Urban Morphology, Environmental Performance and Energy Use: Holistic Transformation of Porto di Mare as Eco-District Via IMM

Carlo Andrea Biraghi, Tommaso Mauri, Maria Coraly Mazzucchelli, Elena Sala, Massimo Tadi, and Gabriele Masera

Abstract

The impact of urban development on climate change is now evident, threatening the living conditions of a growing number of people in developed and developing countries. On the one hand, there is the need to limit soil consumption and urbanisation rates, whereas, on the other hand, the presence of slums and brownfields within formal urban contexts compromises the living conditions in the neighbouring areas. Given the complexity of the topic, a holistic, multi-scale and multi-disciplinary approach is required. This article presents a case study of integrated actions applied at the neighbourhood scale, using the Integrated Modification Methodology (IMM) conceived at Politecnico di Milano, which refers to the built environment as a complex adaptive system (CAS). The IMM is an iterative multi-stage and multi-layer process applied to urban CASs to improve their metabolism and environmental performance. The IMM approach to sustainability is aligned to the UN Sustainable Development Goals (SDGs) 2030 as a systemic methodological interpretation of the SDG11, which suggests local-based actions firmly linked with targets and indicators. Inside IMM, this role is played by the Design Ordering Principles (DOPs), a system of integrated actions and evaluation measures for simultaneous improvements in environmental performance, social inclusion and urban metabolism. The study case is the area of Porto di Mare, located on the south-eastern border of the city of Milan, bounded by important infrastructures, between the city centre and the rural belt surrounding the Milanese metropolitan area. The proposal of an Eco-District for the Porto di Mare area is an opportunity to demonstrate the potential implications of a sustainable regeneration process on territorial low-carbon energy planning strategies, with a significant impact on a larger part of the city. This article presents the process of local optimisation of the Eco-District masterplan by acting on morphological and typological parameters to simulate alternative design scenarios and evaluate their performance using the visual programming interface of a BIM software. The main performance aspects that are considered are thermal loads of buildings, outdoor comfort and energy use intensity. This challenge raised some relevant research questions: is there a plausible amount of the Gross Floor Area (GFA) value which can be considered coherent from an energy and environmental point of view? Which could be the connection between this parameter, the morphological volume and the energy performance at a district scale? How can the Eco-District be evaluated from a sustainable point of view? The presented strategy for the exploration of alternatives, based on existing energy modelling tools, gave an answer to most of the open questions presented here, showing a replicable approach for similar problems and contexts.

Keywords

Urban regeneration • Eco-district • Parametric design • Sustainability

1 Introduction

The impacts of urban development on climate change are evident. More than 70% of the environmental impact of people is determined by where they live, how they commute

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and what they eat (ANCE, 2013). This raises issues that threaten the living conditions of a growing number of people in both developed and developing countries. If, on one the hand, there is the need of limiting soil consumption and urbanisation rates, on the other hand, the presence of brownfields within formal urban contexts compromises the living conditions of the neighbouring areas.

Milan is rapidly gaining importance in the international panorama, attracting people and investments. This process leads to important urban transformations, which started before the Expo 2015 with the completion of the Porta Nuova and City Life areas, continuing also in other important areas through a series of competitions such as the Farini Railway scale one and the two editions of the Reinventing Cities C40, involving 11 sites in 2 years. In the next 10 years, an amount of nearly 10 billion of euro is expected to be invested into the redevelopment of the few remaining available areas (Dezza, 2019). The question, apparently, is therefore not if Urban Transformation Areas (ATU) will be developed or not, but only how and when this process will happen. In this context, designers are asked to minimise the impact of these inevitable transformations not only at the site level, but also trying to implement projects integrated with the surrounding urban subsystems. Given the complexity of the topic, a holistic, multi-scale and multi-disciplinary approach is required.

This article presents a case study of integrated actions applied at the neighbourhood scale and based on a rigorous methodology named "Integrated Modification Methodology" (IMM), which refers to the built environment as a complex adaptive system (CAS) (Tadi et al., 2020). The case presented here is the area of Porto di Mare (ATU 15, PGT[1] Milan 2030), located on the south-eastern border of the city of Milan, bounded by important infrastructures, between the city centre and the rural belt surrounding the Milanese metropolitan area. This area was included into the Europan 12 competition and has recently become property of the municipality after years of abusive settlements and abandonment.

To achieve these goals, an integrated proposal for an Eco-District has been elaborated in accordance with both public and private partners (Milano Depur S.p.a.–Depuratore Milano Nosedo; REsilienceLAB; Gruppo Ecologisti Est Milano–GREEM; Associazione Piccole e Medie Industrie di Milano–API Milano; Wageningen University and Research–WUR). The Eco-District systemic and bottom-up approach tries to act on people, making sustainable behaviour much easier than elsewhere and transforming users into more sensible agents (EcoDistricts, 2014).

[1] Piano di Governo del Territorio (PGT), urban planning tool of Milan Municipality.

2 The Integrated Modification Methodology (IMM) and Its Application to the Porto di Mare Area

The IMM is a phasing process comprehending an open set of scientific techniques for morphologically analysing the built environment in a multi-scale approach and estimating its performance for the actual state or alternative design scenarios. It is a nonlinear phasing process aiming at delivering a systemic understanding of any existing urban context, formulating the modification set-ups with the aim of improving its performance and examining the modification strategies to transform that system. The IMM methodology has been developed at the Department of Architecture, Built Environment and Construction Engineering (DABC) of Politecnico di Milano and considers cities as complex adaptive systems (CAS) consisting of different interacting subsystems: environmental (energy, water, food, transport, health, biodiversity), economic, social and cultural ones. It analyses the correlation between urban structure and environmental performance through a set of scientific and rigorous procedures, among which a wide range of indicators aligned with the 17 UN Sustainable Development Goals (SDGs) for 2030.

Two main factors distinguish this research from similar studies:

- the holistic approach through which the built environment is regarded as a multidimensional synthesis of various systems;
- the intention of visualising mathematical-based predictions of transformation reactions to possible intervention scenarios.

The IMM represents a support tool for transformation and management decisions, flexible enough to conceptually expand with respect to the multi-finality of the built environment and its various environmental and socio-economic subsystems. It is based on a nonlinear phasing process involving the following structure:

- Phase I. Diagnostic: Analysis and Synthesis;
- Phase II. Assessment and Formulation;
- Phase III. Intervention and Modification;
- Phase IV. Retrofit and Local Optimisation.

In the first phase, urban components (Volume, Void, Network, Type of use) are first investigated individually, and subsequently, the emergence of their synergetic interaction, called Key Categories (KCs), can be considered. In the IMM, KCs are a new organisation emerging from the elementary parts, although not as a simple additive result of their properties. By modifying the components or the way in which they interact, different organisations emerge with the possibility of either improving or worsening the current system condition. In the IMM, the Key Categories are as follows: porosity, permeability, diversity, proximity, accessibility, interface and effectiveness. The diagnostic of the system is composed of a horizontal (among components) and vertical (across components, among KCs) investigation, showing the weakest elements that are mostly responsible for the current system performance. To estimate the performance of the built environment, the IMM offers an open list of nearly 150 indicators, organised in 12 families, corresponding to the 12 IMM Design Ordering Principles (DOPs) and clustered on the basis of the SDG targets (United Nations, 2015), with the aim of approaching the performance of the built environment from different angles. Figure 1 shows a flowchart describing IMM elements and their interaction.

The IMM indicators' list includes some of the SDG11 indicators (1.1–2.1–6.1–7.1), although it is broader, as the smaller application scale (city vs. country) allows to have a wider set of measurable aspects. The second phase of the IMM process, called "Formulation", anticipates the design phase and is highly connected with it. It moves from the outputs of the Diagnostic Phase, identifying the transformation catalysts thanks to the KCs and their associated indicators. In this second phase, the DOPs play a significant role, represented by a set of integrated tools composed of 12 descriptive guidelines to orient the designer in the arrangement of the CAS structure.

