of cascade effects start to calculate other things, calculating the compliant with energy regulations, sustainable criteria, etc. The consequences of addressing the sustainability/energy aspects at the end of the design and building process remain small margins to modify the project. Creating a common data environment through BIM across the design and construction team can help teams make choices with higher sustainability impact consideration and address them earlier in the project timeline. Moreover, digital evolution has allowed all designers to use increasingly sophisticated computers and software and rely on them for advanced designs and simulations. Thanks to the exponential increase in computing power, it is possible to incorporate optimization techniques into the design process to support engineers in decision-making when it is not easy to find the optimal solution, due to many factors to consider.

3. Materials and Methods

The presented research aims to analyze the current state and identify the signs of change and the cues to imagine possible virtuous complicity between sustainable goals and the digital revolution's potential, supported by the operational features of optimization methods.

The further intent is to translate the synergy between the three key topics—sustainability, digitization, and optimization—through an operational strategy that can demonstrate what is affirmed and support for designers.

The methodology has been tested and validated on several application examples.

The phase of study and analysis of state of the art gave the necessary input to identify the strengths and weaknesses of the proposed concept of possible virtuous complicity between sustainability, digitization, and optimization. The three topics were studied on three different keys: General overview, specific overview in the field of construction, and concrete aspects/tools to implement the proposed methodology.

This study phase was conducted by analyzing the reference literature and implementing semi-structured interviews to get the point of view of experts in the field and define the current state of use of building information modeling in the case of a design approach in which the objectives of sustainability are considered.

The Proposed Methodology

The research presented focuses on investigating and re-interpreting the transformations in our sector, paying particular attention to sustainability aspects to understand how these changes can contribute to generating new processes and behaviors in design. The study of the reference literature and the current situation, the discussion with experts, and the implementations realized using the latest generation software available have led to the definition of a replicable procedure for optimizing the design and regenerative process of construction.

Based on the whole process, there is the aim to include sustainability from the beginning of the design concept. Literature review and collected data on the actual situation and the future scenarios make us understand the urgency of not leaving this aspect out later. "Sustainability comes later," said one of the interviewees, but sustainability should come sooner. Instead, it should be the first step. In the proposed scheme, the first step is defining the project objectives for the achievement of sustainable construction.

The study from the fourth industrial revolution has allowed us to identify the technological innovation that can contribute to transforming the design process profoundly. Building information modeling has been chosen as a digital tool to develop the proposed methodology. The BIM, thanks to its peculiarities described and analyzed previously, can reduce the fragmentation of communications between experts and collect all the information generated by different disciplines. These aspects can be the keystone to be exploited to support designers to make design choices with a greater awareness of the impact on the result regarding sustainability.

One of the topics that is most frequently dealt with sustainability is energy. So, building performance analysis could be developed to assess and evaluate various aspects as solar and thermal energy, ventilation, daylighting, building massing, site orientation, and the optimization of a building's HVAC systems. Focusing on global challenges, these simulations are becoming increasingly important in the design process to optimize future energy consumption and ensure a good result [47–49]. Optimization means finding the best values of a function with the highest achievable performances under the given constraints, implied or expressed, by maximizing desired factors and minimizing the undesired ones [50]. It consists of finding the most suitable solutions among a wide range of possible options [51]. Optimization methods have been applied in different fields; of course, also in the construction one. In many architecture and construction disciplines, it is used to optimize different criteria, including those related to energy and environmental sustainability aspects.

Several tools for the energy simulation of buildings have been developed over the past decades to assess performance and energy consumption, but only a few have been developed for optimization. Despite this variety of existing tools and many agreeing on the importance of doing something about climate change, not all architectural teams use them. Or, if they are used, they are mostly used as tools for post-design evaluation [52,53]. Several studies have shown the potential to support the identification of optimal design decisions and that approximately 20% of design decisions made in the early design stage account for 80% of the total impact on the final building energy performance [52]. In these early stages, the architects can make choices oriented towards sustainability, also relying on the advice of sub-communities of practice specialized [54], but as can be seen from prior research, the task is left to the engineers to make assessments and energy optimizations at a later stage.

This situation is changing, and architecture and engineering firms are widely involved in evaluating sustainable performances. However, the assessment of sustainable optimization is still a complicated procedure, which usually requires a significant amount of effort, time, and special skills. Furthermore, to reduce coordination across the multiple actors involved, energy optimization is generally conducted after deciding on significant building elements or in 2–3 alternative solutions [55].

In the traditional process, to analyze the building performances with a specific tool, the geometric building information is extracted from the architectural drawings and documents. To use these no-BIM tools, a detailed building model is necessary, with all the information related to the characteristics of the envelope, systems, climatic data, etc. After that, the building sustainable/energy analyst uses this information to define and create the building's thermal model with the simulation tool. The result of this dependent on the knowledge, skill, and experience of the energy analyst. Several tools for energy simulation are available. The most used pieces of software in the world for energy simulation are Energy+ [56] and TRNSYS [57]. Moreover, if these simulations are carried out to assess energy performance and optimize the design solution, an additional optimization tool is needed.

The diagram in Figure 3 shows the essential steps of a simulation and optimization process of a building in a traditional process. It starts from a 3D model from that all the available information are extracted (1); then all the specific information related to the simulation that is being done are entered (2); all these data are input for the optimization tool (3); finally, the result related to the set objectives is obtained (4).

