# Planning City Refurbishment: an Exploratory Study at District Scale

## How to move towards positive energy districts – approach of the SINFONIA project


Yvann Nzengue, Adrien du Boishamon, Karine Laffont-Eloire
TECHNOFI
Professional in management and innovation
France, Sophia Antipolis
klaffont@technofi.eu

Vincent Partenay, Yassine Abdelouadoud
CSTB
French Building Research Institute
France, Sophia Antipolis

Pietro Zambelli, Valentina D'Alonzo, Roberto Vaccaro
EURAC Research
Institute for Renewable Energy
Italy, Bolzano



***Abstract*— This paper presents an exploratory study on planning city refurbishment for the energy transition of Smart Cities. This study was carried out at the district scale in a European pilot city. The applied district template approach is inherited from the EU funded project SINFONIA. We describe this approach which was first explored in the city of Bolzano, based on the analysis of spatialized datasets. The different districts types are first identified and their energy consumption is simulated with a specific tool developed within SINFONIA. In addition to providing key information on the different district types (e.g. energy consumption), the simulations allow to identify the districts with the highest potential for energy refurbishment. The corresponding potential gains, in terms of heat demand, are then simulated in order to confirm how the city refurbishment plans should prioritize the different districts. This is a first step to support, in a quantitative way, the complex exercise of planning urban refurbishment. Our explanatory study confirms the interest of the district template approach. Routes to improve the approach and replicate it to other European cities to demonstrate its relevance are finally presented.**



***Keywords—district template; energy demand; refurbishment plans***


## I. Introduction

Only 1 to 2% of the building stock is replaced annually in the EU; hence, most of the energy savings required to meet Europe 2050 goals must come from existing buildings. However, today's measured rate of refurbishment (1.2%) is much lower than the one that should be observed to remain in line with Europe 2050 ambitions. There is a need to accelerate the large-scale implementation of energy efficient refurbishment solutions and increase the renovation level to 2-3% per year until 2030. This ambition is reflected in several European regulations and roadmaps, such as the Energy Performance of Building Directive, the Energy Efficiency Directive, the SET-Plan (Action 5) and the recent Energy Union Winter Package.

With 80% of European citizens living in urban areas, cities have a crucial role to play in the transition towards a low-carbon economy. Faced with the challenge of ensuring the quality of life of their citizens while becoming more energy efficient, cities must look at the system level and develop integrated urban development strategies that will make them both sustainable and better places to live.

This need for a more systemic approach, with integration at district scale, is the starting point of the SINFONIA project. This five-year initiative aims to deploy large-scale integrated energy solutions in mid-sized European cities to transform existing districts into Low Energy Districts. This will be demonstrated through an integrated set of measures combining the retrofitting of more than 100,000 m² of living surface, optimization of the electricity grid, and solutions for district heating in the pilot cities of Innsbruck and Bolzano. In addition to these demonstrations, new tools and best practices are being developed to pave the way towards the integration of Positive Energy Districts into Smart Cities.

One of these tools is based on the "District template" approach. The central assumption in SINFONIA is indeed that the districts of all medium-sized cities in Europe can be represented by a limited number of district types that are formalized by 'templates'. The districts do not have a pre-defined size and can extend from one building block to a wider area with dozens of blocks (i.e. a functional approach is implemented for more flexibility). The objective of the templates is to facilitate the implementation and replication of large-scale refurbishment plans by providing guidance on the 'optimal' retrofitting solutions for each type of district. Each


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template is therefore associated to a representative set of information on typical baseline consumption. The template also suggests best retrofitting solutions and gives estimates of their potential impacts on energy consumption. A common typology of templates is being developed: a first set of residential templates will be derived from the demonstration in Innsbruck and Bolzano, and the database will be continuously upgraded with new cases, and extended to the non-residential sector.

This paper presents the first steps of exploring the feasibility and adequacy of this "District template" approach in the city of Bolzano.

## II. Relation to existing theories and work

### A. District types

Addressing the energy consumption at the building scale thanks to an in-depth understanding of the factors that influence the energy consumption of archetypes of buildings is a subject widely investigated by the research community. A concrete example is the database developed in the framework of the TABULA project [1], which provides typical energy consumptions for a set of archetypal buildings for a number of European countries. The segmentation is based upon different parameters such as construction types (e.g. single family house, terraced house, multi-family house, apartment block) and construction periods.