The application of these principles intends to modify the structure of the CAS and, consequently, its performance. Hence, within the IMM methodology and its specific phasing process, a direct link between the SDG targets and DOP actions has been established (Fig. 2).

In the third phase, different transformation design scenarios oriented to local modification (neighbourhoods/local nodes) can be elaborated, with the aim of achieving a positive transformation of the whole urban system. As a consequence of this phase, a new structure of the system, with enhanced performance, will emerge. Subsequently, the new CAS resulting from the transformation phase is retrofitted in the last phase, where it is evaluated and compared with the old one using the same procedure and indicators previously applied in the investigation phase (Phase I); finally, it is locally optimised to reach the optimum modification plan.

The case study of the Porto di Mare area, an important and underdeveloped zone in the south-east of Milano, characterised by an unexpressed potential, is here presented as an example of an innovative Eco-District characterised by a full integration of the infrastructural systems (mobility, building, green–blue infrastructure, physical flows of energy, water and waste) in the design in order to reduce its carbon footprint. In the next section, the Eco-District masterplan, developed engaging local stakeholders, is presented and its performance is compared with the state of the art and with that of an alternative transformation scenario.

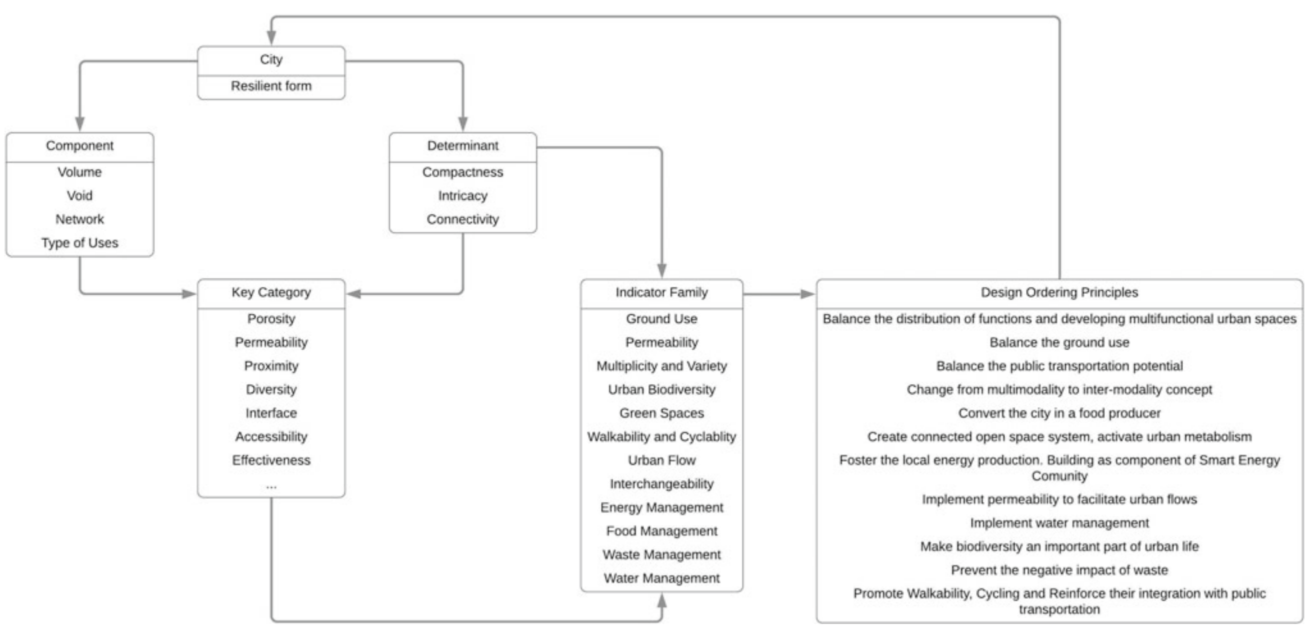

Fig. 1 Flowchart describing the IMM elements and their interaction (Biraghi, 2019)

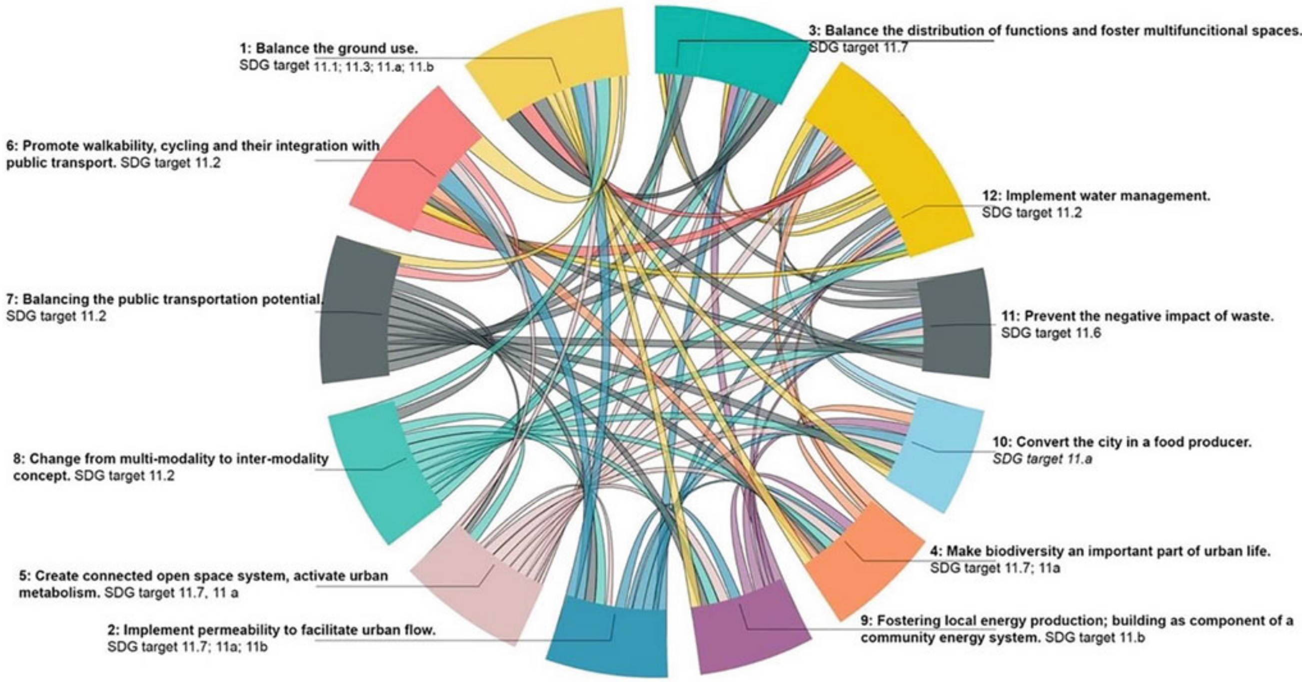

Fig. 2 Diagram showing the interdependency of IMM DOPs and the related SDG11 targets

3 A Masterplan for a New Eco-District at Porto di Mare in Milan

The first two phases, analysis and synthesis and assessment and formulation, widely discussed in Tadi et al. (2019), selected the horizontal (Void component) and vertical (Interface KC) catalysts and provided a site-specific DOP ranking with some design suggestions. Promoting walkability and cycling and reinforcing their integration with public transportation was identified as the priority principle to drive the transformation. A masterplan was then developed to give architectural consistency to all the hints and advices coming from the diagnostic activity. The design process was carried out through two international workshops hosted in the Lecco Campus of Politecnico di Milano in collaboration with the University of Cincinnati, focusing on the energy-related aspects, and the Wageningen University and Research (WUR), integrating the food system into the landscape and urban design. The result was not only an arrangement of volumes but an integrated proposal with attention on qualitative aspects of the open space, modifications to the existing public transportation network and type of uses indications.