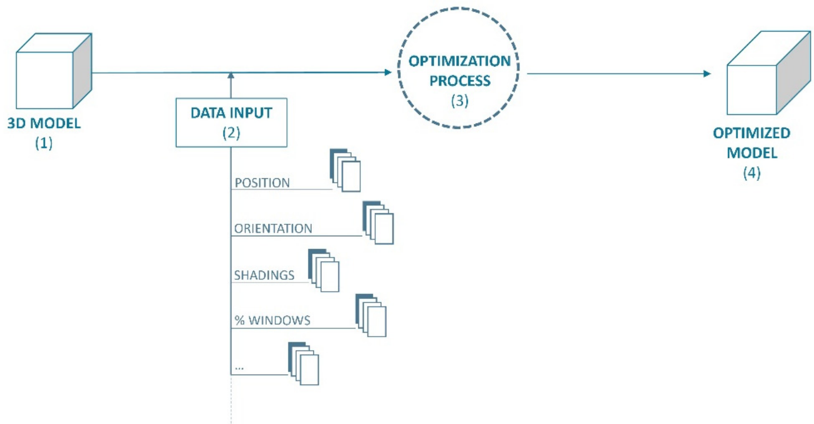

Figure 3. Outline of a traditional optimization process (source: Image created by author C. Vite).

The BIM model is a huge repository of all the data of the entire life cycle of the building. A BIM model does not only include geometric information. It is a complete digital representation of all physical and functional characteristics of the building. Perform simulations and optimization processes in the BIM environment allow us to benefit from the peculiarities of it as an independent and multi-disciplinary data repository.

Using building information modeling to optimize energy consumption, the process described earlier in the traditional way, can speed up. The scheme shows before is now simplified. The second step, which involved adding the missing data to complete the model for the performance simulate, can be deleted due to all of the available information included in the BIM model.

Figure 4 shows the process developed using BIM. It starts from a BIM model that includes information (1); the information needed for the simulation is selected and then entered in the optimization tool (2); finally, the result related to the set objectives is obtained (3).

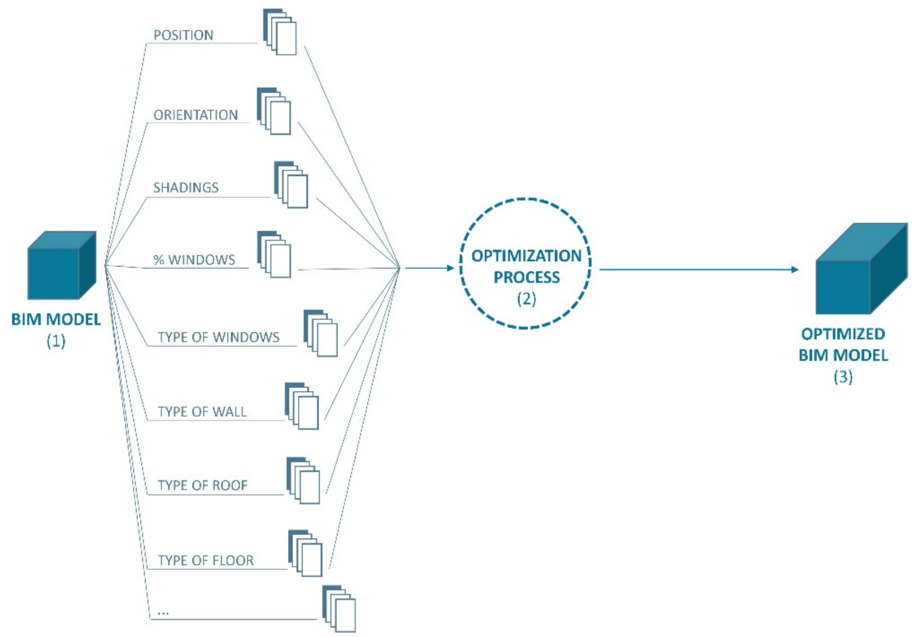

Figure 4. Schema of all the data included in the common data environment of a BIM model (source: Image created by author C. Vite). Based on these considerations and the combination of the three key arguments—sustainability, digitization, and optimization—the methodology proposed in Figure 5 has been defined.