At wider scales, district archetypes seem to be less explored. However this scale allows taking into account shadowing effects between buildings and additional energy flows beyond the building envelope, green spaces, roads, and district-based renewable sources. Evidences for such an approach can be found in [2], [3], [4] and [5], which focus on the urban fabric and district morphology, and their impact on heat demand. They highlight that energy consumption in the residential sector highly depends upon the geometry of the urban form. In particular, Maïzia et al. [5] propose a new approach to compare energy consumption for heating and cooling of different types of residential blocks, defined as a group of contiguous land parcels delineated by streets or public spaces, based on energy simulations applied to representative urban blocks.

### B. Energy demand modelling

Numerous modelling tools exist today to model and predict the energy and environmental performances of individual buildings that can be either new, old or refurbished ones. However, only a few attempts have been made so far to predict the energy demand from an assembly of buildings that compose the so-called districts, and which can be scaled up to predict energy performances of urban areas.

According to Rapp et al. [6], despite a rich literature on energy demand models, addressing the impacts at the different urban scales in an integrated way remains partial. There is a strong need of integration of the various approaches into a system perspective, with a better understanding of the link between urban texture and energy consumption [7] and taking into account urban climate [8]. Integration is expected to be favored by the rapid deployment of Geographic Information Systems (GIS) and related services that could propose a data oriented integration framework.

Three main approaches have been proposed in the literature for addressing the energy consumption at district scale [5] based on: i) building simulation models, ii) a statistical approach for the prediction of buildings within a district, and iii) land use analyses integrating both building and transport energy consumption.

The first approach is one of the most accurate - albeit with some negative impact on calculation time - and simulates individual buildings but considered embedded in a district. This simulation takes into account the respective shadowing and radiating exchanges between façades as well as the solar energy potential of buildings. Several tools enable energy simulations of a block of buildings, including Izuba's Comfie-Pleiades [9] and CSTB's DIMOSIM (DIstrict MOdeler & SIMulator, [10], [11] and [12]).

The latter is a modeling platform that provides fine-grained, coupled and bottom-up simulation of building energy demand at district scale. It allows to take into account dynamically the physical interactions between multi-energy distributed components of consumption, production and storage, on a central or local level. It is mainly dedicated to large-scale simulations with a high number of equations to be solved numerically and also a significant uncertainty about local phenomena in buildings; as occupancy or equipment that excludes the use of the same modelling and parameterization approach as in the case of a single building. This platform has been developed and enhanced through several European (Resilient, Smart Med Parks, Sinfonia, E2District, Thermoss) and national research projects (Efficacity, Tammis, Nice Meridia, Shape).

## III. Approach

### A. Data collection and pre-processing

The district template approach is first experimented on a real city, partner of SINFONIA: Bolzano (105,000 inhabitants), the capital city of the province of South Tyrol in northern Italy.

Since 2005, Bolzano has developed an ambitious investment plan for large scale urban refurbishment in collaboration with both public and private stakeholders. The work undertaken in SINFONIA is part of this plan, and aims to achieve 40% to 50% primary energy savings in the pilot sites and to increase the share of renewables in the district of Bolzano South West by 20%.

Various datasets were made available by the City of Bolzano. The municipality provided a geo-referenced dataset of the building volume, age classes and civic numbers and tabular data concerning the number of residents per civic number and the list of the approved building construction permits. EURAC (European Academy of Bolzano) pre-processed the tabular data, developing a set of tools to clean and harmonize the addresses in order to geo-reference the datasets. The data concerning the building age class was manually updated comparing the building age class with the provided building construction permits. Whenever the age class was missing, the age class was assigned to the most common age class of the closest buildings. For this task a new dedicated tool was developed by EURAC. The building volumes were merged in a supervised process in order to preserve the age class information and the volumes were filtered to exclude all the volumes that were not heated (i.e. stairs, small attics, balconies, arcades, etc.). The buildings volumes were merged in a unique geometry to assign and aggregate for each building the information related to the number of residents. Based on the building footprint, volumes and age class, the main characteristics of the building, such as: the number of floors, numbers of dwellings and compactness of the buildings were estimated. This data treatment focused on the residential sector for the parts of the city covered by the SINFONIA project, which excludes the old city center and the commercial area.