Before going into the explanation of the masterplan, reported in Fig. 3, it should be mentioned that all built volumes have been established on the portion of soil, property of the municipality, already consumed and currently occupied by informal illegal settlements whose demolition is already foreseen.

Starting from the northern corner of the area, the first modification involved the existing metro stop. A simple exit facing a highly congested street has been integrated into an interchange hub where it is possible to switch to both different individual and public transportation modes, encouraging soft mobility solutions. The street network has been modified to host a large pedestrian area in correspondence with the hub, characterised by safe paved ways surrounded by green cool islands. In this area, another key function of the district, the local food market, has been established because of its high level of accessibility given by the proximity to both roads and open landscape. This intervention connected an existing garden located in the bottom part of a large block with a dozen of social housing buildings to the public park “Gino Cassinis”, fading into the countryside towards south. From that area, a north–south green spine delimitates the buildable area on the left from the surrounding natural one on the right. This vertical urban axis is balanced by the presence of a horizontal natural corridor connecting the countryside with the agricultural area located in the top-left corner beside Cascina San Giacomo and the Nocetum association offices. A system of finer grain green public and semi-public spaces permeates the residential blocks, offering a diversified outdoor experience. The natural landscape, result of the incomplete projects for the creation of a Milanese harbour developed in the twentieth century, is

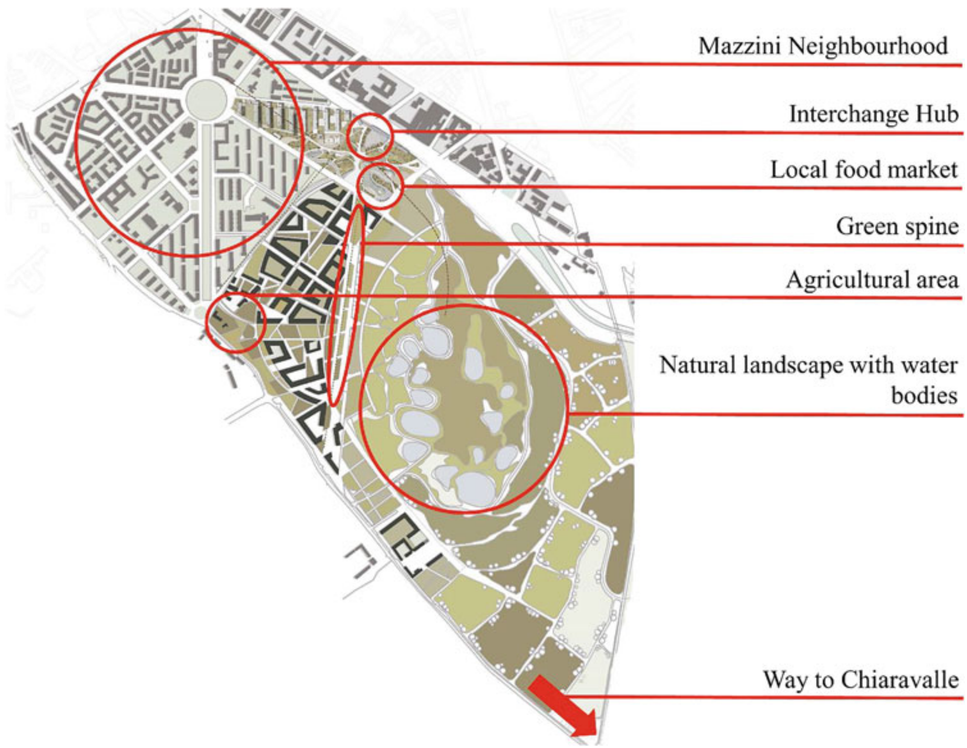

Fig. 3 Porto di Mare masterplan (Tadi et al., 2019)

preserved and integrated with water bodies for climate mitigation and recreational fishing activity. The presence of water is somehow natural in this area, which is the lowest of the Milanese context in terms of height above sea level and where the aquifer is almost superficial.

To support the decision of a whole car-free district, a local electric bus line crosses the area, stopping along the spine, and into the existing street network, forming a loop that serves both the new and the existing inhabitants. In addition, the existing cyclable network coming from south and connecting to Chiaravalle and La Valle Dei Monaci is extended inside the district and over, reaching the three main city train stations (Centrale, Garibaldi and Rogoredo), intercepting and reconnecting existing network segments. Buildings along the main axis of the district are mix-use, with the presence of commercial and community spaces at the ground floor also to balance the lack of services of the nearby Mazzini neighbourhood, characterised by a zoning approach with few blocks containing all the public buildings surrounded by linear popular residential buildings fenced together. The typology of the court has been used to increase the sense of enclosure, totally missing, to limit the amount of residual space, and as a typology suitable for hosting social housing, representing more than 30% of the residential offer. The same set of maps used in the investigation phase to represent the state of the art (Tadi et al., 2019) is used here to show the Eco-District transformation scenario, drawing a profound vision transformation impact on the CAS. Key category maps[2] (porosity, proximity, accessibility, diversity, effectiveness and interface), representing a functional symbiosis between the four component layers, are reported in Fig. 4.

To provide a better assessment of the impact on environmental performance, an alternative transformation scenario has been tested against the Eco-District 1 and the starting condition. This project has been developed by students of the course Architectural Design Studio 2 of the Politecnico di Milano, held by Professor Michele Caja, under the supervision of Arch. Carlo Andrea Biraghi and Sotirios Zaroulas in the academic year 2017/2018 (Biraghi, 2019). Each group was in charge to design a set of mix-use buildings in a predefined grid of blocks with maximum heights allowed. For doing that, a subset of 25 IMM Performance Indicators, covering 10 out of the 12 families,[3] has been used to obtain a preliminary understanding of the transformation impact. The full list of indicators is reported in Table 1, with each of them indicating the IMM family, the progressive number inside the IMM indicator list, the name and the acronym, the value for the three different system arrangements and the ranking position in respect to the other

[2] Permeability Key Category map has not been included as, at the time of the diagnostic of the state of the art (Tadi et al., 2019), its representation was not yet implemented.

[3] Waste management family has not been included because for a lack of data. Energy management family has been treated separately in more detail in Sect. 4.