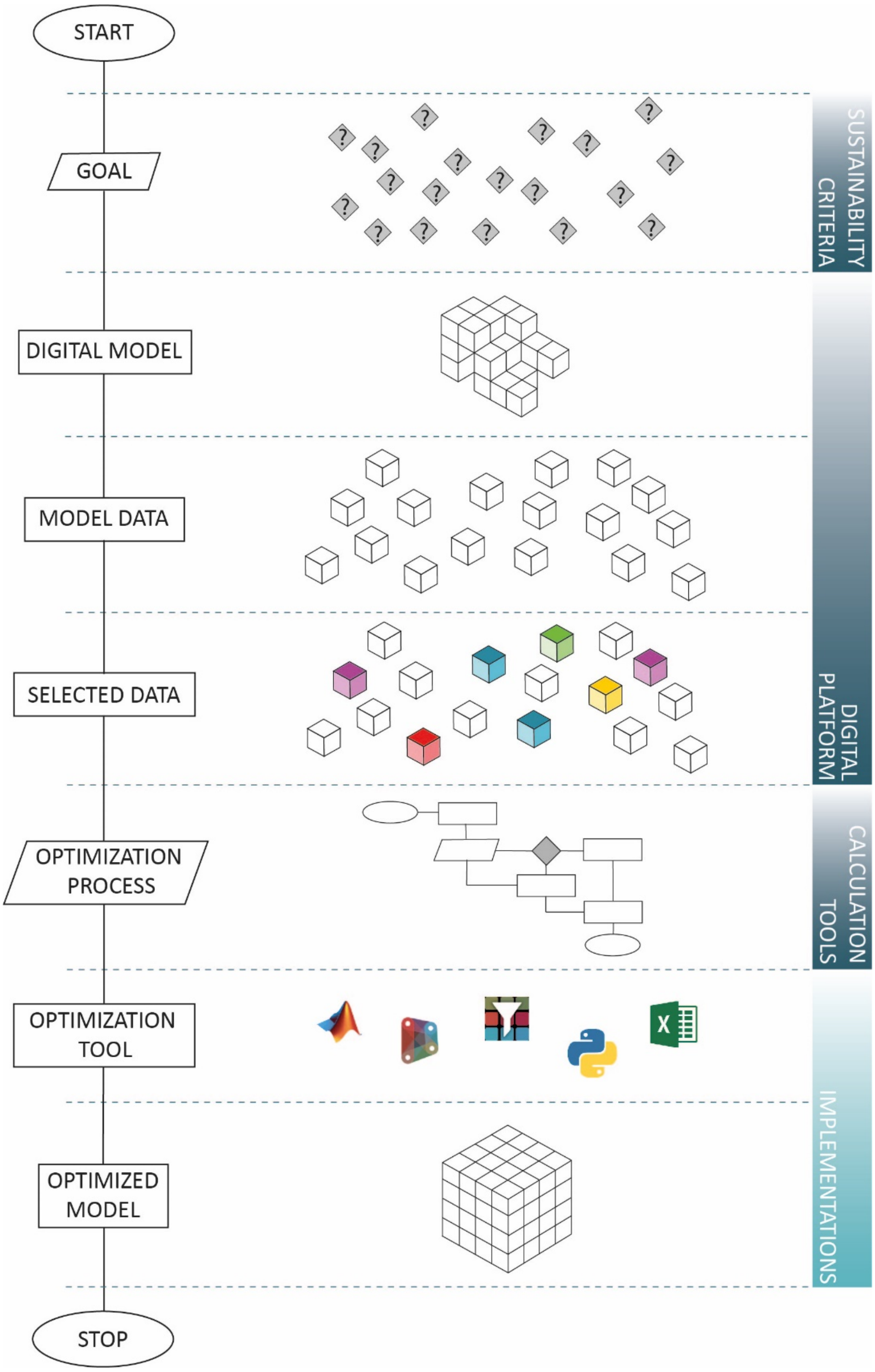

Figure 5. Schema of the proposed methodology (source: Image created by author C. Vite).

In the development of this procedure, attention is paid to the choice of intervention strategies aimed at achieving the objectives of the project itself, minimizing the dispersion of information, and improving collaboration between the various specialists involved. Specifically, it is a sequence of steps to be able to include sustainability as a design criterion from the very beginning, using a digital model developed in the BIM field, to then arrive at the choice of optimal solutions thanks to the use of decision theory.

The methodology consists of the steps described below.

- GOALS

The first step to be taken is to establish the goals that must be met based on the aims of the project. Besides, it is necessary to define whether there are constraints that restrict the scope of identifiable feasible solutions.

The multiple goals of an architectural project can be enclosed in the three pillars of sustainable development: environmental, social, and economic. These can include objectives, such as energy, economic, comfort, environmental, social, urban planning, etc. Within these macro-categories, specific objectives can be identified.

- DIGITAL MODEL AND DATA SELECTION

The next steps are related to the development of the digital model and the selection of data useful for the optimization process. A digital platform (more specifically, Autodesk Revit [37]) chosen to develop BIM models is used in the implementations presented below. The BIM model is the key to the methodology. Thanks to its features already described and analyzed above, it avoids the need to collect and implement missing information to develop the entire process. Everything that is developed in the design process is contained within the BIM model. Once the goals and constraints have been set, the next step concerning the digital model of the building to explore and extract the input data necessary to develop the optimization process.

- OPTIMIZATION PROCESS

The next phase of the methodology is the formulation of the optimization process. There are some elements common to all optimization problems, which consist of:

- A set of independent variables or design parameters;
- A set of constraints that bound the respective;
- Domains of the independent and dependent variables;
- One or more objectives to be optimized.

At this stage, it is already verified that we have all these elements necessary to build the optimization process. Then the methodology proceeds with the identification of the resolution technique to be used among all those belonging to the decision-making methods. There are many techniques applicable to complex optimization problems, but not all of them are adequate and applicable in the field of construction and for the type of information available.

- TOOLS

In the previous phases, the objectives were identified, the digital model was developed, and the data and methods were chosen. Thanks to all this information, it is possible now using specific software to develop the optimization process and solve the problem.

There are some existing optimization tools specifically developed for that, including the resolution techniques—but thanks to visual programming tools, such as Dynamo [36] and Grasshopper [58], it is also possible to write new ones.

- FINAL RESULT

The result of the optimization process, after several iterations and the elimination of unfit solutions, is an optimal solution or a pool of optimized design alternatives that meet the objective functions set. From this, the designer can obtain indications on the design solutions that allow him to make his choices with greater awareness and face highly complex problems, such as evaluating the sustainable aspects of construction from the beginning.

4. Results

The proposed methodology has been tested through some application cases. The examples have been diversified to achieve different goals related to sustainable design, use different tools, and calculate methods for resolving the optimization process. The case studies have been realized on prototypes to focus the attention on the whole process, rather than on the digital model development. In particular, the methodology was tested on several case studies to optimize the properties of different building components to pursue sustainability goals. In particular, the following case studies are reported:

1. Properties' optimization of the transparent envelope;
2. Properties' optimization of the opaque envelope;
3. Properties' optimization of the entire envelope;
4. Optimization of façade's geometry;
5. Volume and solar radiation optimization.

Following the steps of the proposed methodology, a description is given for the five application examples.

- GOALS

The first case study's objective is to optimize the thermal performance of the transparent elements present, in terms of thermal resistance [m^2K/W], keeping the geometrical characteristics fixed. Specifically, we want to exploit the potential of BIM to be a database of digital objects. The example aims to compare the elements inserted in the digital model with those present in the database and make replacements if objects with "better" thermal performance are identified.

The objective set for the second case study is to optimize the thermal performance of the opaque elements present in the model, while keeping the geometric characteristics of the building fixed. Specifically, it was chosen to minimize the vertical opaque elements' thermal transmittance value and fix a maximum threshold value.

The third application example is the extension and merging of the two previous scripts to simultaneously optimize all building envelope elements' properties, both opaque and transparent.

The fourth application example aims to optimize the solar radiation inside the building by changing the façade cladding panels' geometry according to their exposure to the sun.