TECHNOFI integrated the geo-referenced data into a GIS project, using the free and Open Source Geographic Information System QGIS, to identify the district types and prepare the data for the simulation.

*B. Identification of district types in Bolzano*

As previously introduced, a basic assumption of this study relies on district typologies identification. This allows applying homogeneous parameters to buildings within these typologies in order to have an estimation of thermal gains and losses as well as heat energy demand. The district typology is closely related to the buildings typologies and to the urban form: the classification of districts is therefore based on morphological characteristics, such as: building shape, which is related to height and footprint, district density, and to other parameters such as the age of the buildings.

The building age indeed affects the energy demand of the building as the construction methods and material types vary according to the construction period. Indeed, the thermal transmittance of construction materials (so called U-value of the walls, roof or windows) and the way these materials are implemented influences the building thermal performance.

The compactness of the buildings, based on the ratio between the building envelope and its volume, also affects the energy consumption because of the heat exchanges through the envelope. High surface to volume ratio indeed results in high heat loss during the winter season and high heat gain due to exposure to solar radiation during the summer season [7].

These two characteristics allow us to elaborate a first classification by grouping the buildings by morphology and by age. It is a first step that gives us an estimation of the average energy consumption of the buildings in a district.

The parameter of district density is also to be taken into consideration. The district density reflects the layout of the buildings within the district, i.e. whether they are dense or dispersed. A district with a high density has a less important "sky view factor" and it reduces the solar radiation for most of the buildings. This solar radiation is an important factor since it impacts directly heating and lighting consumption. A building located in a district with a low density will be more exposed to sun and less energy is needed to warm-up/light the housings.

The combination of these three parameters influencing heat demand leads to a first segmentation of Bolzano into "energetic" district types. These districts are composed of neighboring buildings with similar behavior in terms of energy consumption.

The energy consumption of each identified district is then simulated with a dedicated tool.

*C. Development of the simulation tool*

The modelling and simulation tool developed in SINFONIA (CROCUS: deCision suppoRt fOr distriCt refurbishment) has the capability to link the building scale with the city scale in order to quantify along time impacts of various building refurbishment strategies on the reduction of energy consumption in cities. The tool aims at providing decision support to technical departments of European middle size cities and city players when planning long-term district refurbishment. CROCUS will enable technical experts to model, simulate and compare district refurbishment options for the whole city, based on a set of agreed Key Performance Indicators (KPI). The tool thus promotes a collective approach to optimize city districts, since requiring inputs and knowledge from various experts located in several technical departments of such European middle size cities, who are in charge, amongst others, of city planning, infrastructure management, housing policy, etc.

CROCUS, whose development is coordinated by TECHNOFI, integrates modules provided by SINFONIA partners CSTB and RISE:

- *DIMOSIM / building loads module (CSTB):* dynamic simulation of building loads at building scale (thermal and electric, including heat, domestic hot water and household appliances such as fridge, washing machine etc.) and production (from e.g. Building Integrated Photovoltaics (BIPV)), taking into account the characteristics of the buildings as well as statistical data on the occupancy

- *FriendlySam (RISE):* optimization based dispatch model utilizing linear programming. The model optimizes use of available generation technologies or power plants in order to fulfil an exogenous demand, at aggregated level such as a districts demand, for a predefined system. This is achieved by either minimizing or maximizing an objective function (typically total system cost or CO2 emissions). FriendlySam is an Open Source software available on GitHub [13].

For the purpose of this article, only the heat demand was calculated, using the DIMOSIM module (simulation of buildings load at district scale). It is the intention of the authors to then complement the analysis by calculating the whole building load and taking into account the district heating component thanks to Friendly Sam.

### D. *Calibration and simulation of energy demand at district scale*

So as to characterize the heat demand, the DIMOSIM module requires various types of data to run the energy simulations:

- *Geometric data - Building footprint and height:* These data are provided as a GIS shapefile.
- *U-value and surface ratio of the different components of the envelope (walls, roof, windows and floor):* no data currently exist at building scale in Bolzano. Values for these characteristics were therefore attributed to each building based on regional average data (derived from the TABULA project), depending on their age class and type (e.g. single-family house, small multi-family house, big multi-family house, apartment block)
- *Climatic characteristics* (e.g. air temperature, solar radiation, ground temperature, etc.)
- *Heating, Ventilation and Air-Conditioning systems characteristics (*e.g. nominal power, cooling and heating set point, air change rate, etc.)
- *Data on user behavior* (based on occupancy rate and socio-professional category, which were derived from local statistics)
- *Insulation type (e.g. indoor or outdoor) and inertia level*

DIMOSIM also calculates the incident radiation on building taking into account solar masks. The resulting solar fluxes can strongly depend on the district shape and its location.