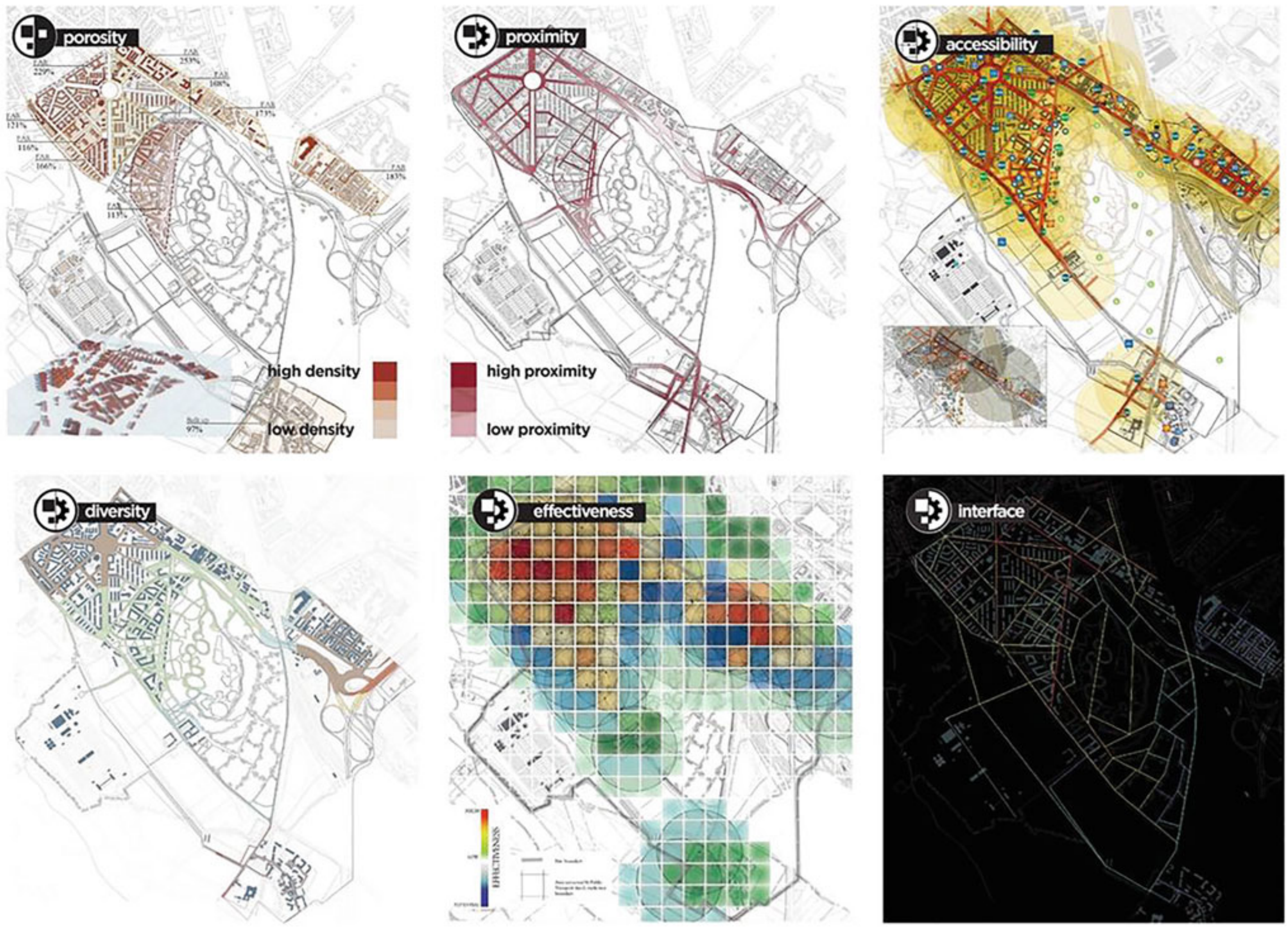

Fig. 4 Key category maps of the Eco-District proposal: porosity, proximity, accessibility, diversity, effectiveness and interface

Table 1 Performance assessment of the three compared scenarios using a subset of IMM indicators

Indicator family	Nr	Indicator	Acr	State of the art		Eco-District		Alternative scenario	
				Value	Rank	Value	Rank	Value	Rank
1 Ground use	1	Volume density	VD	2.42	45	4.19	26	3.77	29
	2	Building density	BD	417	43	401	43	419	43
	3	Population density	PD	8926	34	9405	32	9332	32
2 Permeability	5	Street cover ratio	SCR	0.18	46	0.24	31	0.22	36
	8	Block density	BLD	0.24	38	0.32	32	0.27	36
3 Multiplicity and variety	11	Population activities ratio	PAcR	13.65	33	12.7	33	12.85	32
	13	Job housing ratio	JHR	0.27	64	0.29	61	0.28	63
4 Biodiversity	17	Land use share	Lush	0.89	3	0.94	1	0.94	1
5 Green spaces	26	Green coverage ratio total	GCRt	0.35	35	0.32	39	0.41	27
	28	Green coverage ratio urban	GCRu	0.14	52	0.22	26	0.16	42
	29	Tree density	TD	2960	19	3176	16	3158	17
6a Cyclability	31	Bike lane density	BikeD	433	54	2381	5	1948	12
	32	Bike lane average length	BikeAl	63	47	521	1	485	1

(continued)

Table 1 (continued)

Indicator family	Nr	Indicator	Acr	State of the art		Eco-District		Alternative scenario	
				Value	Rank	Value	Rank	Value	Rank
6b Walkability	41	Node density	ND	104	48	113	43	107	48
	45	Accesses per block	AxBLP	1.88	59	1.86	60	2.15	53
	48	Ground floor activities	GFAc	0.49	41	0.58	32	0.59	32
7 Flows	50	Public transportation accessibility	PTA	0.93	65	1.26	58	0.96	63
	51	Road per capita	LIPR	1.32	67	1.7	46	1.3	68
	42	Dead-end nodes ratio	NDER	0.15	45	0.13	54	0.13	54
8 Interchangeability	67	Transportation mode share	Modesh	0.67	33	0.88	15	0.67	33
	68	Metro line share	MMsh	0.2	30	0.2	30	0.2	30
	69	Stop density	StopD	15.7	58	17.03	55	15.94	58
	70	Line density	LineD	5.5	73	5.8	71	5.5	73
10 Food management	78	Green coverage ratio agricultural	GCRa	0.22	22	0.1	22	0.25	18
12 Water management	86	Water area ratio	WAR	0	40	0.08	2	0	47
			Perf. index	41		14		21	

87 Nuclei of Local Identity (NIL), a neighbourhood-like partition existing in the city of Milan. A 3D view of the three layouts (State of the art, Eco-District and Alternative scenario) and a plan of NIL 35 Lodi-Corvetto, including the Porto di Mare transformation area, are shown in Fig. 5. An overall simplified performance index was used here to obtain a synthetic performance value, calculated giving the same weight to all indicators and using the rank as a shared unit of measure. In this sense, a higher overall performance ranking among the NIL means a more sustainable design proposal.

This analysis showed, as expected, an improvement in respect to the state of the art for both transformation scenarios, with better results for the Eco-District proposal mainly because of the higher attention to the network component both in terms of public transportation integration and relationship with the countryside, managed with a smoother transition. Having consolidated this result, a finer grain optimisation process was carried out, focusing on thermal loads of buildings, outdoor comfort and energy use intensity.

4 Local Optimisation Via the Multi-layered Modelling Process

Once the overall arrangement of the masterplan was defined based on the process described above, a local optimisation process was started to assess the impact of smaller scale design decisions, regarding typological aspects, such as the roof shape, but also micro-modifications to the overall design layout (Li et al., 2016) and even technological choices. In this case study, the investigation specifically regarded some energy-related aspects that are used to evaluate the achievement of the following design principles:

– roads should be sunny during winter and shaded in summer (Li et al., 2016);
– south facades should be exposed to sun in winter and mid-seasons and shaded in summer (Johansson, 2006);
– roofing should avoid receiving shade to maximise electricity production from PV panels (Compagnon, 2004).

The indicators that will be used to assess the effects of the design choices belong to the Energy Management Family and are therefore part of the wider set of indicators of the IMM methodology:

– energy use intensity (EUI);
– solar radiation falling on the south-oriented surfaces;
– potential production of renewable energy from roof-mounted photovoltaic panels;
– solar radiation falling on the ground.

The local optimisation process will focus on the variation of these aspects at the building scale:

– building height;
– floor plan depth;
– roof slope;

Fig. 5 NIL #35 plan with ATU 15 perimeter highlighted and 3D aerial view from Via Fabio Massimo of the three compared scenarios for ATU 15: state of the art; Eco-District; Alternative transformation scenario (Biraghi, 2019)

- average U-value of the building envelope (perimeter walls, windows and roofs);
- window-to-wall ratio (WWR).