The fifth example aims to optimize the building's compactness ratio and solar radiation on the vertical walls. Specifically, it was decided to minimize the S/V ratio between the building's dispersing surface and its volume by freely varying the dimensions of width, length, and height of the starting volume up to a limit set.

- DIGITAL MODEL AND DATA SELECTION

The first three application examples were conducted on the same digital model developed in Autodesk Revit (Figure 6). The model is a simple building with 10 m by 10 m and 3 m in height. The starting building envelope consists of the following elements: The first floor is a brick slab; vertical external brick walls with cavity insulation; single-glazed PVC windows and doors; flat roof made of the brick slab and extrados insulation. No entrance doors and internal partitions have been inserted in the model; a window frame has been inserted for each side, and all four elements have different geometric characteristics.

The digital model used in the fourth case study is a volume created in Autodesk Revit (Figure 6). Contrary to previous models, the building is designed as a volume, or "mass", consisting of surfaces only and without specific information about the building envelope. The south-facing side on which the cladding will be applied has been deformed to have different radiation over the entire extension of the façade.

The digital model used in the fifth case study is a cube created in Autodesk Revit (Figure 6). Like the previous example model, the building was designed as a volume, or "mass," consisting of surfaces only and without specific information about the building envelope. The starting cube side is 10 m.

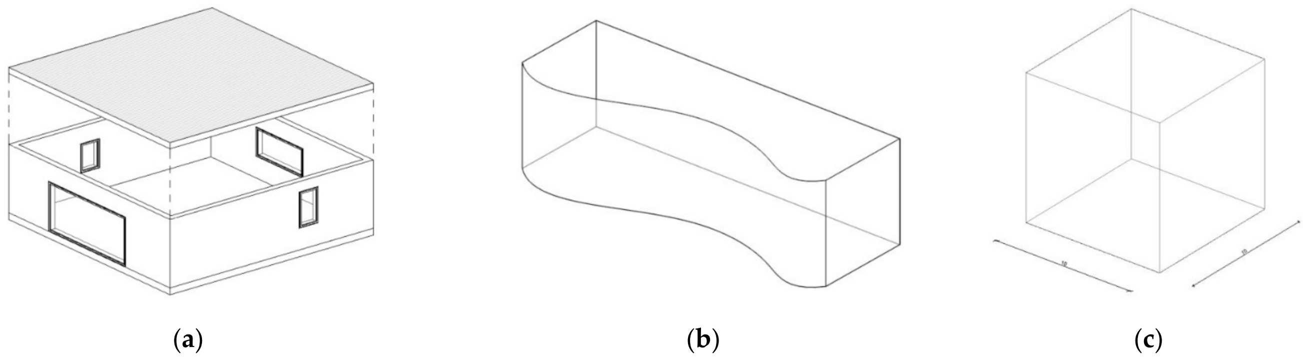

Figure 6. 3D views of the digital models created in Autodesk Revit ®: (**a**) Model used in case studies one, two, and three; (**b**) model used in case studies four; (**c**) model used in case studies five (source: Image created by author C. Vite).

- OPTIMIZATION PROCESS

The optimization process has been structured, as shown in Figure 7. After defining the target, the BIM model is drawn and linked to the visual programming program. The script developed in Dynamo allows extracting the data of the BIM model.

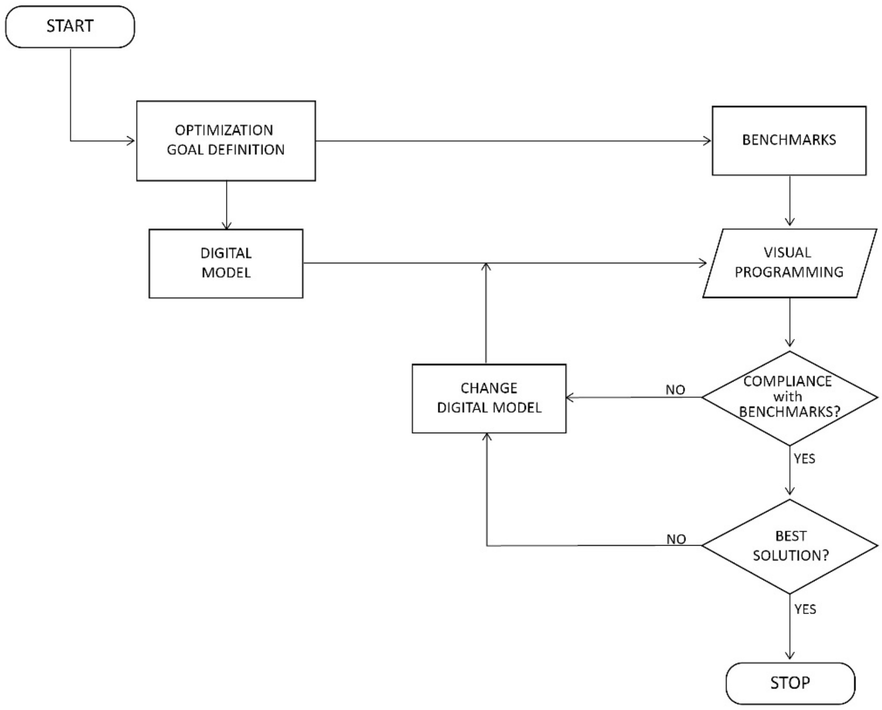

Figure 7. The workflow of the optimization process (source: Image created by author C. Vite).

The extracted data are then compared with the limits and thresholds set. In the first case, transmittance data extracted from the model and those found in the database are compared. In the second one, transmittance data of the individual objects drawn are compared with the reference value from the standards. The third application is the union of the two previous ones. In the fourth case study angle of incidence of the sun on the panel and its normal vector are compared. Finally, in the fifth case study, the optimization process calculates the S/V ratio and the amount of radiation on the vertical surfaces of the volume and calculates all possible solutions based on the data and constraints set.