A critical step to ensure the reliability of the simulated building loads and corresponding energy demand is then to calibrate the tool, and to make sure that all parameters entered into the tool are consistent.

As a starting point, general information about the typical energy demand of existing buildings was obtained for Bolzano thanks to first estimations compiled by EURAC, supported by the TABULA database, on the average energy demand of representative buildings depending on their morphology and age [14], [15]. By linking these elements with the information provided by the City of Bolzano, a first rough assessment of the expected energy demand of Bolzano's buildings was carried out, and compared to first results of the simulations.

The U-values attributed to each building types were then fine-tuned to adjust the simulations and narrow down the gap between the simulated energy demand and the typical one. These "effective" U-values take into account the fact that some of the rooms may be less heated than others (or completely unheated) and that some of the buildings may already have undergone refurbishment measures. This allows reaching more realistic estimates of energy demand.

Once the calibration is complete, the "baseline" consumption of the districts is simulated.

### E. *Assessing the impacts of district refurbishment for Low Energy Districts*

Finally, so as to estimate the potential impact of energy refurbishment, the energy savings that could be achieved are calculated for the most "energy intensive" districts, i.e. the districts that should be renovated first. These districts are identified using two indicators: the average energy demand (in $kWh/m^2.a$) and the building heated surface over the district (reflecting the potential in terms of building stock).

In a first simplified approach, the simulation of the consumption after refurbishment is carried out by modifying, for each targeted district, the U-values attributed to the building envelope, similar to that of buildings built today. This reflects a better insulation of this envelope, through the implementation of solutions such as: better roof insulation, indoor or outdoor insulation, new windows. Other types of energy refurbishment are not included in this approximation. The impact of changing energy systems or promoting local energy generation (with for example BIPV) will be integrated at a later stage.

The energy savings are then obtained by subtracting the amount of energy demand after refurbishment to the "baseline" one.

## IV. Findings

### A. *Definition of a first set of district templates*

The district classification relies on three main clusters of parameters: building shape, district density, and building age. Four types of building shape have been defined: apartment block (21m-50m), high rise (17m-33m), midrise (10m-27m) and low rise (3m-17m). District density is the second level of assessment and two types have been defined: compact and open. Finally, five different periods of time have been distinguished: modern (2000-2016), semi-modern (1980-2000), old (1950-1980), very old (1920-1950) and ancient (1850-1920). The combination of these parameters leads to the segmentation of Bolzano into several districts with distinctive energy characteristics.

Ten different district types are identified to start with, covering 72% of the heated surface of the city, and 50% of the number of buildings (see Fig. 1). The parts of the city not covered yet by this study include mixed districts for which the district template approach is more difficult to implement.

Table I. summarizes the main characteristics of these ten types of districts and sets the basis of the district template database. The average heat demand of each district type is based on simulation results, consistent with the TABULA database values.

### B. *Results of simulations*

The "baseline" energy demand is first simulated for all buildings within the districts previously defined. The average energy demand of each district (in $kWh/m^2.a$) is then calculated by aggregating all the buildings energy demand within the district, excluding the "outliers", i.e. buildings having values below the third percentile or above ninety-seventh percentile as shown in Fig. 2.

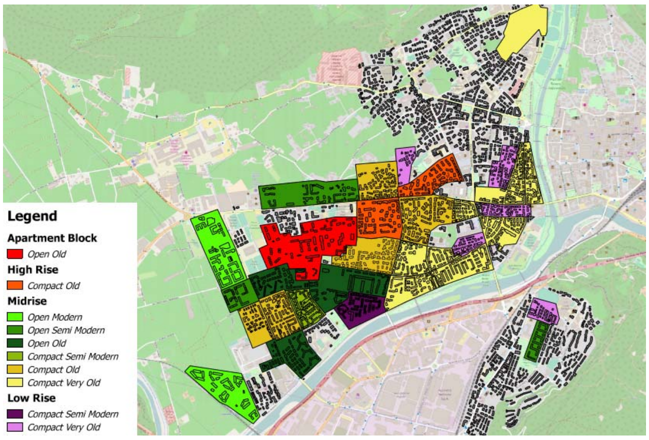


Fig. 1: Bolzano District Segmentation

The obtained district average energy demand is shown in Fig. 3. This reflects the energy "intensity" of each district, which can be easily compared between the districts, independently of their size and number of buildings.