To control the variation of these parameters and obtain the related values for the indicators, a multi-layered modelling process was implemented, exploiting the dynamic synergies between a proprietary BIM software (Autodesk Revit) and its visual programming plug-in Dynamo, an open-source computational software which extends the BIM domain with the data and the logic environment of a graphical algorithm editor. Dynamo was crucial to automate repetitive tasks through the creation of scripts that allowed to handle multiple combinations of parameters in a manageable time. The modifications to the geometry of buildings were managed via an algorithm inside Dynamo developed by the authors, and energy analysis was managed through Green Building Studio, a flexible cloud-based service by Autodesk, running building performance simulations to optimise energy efficiency from the early design process (Mousiadis & Mengana, 2016). During this relatively early stage of design, energy analysis was performed using a combination of Revit conceptual masses and building elements.

It must be highlighted that the intervention area was of particular interest for an additional reason related to institutional planning procedures. From one edition to the other of the PGT, the admissible GFA to be located increased from 127,719 m^2 in 2015 to 819,761 m^2 in 2020. This raised the question of which could be an acceptable amount of GFA in this extremely large range, considering the overall goals of energy efficiency and comfort. A preliminary analysis of the resulting building masses led the authors to cap the allowable GFA to 260,000 m^2, in the hypothesis of a relatively consistent height of the buildings across the site (i.e. no towers or very tall blocks) (Fig. 6).

To deal with a more manageable amount of data, the masterplan was divided into three sectors (1 pink, 2 yellow, 3 light blue) by the main south-east/north-west axis, going from the countryside to the city. Each building was then classified into five parametric typological families identified by a letter (C: “C” shape open court; CC: closed court; L: “L” shape; P: parallelogram; T: triangle; PE: customised shape). Combined, this information forms an alphanumeric code (i.e. C_1_A) uniquely identifying a specific building (Fig. 7). Moreover, height limits are defined in relationship to the surrounding context to assure a coherent urban transition from city to countryside, as indicated in PGT 2015.

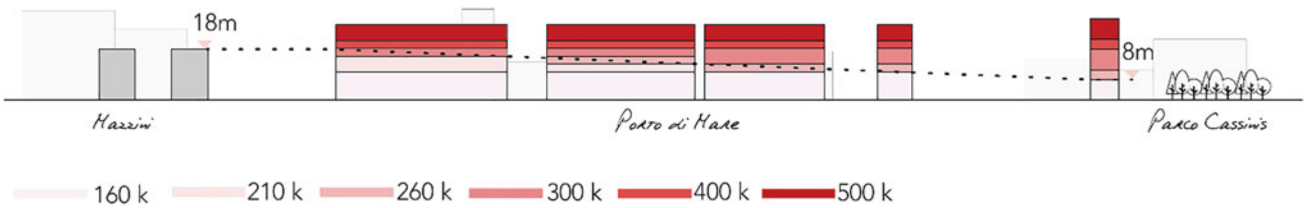

Fig. 6 Cross section for determining the maximum admittable height to provide a smooth urban transition from the existing city to the surrounding green areas

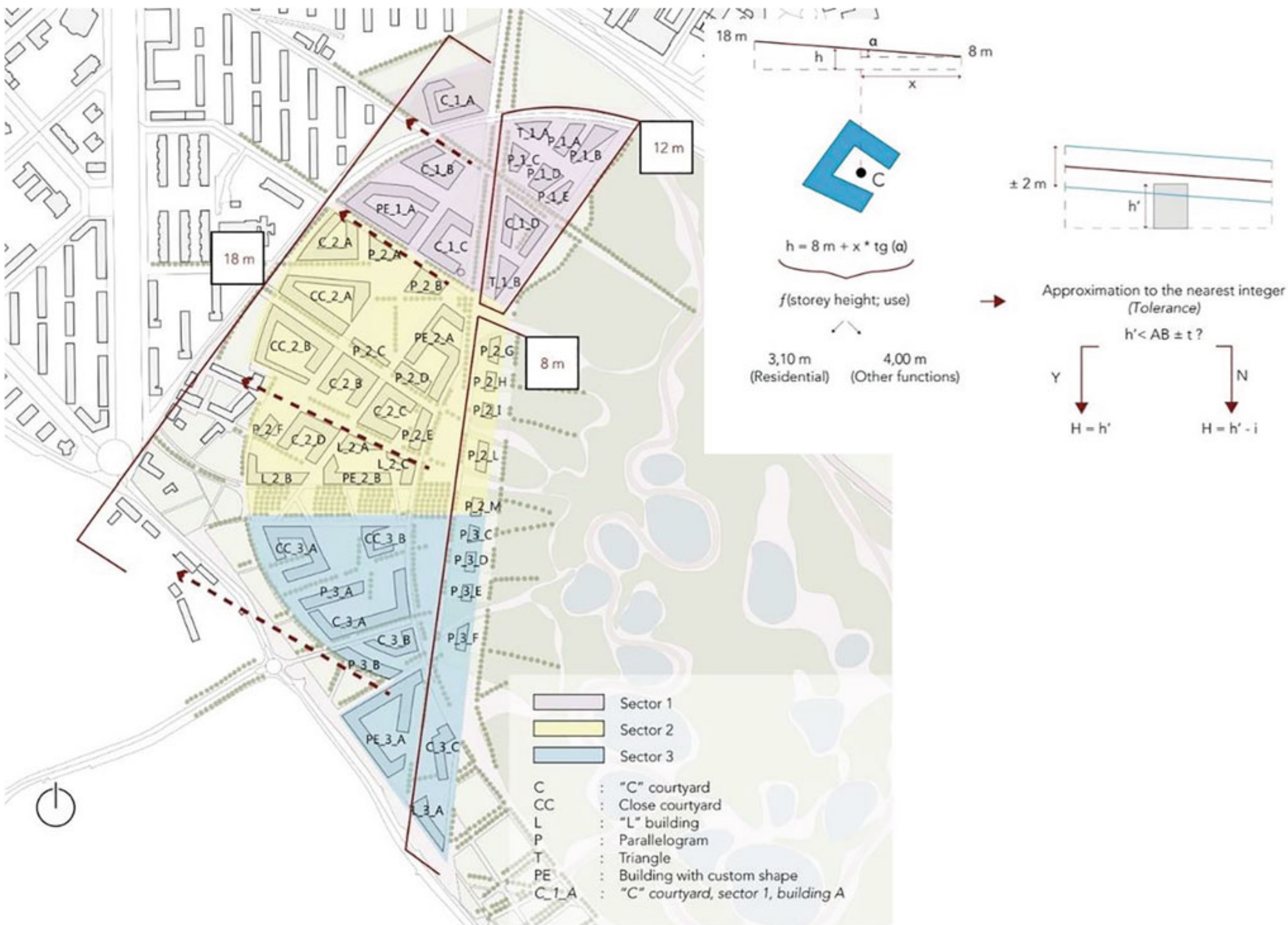

Fig. 7 Masterplan subdivision and building typological classification for modelling purposes

The height of the tallest buildings on Via Fabio Massimo (18 m) was used as the upper limit, whereas at the lower end, two-storey agricultural buildings (approx. 8 m) were used as reference (Mauri et al., 2018). Volume modelling followed three steps:

– creation of an inclined plane corresponding to the 8–18-m-high line;
– mathematical evaluation of building height (as a function of storey height and use);
– verification of the height value with the tolerance range.

Considering the aspects mentioned above, the multi-layered modelling therefore presents 54 scenarios resulting from all the possible combinations of the following variables:

– three GFA configurations: 160 k m^2–210 k m^2–260 k m^2;
– two U-value scenarios for building envelope components: "Law" (mandatory values) and "Top" (improved);
– three cases with different window-to-wall ratios (WWR): 15% (baseline), 30% and 50%;

- three footprints: the one defined by the masterplan (1), fixed at 12 m (2) or increased by 10% (3);
- two roof geometry types: constant height or decreasing heights (computed according to the previously illustrated principle).