If the comparison of these data does not meet the set conditions, the optimization process involves going back to the digital model and making changes until the optimized solution is reached.

- TOOLS

Autodesk Revit ® is the building information modeling tool that was selected to develop the digital model. A visual programming workspace linked to Revit ® named Dynamo is the tool used to develop the workflow by connecting Nodes with Wires to specify the logical flow. In the fifth example, it was also used Refinery [59], a dynamo plugin still available in beta version, that allows using genetic algorithms, particularly the NSGA II (Non-dominated Sorting Genetic Algorithm II) [60].

An image of the script developed for the first example concerning the properties optimization of the transparent envelope is shown as an example (Figure 8). The workflow has four main sections of nodes:

- An initial part links the script to the BIM model and selects a specific type of family, like "window" in this example (blue);
- A part to analyze the model instances and extract the data (green);
- A part to analyze the database and find a better solution (orange);
- A final part compares the different values and replaces the elements if necessary (pink).
- FINAL RESULT

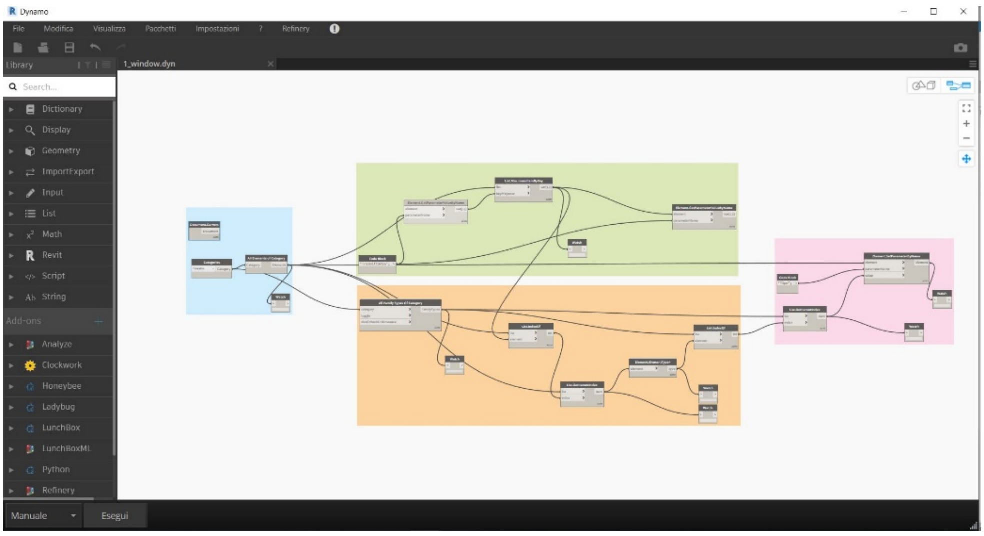

Figure 8. The developed Dynamo workflow. The different sections of the workflow are visible: BIM model (blue); instance analysis (green); database analysis (orange); comparison and substitution (pink). (Source: Image created by author C. Vite).

The optimization process results are an optimal solution or a pool of optimized design alternatives that meet the objective functions set.

In the first three examples, the result is the digital model optimized concerning the building envelope's chosen property, i.e., the thermal resistance. Apparently, from the graphic point of view, there are no evident changes, but by exploring the elements and properties, the changes made by the process to the model's glazed elements, or the thickness of the opaque elements can be found.

The result obtained in the fourth example is the cladding of the selected surface with panels of different geometry according to the solar incidence (Figure 9). Finally, the result obtained through genetic algorithms in the fifth case study is a set of possible solutions with different geometric configurations of the starting cube for the intended goal (Figure 9).

The different examples showed how it could be used to organize and sequence the steps leading to the identification and choice of the optimal solution based on the set objects. The case studies did not aim to cover the whole range of possible design choices but, starting from some simple elements, highlight their adaptability and replicability to more complex situations with different objectives and available information to achieve an optimized result.

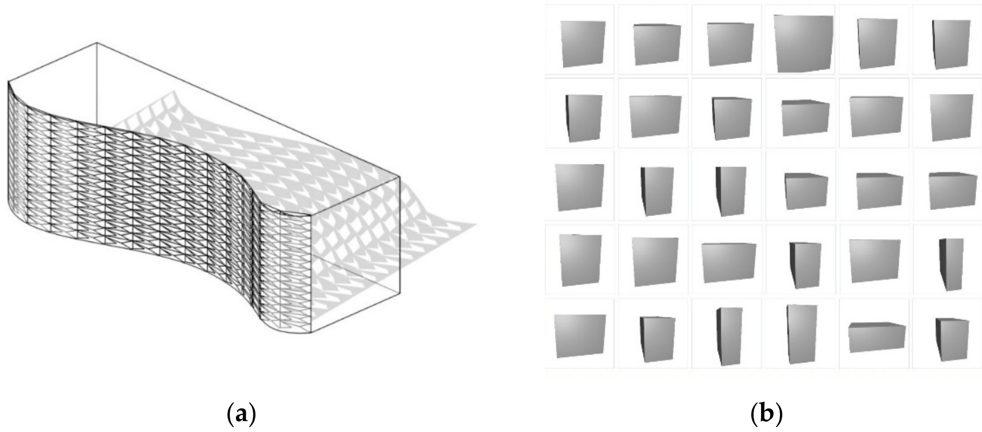

Figure 9. The solutions that were obtained for the fourth and fifth case studies, respectively. Specifically: (**a**) Optimized model on which a cladding has been realized on the south wall with panels with variable geometry; (**b**) some of the solutions obtained using genetic algorithms (source: Image created by author C. Vite).

5. Discussion

The goals of sustainable development require a significant commitment from the construction sector, as the environmental, social, and economic impacts generated by it are also significant. All activities and people working in this sector are called upon to actively contribute to the global challenge for adaptation and mitigation to climate change.