Only districts with an average energy demand higher than 150 kWh/m$^2$.a are kept for the rest of the study, representing about half of the total heated surface of the initial scope. This value of 150 kWh/m$^2$.a is for the time being completely arbitrary and interactions will be required with the City of Bolzano to define a more sensible one.

The potential maximum impact of the energy refurbishment, related to improving the building envelope insulation, is finally estimated. Fig. 4 shows the average potential energy savings, in terms of heat demand, by district. The refurbishment of these districts could lower the heat demand to as much as 50% of the initial demand (around 100 GWh for a year for the studied districts).

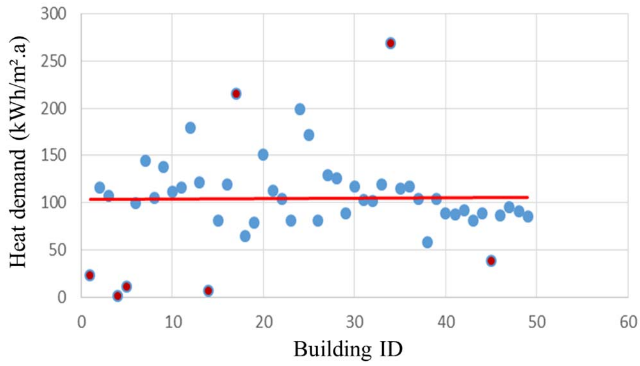


Fig. 2: Distribution of energy need for heating, example of an open semi modern district (outliers are highlighted in red)

## V. Conclusion

### A. *Conclusion of the district template approach in Bolzano*

The choice of districts to be refurbished in priority by a city is a complex exercise, but the long term planning of urban refurbishment at district scale is critical if the EU 2050 objectives are to be met.

This choice is the result of an extensive analysis taking into account multiple criteria, including (but not limited to):

- The initial energy performance of each district (i.e. level of energy demand);
- The potential impact of deep refurbishment, and corresponding global cost and payback time, with the aim of achieving maximum savings in a cost efficient way ;
- The local constraints and social characteristics of the districts (e.g. presence of historical buildings, districts with a high level of fuel poverty, type of occupancy i.e. owner-occupiers vs. tenants);

TABLE I. First district types identified in Bolzano

| | District 1 | District 2 | District 3 | District 4 | District 5 | District 6 | District 7 | District 8 | District 9 | District 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 3D top view | | | | | | | | | | |
| Characteristic | Apartment blocks | High Rise | Mid Rise | Mid Rise | Mid Rise | Mid Rise | Mid Rise | Mid Rise | Low Rise | Low Rise |
| Average height (m) | 21.89 | 19.86 | 14.92 | 12.87 | 15 | 12.5 | 14.52 | 14.72 | 11.04 | 11.92 |
| Example of building type | | | | | | | | | | |
| Density | Open | Compact | Open | Open | Open | Compact | Compact | Compact | Compact | Compact |
| District shape | | | | | | | | | | |
| Age class | Old to Semi-Modern | Old | Modern | Semi-Modern | Old | Semi-Modern | Old | Very Old | Old to Semi Modern | Very Old to Old |
| Age distribution | 1981-1990 39%; 1971-1980 53% | 1971-1980 14%; 1946-1960 24%; 1961-1970 52% | After 2005 | 2001-2005 29%; 1981-1990 19%; 1991-2000 40% | 1971-1980 18%; 1946-1960 43%; 1961-1970 26% | 2001-2005 18%; 1991-2000 23%; 1981-1990 59% | 1961-1970 41%; 1946-1960 31% | 1946-1960 33%; 1919-1945 49% | 1971-1980 35%; 1981-1990 65% | 1919-1945 32%; 1946-1960 38% |
| Heating demand range (kWh/m².a) | [90-130] | [130-170] | [20-60] | [85-125] | [145-185] | [60-100] | [145-185] | [165-205] | [170-210] | [190-230] |