Evaluation of energy use intensity (EUI)

The starting case for this investigation is named “Baseline, 1” and corresponds to the masterplan presenting the following characteristics: a GFA of 160 k m^2, a “Law” U-value, constant building height and no footprint modification in comparison to the original proposal.

To perform whole-building energy simulations, Revit exploits the built-in plug-in Energy Analysis. This add-in provides an estimate of the expected energy use (fuel and electricity) based on the building’s geometry, climate, type, envelope properties and active systems (HVAC and lighting). Through this analysis, the 54 possible cases were analysed, and among them, only 7 showed better EUI performances than the reference case “Baseline, 1”, as shown in Fig. 8. For each case of GFA, the best geometric configuration was Type 3, corresponding to a footprint increased by 10%, meaning a more compact arrangement of volumes.

The results show that the differences in the various scenarios refer mainly to the cooling and heating parameters. As an example, in Fig. 9, the outcomes for the 160 k m^2 configuration with the U-values required under the current law are shown according to the different window-to-wall ratios: since Type 3 always performs better, it was selected for further analyses.

Solar radiation on south-facing surfaces

Analysis of solar radiation falling on surfaces facing south shows that it decreases as the total GFA increases, as this is translated into taller buildings and a more mutual shadow cast by the volumes (Fig. 10). Furthermore, Type 3 showed a lower average annual solar radiation than the other configurations, resulting in a lower requirement of energy for cooling (Fig. 9); its more compact arrangement of volumes compensates for the reduced access to solar radiation in winter. The results obtained confirm the hypothesis that geometry and compactness are significantly linked to the overall energy requirement.

Solar radiation falling on the ground

Subsequently, the correlation between GFA and annual average radiation falling on the ground was examined as an indicator of potential comfort conditions in the open spaces, concluding that, for the selected masterplan, there is an inversely nonlinear correlation between the two variables, as shown in Fig. 11. The results given by the simulation of the

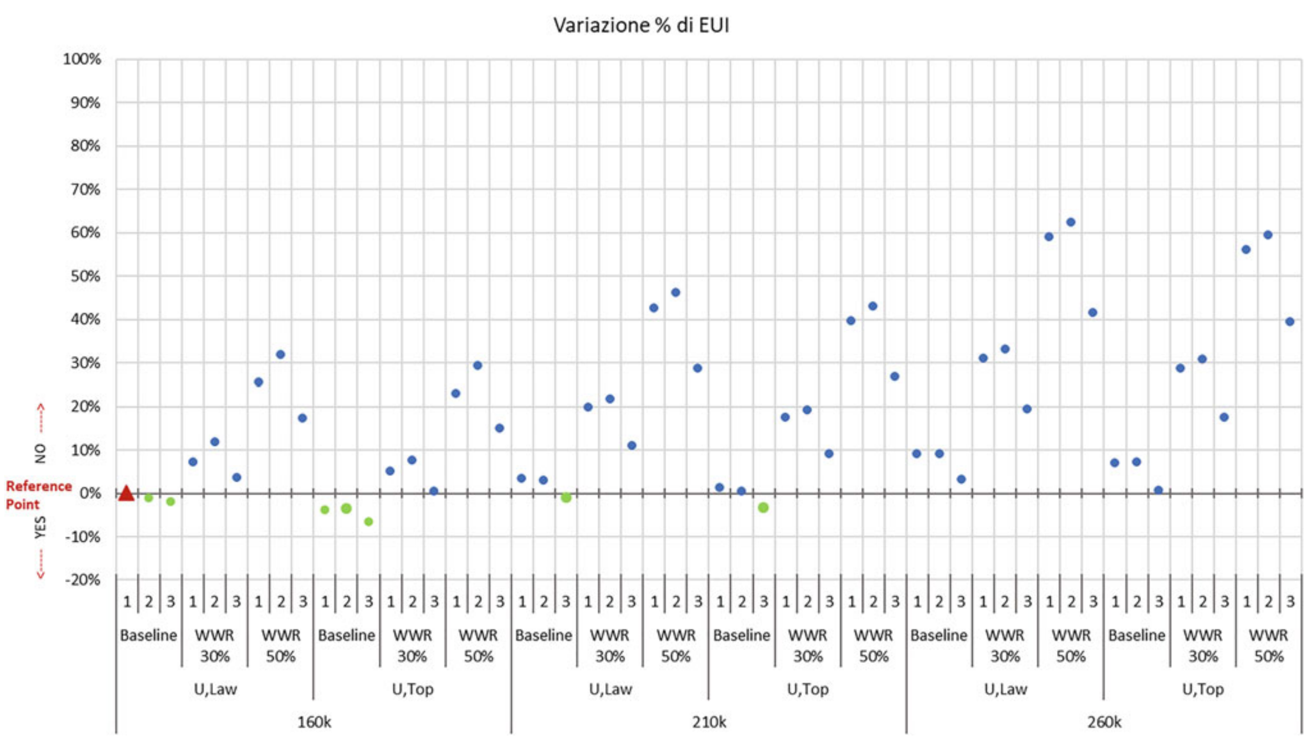

Fig. 8 Comparison of the 54 scenarios resulting from the combination of the modelling parameters

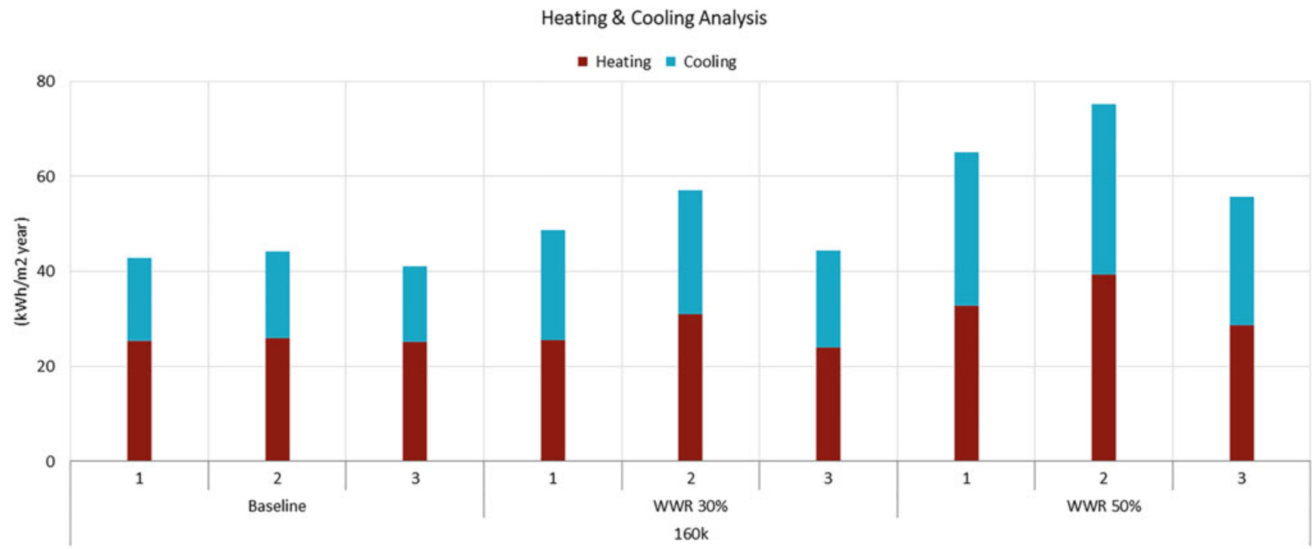

Fig. 9 Heating and cooling analysis for the different configurations of the 160 k m^2 scenario