There is much potential for improvement in the construction sector if we consider that despite the wide variety of existing tools and the shared awareness of the importance of doing something about climate change, not all teams' experts use them or if they are used, mostly as tools for post-design assessment. Although all recent technological innovations are vehicles of many benefits, they also have practical and economic limitations that limit their use and diffusion. There are also multiple risks, some of which have not yet been adequately addressed and explored, such as security, privacy, user protection aspects, or management of the enormity of the data produced.

The research presented here has been conducted through the study and in-depth analysis of the state of the art of the three chosen areas of investigation: Sustainability, digitization, and optimization. The objective was to take inspiration from these analyses to imagine possible virtuous complicity between sustainable objectives and the digital revolution's potential, supported by the operational characteristics of optimization methods. The intent was to identify a new way to respond in the field of construction to the global challenges of sustainable development to which we are all called. A replicable procedure has been developed to optimize sustainable project characteristics. This strategy is a sequence of steps that can include sustainability parameters as a design criterion from the beginning phase, using a digital model and arriving at the optimal choice of design solutions through decision-making methods. The methodology has been tested through case studies aiming to test the procedure's adaptability and replicability to different and more complicated situations with different objectives and information.

The building information modeling was chosen as the digital environment and tool to develop the proposed methodology. BIM can reduce some of the critical issues generated by a "group of experts" who collaborate in a project. First, the necessary information collection for the simulation and evaluation of the project choices to be adopted. The possibility to work with a digital twin of the built is an essential innovation of the process, and the data contained in the common data environment (CDE) are the heart of BIM. However, there are still several challenges to use BIM and CDE to manage all aspects of sustainability. From a theoretical point of view, it is already considered possible, but, in practice, there are still no standardized procedures and consolidated tools for the management of BIM 7D data and information. This gap between reference literature and work practice is a recurrent element in BIM. It is expected that soon this fragmented picture of building information modeling, the result of the different sensitivities of government agencies and individual professionals, will be smoothed out by the recent ISO 19650:2018 [26]. The standard primarily aims to reorganize all existing standards by providing a single internationally valid definition to exchange data and establish standard protocols for information sharing between the various stakeholders in the construction industry. Secondly, this new legislation may also be the inspiration and support needed to trigger a renewal process in those countries that are less advanced in construction 4.0.

The design process is subject to time constraints, and designers must make decisions quickly. The use of software certainly helps speed up the process, but parametric models' creation takes time. BIM has undoubtedly proved to be a useful tool because of its parametric nature and because it allows us to quickly capture any changes and information that could be made and added by designers at any time, without the need to rewrite and redo the model entirely. Nevertheless, the methodology's implementations have shown that many skills in BIM and visual programming are needed and must be developed from time to time based on the problem to be addressed. The designer's dependence and skills are evident, as it was also in the research path. That is a limit that must and will be overcome thanks to the spread of these tools; some are still in beta versions, updated continuously, and modified.

6. Conclusions

The paper presented, explored, and discussed the challenges for sustainable development and the contribution that it can make, as well as the change that our industry can make. This change is believed to be fostered by the digital revolution and the integration of optimization techniques that are still underutilized today.

During this research, and the study of state of the art, standards, and the reference letter, we had the opportunity to confront experts in the field to understand the real problems that designers face. We studied the innovations of the digital revolution and identified building information modeling as the key. It is often understood as a new tool, but even more powerful is the possibility it provides a shared data environment that ensures a close coupling of work during the design and construction of a building. The different professionals work in unison with the BIM, reducing time and loss of information in favor of more conscious and shared choices that can include sustainability. These choices are often left behind compared to others because of the difficulty of finding data or the limited possibilities for changes to projects that are already well underway. The theory is still a long way from practice, and the possibility of managing all aspects of construction in BIM is not yet really feasible. Moreover, there is another area that is still under-supported in the construction industry: Optimization. The evolution of computers and the development of new optimization techniques have enabled them to be more widely used. Despite this, it remains a developing research field, especially concerning the optimization of specific construction aspects, such as those related to sustainability.

Specifically, the article proposes a methodology that exploits and combines the potential of these three areas. It is a sequence of steps to include sustainability as a design criterion from the beginning, using a digital model developed in the BIM environment to arrive at the optimal solutions using decision theory. This is then applied to some case studies that highlight how these elements can be put together and used by designers to operate in this new scenario—although these are still too few and are limited to specific objectives and situations. The examples of implementation emphasize how the methodology, starting from individual building elements, and can be used to scale the building or neighborhood to address real decision-making problems in sustainable design.

In the future, this potential (highlighted by the synergy between sustainability and the digital revolution, and supported by optimization methods) could be the answer in our industry to the increasingly stringent demands of regulations and customers on requirements and performance regarding construction sustainability.

Author Contributions: Conceptualization, C.V.; methodology and validation, C.V.; writing—original draft preparation, C.V.; writing—review and editing, C.V. and R.M.; supervision, R.M.; funding acquisition, R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was co-funded by Seventh Framework Programme, grant number 314473.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: Oxford, NY, USA, 1987; p. 43.
2. United Nations General Assembly. *A/RES/70/1—Transforming our world: The 2030 Agenda for Sustainable Development*; United Nations General Assembly: New York, NY, USA, 21 October 2015; pp. 2–22. Available online: https://sdgs.un.org/2030agenda (accessed on 27 December 2020).
3. United Nations, Department of Economic and Social Affairs, Population Division. *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables*; Working Paper No. ESA/P/WP/248; United Nations: New York, NY, USA, 2017; pp. 2–8. Available online: https://population.un.org/wpp/Publications/Files/WPP2017_KeyFindings.pdf (accessed on 27 December 2020).
4. Kagermann, H.; Wolf-Dieter, L.; Wahlster, W. Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. *VDI Nachr.* **2011**, *13*, 2–3.
5. Gerbert, P.; Castagnino, S.; Rothballer, C.; Renz, A.; Filitz, R. Digital in Engineering and Construction. 2016. Available online: http://futureofconstruction.org/content/uploads/2016/09/BCG-Digital-in-Engineering-and-Construction-Mar-2016.pdf (accessed on 27 December 2020).
6. United Nations Development Programme. *NDC Global Outlook Report 2019. The Heat Is On. Taking Stock of Global Climate Ambition*; United Nations General Assembly: New York, NY, USA, 2019; p. 5. Available online: https://www.undp.org/content/undp/en/home/librarypage/environment-energy/climate_change/ndc-global-outlook-report-2019.html (accessed on 27 December 2020).
7. IPCC (The Intergovernmental Panel on Climate Change). Available online: https://www.ipcc.ch (accessed on 27 December 2020).
8. IPCC. *Global Warming of 1.5 °C*; The Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2019. Available online: https://www.ipcc.ch/sr15/ (accessed on 27 December 2020).
9. United Nations. *Adoption of the Paris Agreement. Decision 1/CP.21*; United Nations: New York, NY, USA, 2015; p. 4. Available online: https://unfccc.int/process-and-meetings/conferences/past-conferences/paris-climate-change-conference-november-2015/cop-21/cop-21-decisions (accessed on 27 December 2020).
10. United Nations Environment Programme. *Emissions Gap Report 2019*; United Nations Environment Programme: Nairobi, Kenya, 2019. Available online: https://www.unenvironment.org/resources/emissions-gap-report-2019 (accessed on 27 December 2020).
11. United Nations, Department of Economic and Social Affairs, Population Division. *World Population Prospects 2019: Highlights*; ST/ESA/SER.A/423; United Nations, Department of Economic and Social Affairs, Population Division: New York, NY, USA, 2019; p. 5. Available online: https://population.un.org/wpp/Publications/ (accessed on 27 December 2020).
12. World Economic Forum. *Shaping the Future of Construction*; World Economic Forum: Cologny, Switzerland, 2016; p. 5. Available online: http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report__.pdf (accessed on 27 December 2020).
13. International Energy Agency. *Energy Technology Perspectives 2017*; IEA/OECD: Paris, France, 2017. Available online: https://webstore.iea.org/energy-technology-perspectives-2017 (accessed on 28 December 2020).
14. EESI (Environmental and Energy Study Institute). Available online: https://www.eesi.org/briefings/view/042214recycling (accessed on 27 December 2020).
15. Fischer, C.; Werge, M. *EU as a Recycling Society. Present Recycling Levels of Municipal Waste and Construction & Demolition Waste in the EU*; ETC/SCP 2/2009; European Topic Centre on Resource and Waste Management: Copenhagen, Danmark, 2009; p. 25. Available online: http://avfallnorge.web123.no/article_docs/EUgjenvinningsstudie.pdf (accessed on 27 December 2020).
16. Tojo, N.; Fischer, C. *Europe as a Recycling Society. European Recycling Policies in Relation to the Actual Recycling Achieved*; ETC/SCP 2/2011; European Topic Centre on Sustainable Consumption and Production: Copenhagen, Danmark, 2011; pp. 19–21. Available online: http://waste-prevention.gr/waste/wp-content/uploads/2015/10/2011_Europe%20as%20a%20Recycling%20Society_EN.pdf (accessed on 27 December 2020).
17. ISPRA. *Rapporto Rifiuti Speciali 2017*; Rapporti n. 265/2017; ISPRA—Settore Editoria: Roma, Italy, 2017.