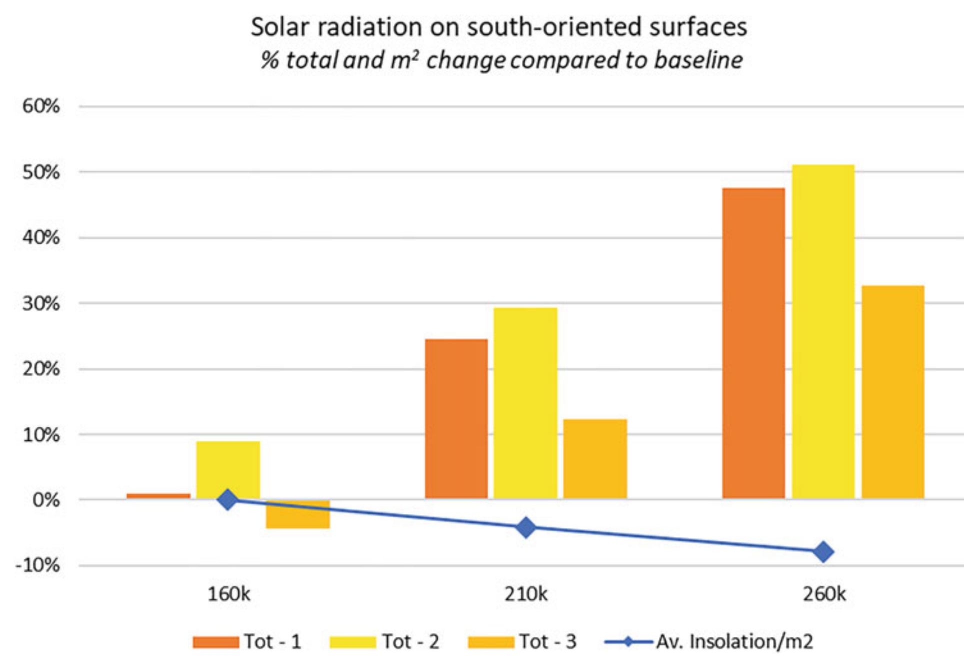

Fig. 10 Graph showing the solar radiation on south-oriented surfaces: total and variation per m^2 compared to the reference case "Baseline, 1"

different scenarios were projected through polynomial trendlines, chosen for R2 values very close to 1 (indicating the maximum reliability).

Roof geometry

Once the analyses on solar radiation incidence were concluded, it was possible to investigate the correlation between the roof type of the buildings and their implication on the potential energy production by photovoltaic panels, designed to offset at least part of the energy consumption calculated above.

Three different roof geometry configurations were simulated: single pitch (10° inclination across the whole site), south-inclined (10° north–south inclination through the barycentre of each building to increase solar exposure) and flat. This led to a total of 66 different scenarios. By analysing the output given on the heating and cooling needs (EUI), it was clear that the roof morphology has a considerable impact on the energy requirement, since the inclined solutions showed an average energy saving of about 5% compared to the flat roof scenarios and a 10% higher electricity production by photovoltaic panels.

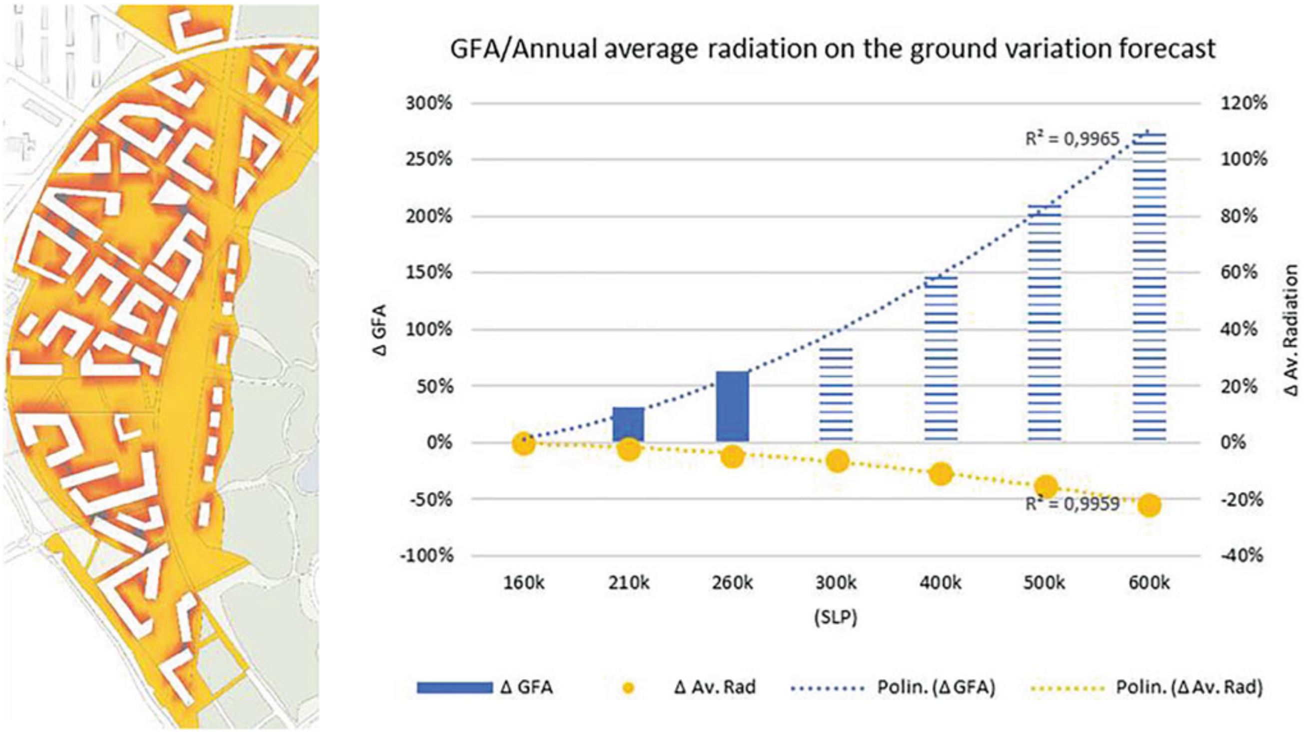

Fig. 11 Solar radiation on the ground and variation forecast

Based on these results, it is possible to understand the evolution of the trend of the overall EUI (including both energy required and energy produced by photovoltaic panels) as a function of the variation of the GFA (Fig. 12).

The forecast shows a widening gap between the two projections as the GFA increases. As the geometrical parameters (height and footprint) remain constant, a non-linear correlation between GFA and EUI is visible due to the growing density of the district, leading to more shade and a smaller impact of the energy produced by photovoltaic panels since the roof surfaces remain the same, while the floor area to be heated and cooled increases.