18. Mrugalska, B.; Wyrwicka, M.K. Towards Lean Production in Industry 4.0 Procedia Engineering. In Proceedings of the 7th International Conference on Engineering, Project, and Production Management, Bialystok, Poland, 21–23 September 2016; Volume 182, pp. 466–473. [CrossRef]
19. Schwab, K. *The Fourth Industrial Revolution*; Currency: New York, NY, USA, 2017.
20. Hannover Mess. Available online: https://www.hannovermesse.de/en/ (accessed on 28 December 2020).
21. Internet World Stats. Available online: https://www.internetworldstats.com/stats.htm (accessed on 28 December 2020).
22. Probst, L.; Lefebvre, V.; Martinez-Diaz, C.; Bohn, N.U.; PwC; Klitou, D.; Conrads, J.; CARSA. *Digital Transformation Scoreboard 2018. EU Businesses Go Digital: Opportunities, Outcomes and Uptake*; Publications Office of the European Union: Luxembourg, 2018; p. 7. Available online: https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/Digital%20Transformation%20Scoreboard%202018_0.pdf (accessed on 28 December 2020).
23. EURACTIV. *Digitising the EU's Construction Industry*; Manifesto Report; EURACTIV: Brussels, Belgium, January–March 2019; p. 7. Available online: http://eurac.tv/9Q2S (accessed on 28 December 2020).
24. World Economic Forum. *Shaping the Future of Construction*; World Economic Forum: Cologny, Switzerland, 2017; p. 9. Available online: http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_Inspiring_Innovators_redefine_the_industry_2017.pdf (accessed on 28 December 2020).
25. Publicly Available Specification. *Specification for Information Management for the Capital/Delivery Phase of Construction Projects Using Building Information Modelling*; PAS 1192-2:2013. Status: Withdrawn; British Standards Institution: London, UK, 2013.
26. International Organization for Standardization. *Organization and Digitization of Information about Buildings and Civil Engineering Works, including Building Information Modelling (BIM)—Information Management Using Building Information Modelling—Part 1: Concepts and Principles*; ISO 19650-1:2018; International Organization for Standardization: Geneva, Switzerland, 2018.
27. Sawhney, A.; Singhal, P. Drivers and Barriers to the Use of Building Information Modelling in India. *Int. J. 3D Inf. Model.* **2013**, *2*, 46–63. [CrossRef]
28. Eastman, C.; Fisher, D.; Lafue, G.; Lividini, J.; Stoker, D.; Yessios, C. *An Outline of the Building Description System*; Research Report No. 50; Univerisity of Pittsburgh Carnegie-Mellon: Pittsburgh, PA, USA, 1974.
29. Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, 2nd ed.; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2011.
30. Bew, M.; Richards, M. *Bew-Richards BIM Maturity Model*; BuildingSMART Construct IT Autumn Members Meeting: Brighton, UK, 2008.
31. Simon, H.A. *The New Science of Management Decision*; Rev. ed.; Prentice-Hall: Englewood Cliffs, NJ, USA, 1977.
32. Papalambros, P.Y.; Wilde, D.J. *Principles of Optimal Design: Modeling and Computation*, 2nd ed.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2000.
33. Tzeng, G.-H.; Huang, J.-J. *Multiple Attribute Decision Making: Methods and Applications*, 1st ed.; CRC Press: New York, NY, USA, 2011.
34. Hwang, C.-L.; Yoon, K. *Multiple Attribute Decision Making*; Springer: Berlin/Heidelberg, Germany, 1981.
35. Ente Nazionale Italiano di Unificazione. *Building and Civil Engineering Works—Digital Management of the Informative Processes—Part 1: Models, Documents and Informative Objects for Products and Processes*; UNI 11337-1:2017; UNI: Roma, Italy, 2017.
36. Autodesk, Inc. AutoCAD®. Available online: https://www.autodesk.com/products (accessed on 28 December 2020).
37. BuildingSMART. Available online: https://www.buildingsmart.org/ (accessed on 28 December 2020).
38. Graphisoft. Archicad®. Available online: https://graphisoft.com/it/solutions/products/archicad (accessed on 28 December 2020).
39. Trimble Solutions Corporation. Tekla BIMsight®. Available online: https://www.tekla.com/products/tekla-bimsight/download (accessed on 28 December 2020).
40. Nemetschek. Allplan®. Available online: https://www.allplan.com/it/ (accessed on 28 December 2020).
41. Solibri Inc. Solibri®. Available online: https://www.solibri.com/ (accessed on 28 December 2020).
42. KUBUS. BIMcollab®. Available online: https://www.bimcollab.com/en/products/bimcollab-cloud (accessed on 28 December 2020).
43. Bentley System Inc. Synchro®. Available online: https://www.bentley.com/en/products (accessed on 28 December 2020).
44. Assemble System®. Available online: https://assemblesystems.com/ (accessed on 28 December 2020).
45. Autodesk, Inc. Green Building Studio®. Available online: https://gbs.autodesk.com/GBS/ (accessed on 28 December 2020).
46. ACCA Software S.p.A. usBIM®. Available online: https://www.acca.it/bim-management-system (accessed on 28 December 2020).
47. Allouhi, A.; El Fouih, Y.; Kousksou, T.; Jamil, A.; Zeraouli, Y.; Mourad, Y. Energy consumption and efficiency in buildings: Current status and future trends. *J. Clean. Prod.* **2015**, *109*, 118–130. [CrossRef]
48. Foucquier, A.; Robert, S.; Suard, F.; Stéphan, L.; Jay, A. State of the art in building modelling and energy performances prediction: A review. *Renew. Sustain. Energy Rev.* **2013**, *23*, 272–288. [CrossRef]
49. Shabani, A.; Zavalani, O. Predicting Building Energy Consumption using Engineering and Data Driven Approaches: A Review. *Eur. J. Eng. Res. Sci.* **2017**, *2*, 44–49. [CrossRef]

50. Attia, S.G.; Hamdy, M.; Carlucci, S.; Pagliano, L.; Bucking, S.; Hasan, A. Building performance optimization of net zero-energy buildings. In *Modeling, Design, and Optimization of Net-Zero Energy Buildings*; John Wiley & Sons Ltd.: Berlin, Germany, 2015; pp. 175–206. [CrossRef]
51. Vite, C. Decision-making methods applied to regenerative process of existing buildings. *Tema Technol. Eng. Mater. Archit.* **2016**, *2*, 31–41. [CrossRef]
52. Tian, Z.C.; Chen, W.Q.; Tang, P.; Wang, J.G.; Shi, X. Building Energy Optimization Tools and Their Applicability in Architectural Conceptual Design Stage. Energy Procedia. In Proceedings of the 6th International Building Physics Conference, IBPC, Torino, Italy, 14–17 June 2015; Volume 78, pp. 2572–2577. [CrossRef]
53. Weytjens, L.; Verbeeck, G. Towards "architect-friendly" energy evaluation tools. In Proceedings of the 2010 Spring Simulation Multiconference, SpringSim'10, San Diego, CA, USA, 11–15 April 2010; Society for Computer Simulation International: San Diego, CA, USA, 2010; pp. 1–8. [CrossRef]
54. Wenger, E. *Communities of Practice: Learning, Meaning, and Identity*; Cambridge University Press: New York, NY, USA, 1998. [CrossRef]
55. Touloupaki, E.; Theodosiou, T. Optimization of Building Form to Minimize Energy Consumption through Parametric Modelling. *Procedia Environ. Sci.* **2017**, *38*, 509–514. [CrossRef]
56. U.S. Department of Energy's (DOE). EnergyPlus™. Available online: https://energyplus.net/ (accessed on 28 December 2020).
57. Thermal Energy System Specialists, LLC. TRNSYS. Available online: http://www.trnsys.com/ (accessed on 28 December 2020).
58. Grasshopper. Available online: https://www.grasshopper3d.com/page/download-1 (accessed on 28 December 2020).
59. Autodesk, Inc. Refinery. Available online: https://dynamobim.org/project-refinery-0-62-2-now-available/ (accessed on 28 December 2020).
60. Deb, K.; Pratap, A.; Agarwal, S.; Meyarivan, T. A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Trans. Evol. Comput.* **2002**, *6*, 182–197. [CrossRef]