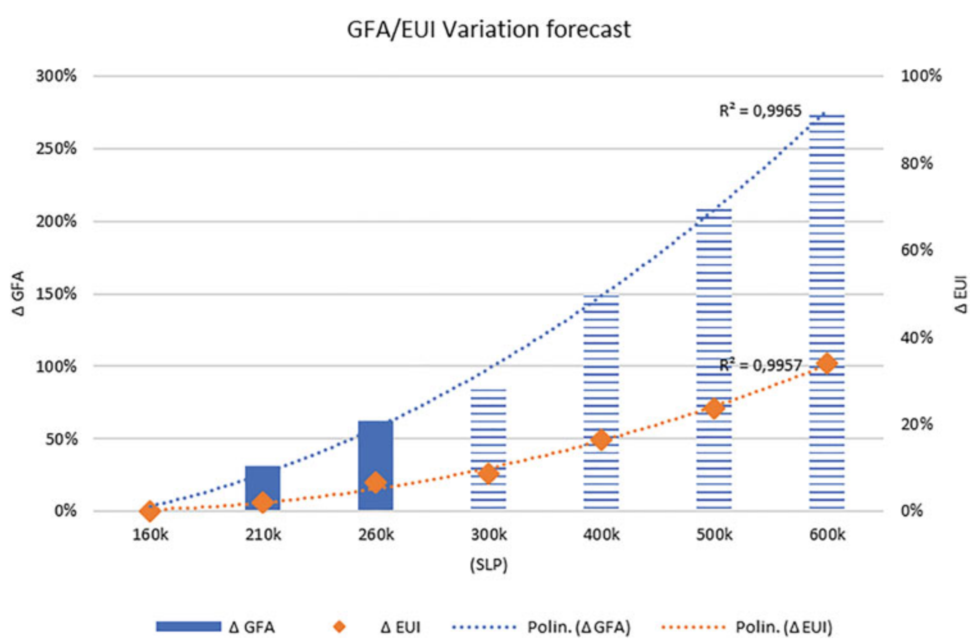

Fig. 12 GFA/EUI variation forecast graph

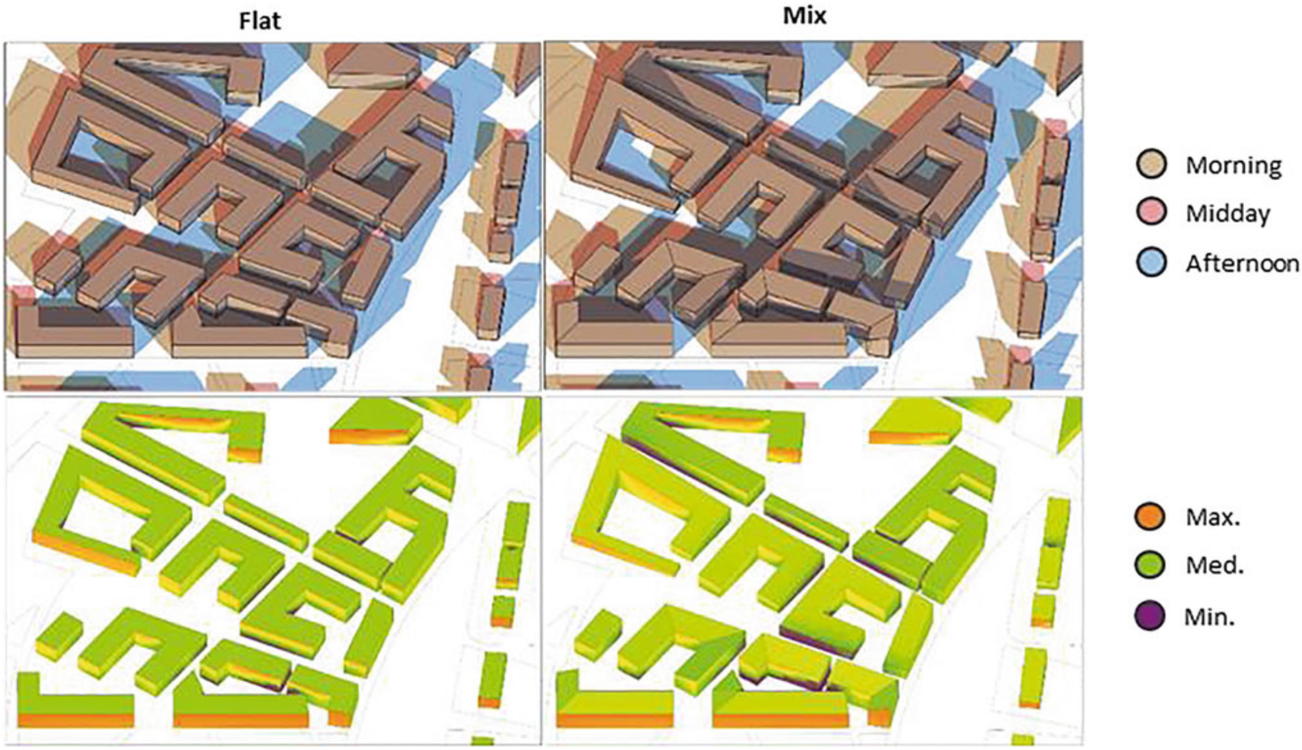

Fig. 13 Shadow (up) and solar radiation (bottom) analysis in sector 2. Comparison between flat and mixed roofing

Introducing variations

The process described above provides an overall picture of how the selected indicators react to design solutions applied to the whole district without any differentiation. To achieve more diversity in the volumes and the architectural expression of the new city, it was imagined that the actual design will be a combination of the configurations with the better performances.

The masterplan was therefore divided into six sectors, where different building types were mixed and shadow analyses were performed to assess the achievement of the goals stated at the beginning of this paragraph. For this study, only a qualitative analysis was carried out considering shadow cast on the ground and on the neighbouring buildings. The best configuration determined the typology of roofing for each specific sector; the new mixed district composition was analysed to verify the above criteria and to obtain details about energy use, solar radiation and shadows. This method was applied for each satisfactory GFA configuration in winter, summer and mid-seasons, evaluating the shadows in the morning, at mid-day and in the afternoon.

Finally, to most effectively evaluate the interactions among buildings, projected shadows in Sectors 2 and 3 were more precisely analysed by further subdividing the buildings into subgroups and evaluating the incident average radiation per square metre on facades and roofs. The analysis highlighted that with increasing building height, the impacts of the roof geometry decrease. Figure 13 shows the 160 k m^2 configuration as an example: it is possible to detect some differences between the flat and the mixed roofing, which can provide a better production by photovoltaic panels and a more efficient energy profile.

5 Conclusions

We used a case study transformation area to demonstrate the advantages of the application of the IMM methodology and its integrated and holistic approach for the redevelopment of an area. The application to an area in a large city of a developed country confirms the flexibility of the methodology, previously successfully applied also in informal settlements (Masera et al., 2020). While Tadi et al. (2019) focused on the Diagnostic and Formulation phases, here, the attention is on the Modification, Retrofitting and Local Optimisation phases. The overall assessment of a district performance via IMM methodology is effective and able to grasp differences between alternative transformation scenarios even in a partial application of its indicators. Local Optimisation demonstrated how a consistent improvement in the energy performance of a district can be obtained with minor morphological modifications.

This showed how a simplified volumetric masterplan can be sufficient to measure performance aspects related to urban dynamics and the interaction with the surroundings, whereas energy aspects benefit from a finer grain investigation. Parametric design tools were used not for the automatic generation of shapes (form-finding), but rather to adjust a given layout on the basis of minor typological building modifications (height, floor plan depth, roof, WWR).

The presented modelling strategy provides a possible answer to some open questions, showing a possible replicable approach for similar contexts. Given the urban features of the Porto di Mare context and the existing regulations, three scenarios of GFA were considered acceptable and coherent from both the energy use and the environmental point of view: 160 k, 210 k and 260 k m^2. Another interesting result is the benefit for the energy consumption provided by an increase of 10% of the actual building footprint (i.e. deeper floor plans) for each GFA scenario.

Given the lack of obstructions, in this case study, it is suggested to adopt inclined roofs towards the south to maximise the incidence of solar radiation and therefore increase the potential for energy production by photovoltaic panels. An accurate local evaluation of roof types, adopting mixed solutions at the smaller local scale, can provide advantages by avoiding self-shadowing and improving the outdoor comfort for users.

From a building technology point of view, the thermal transmittance values provided by the law are considered acceptable, but a better insulation, especially for the opaque components, is strongly suggested given the evident advantages of the improved scenarios. Finally, it is suggested to not exceed a value of 15% of window-to-wall ratio.

The potential given by a dynamic control of design parameters through specific tools can be exploited even while working on building masses at an intermediate design stage, providing precious insights for the designers.

A better investigation of social and economic aspects, albeit not neglected, could ultimately provide a complete and effective tool for decision-makers to evaluate the current level of urban system performance and the impacts of future transformations. In addition, new data sources such as satellite images, sensors and citizen science data will be explored and integrated in the performance assessment to grant a more reliable and up-to-date picture of the behaviour of the urban system.

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