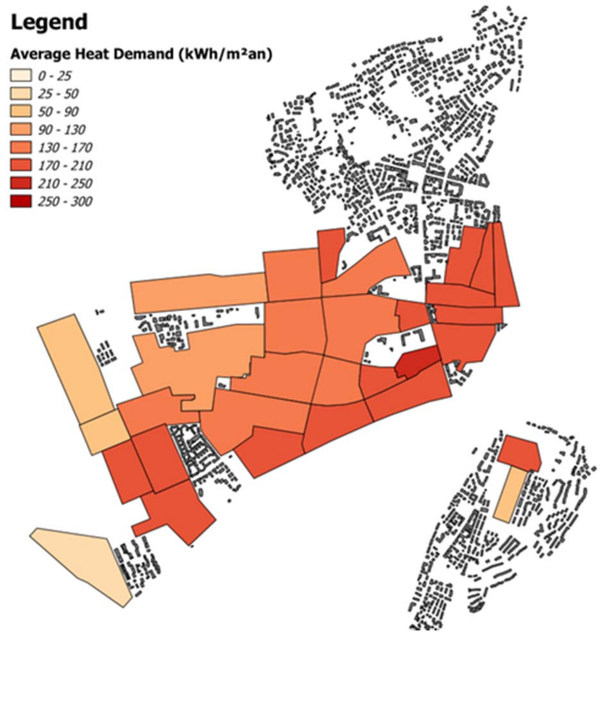


Fig. 3: Average energy demand for heating

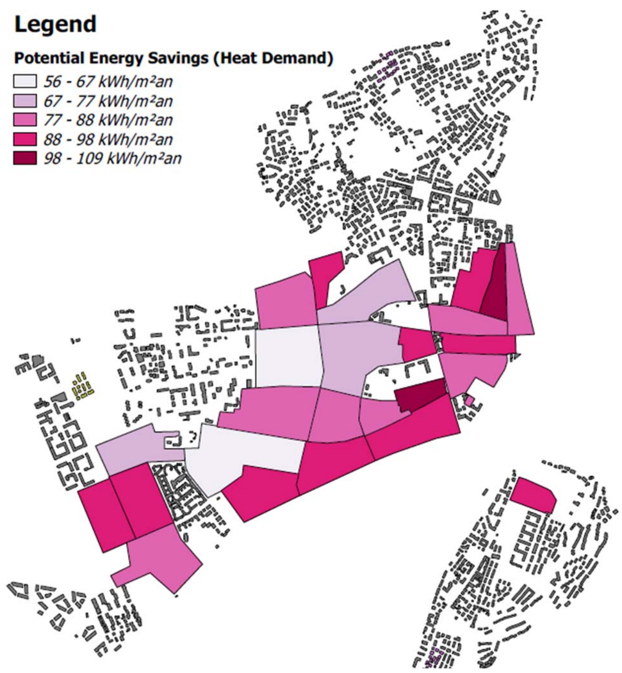


Fig. 4: Potential energy savings related to heat demand

- The available budget and available public incentives to support the refurbishments;
- The city long-term energy targets.

The approach presented here is a first step to address, in a quantitative way, the two first points and to support methods that are usually qualitative. Emphasis has been put on visualization to facilitate the decision-making process. Collecting all the data required for the simulations also promoted a collective approach, since requiring inputs and knowledge from various experts located in several technical departments, such as city planning, infrastructure management, housing policy.

As the objective was to quickly test the feasibility of an approach based on the concept of "District templates", several simplifications have been done to speed up the analysis, which results in a rather "simplistic" study:

- The impact of local energy generation by district heating and photovoltaic panels has not been taken into account;
- Only the heat demand has been simulated, and not the other energy uses (e.g. domestic hot water, lighting, electrical appliances) which nevertheless account for a non-negligible part of the energy demand of a household;
- The modelling of energy refurbishment only reflects the insulation of the envelope;
- The economic aspect (e.g. required investment, profitability) has not been integrated yet.

The challenge is now to refine this approach, complete it with additional data where required, and extend it with more extensive simulations thanks to new functionalities, in order to demonstrate its robustness and interest for European mid-sized cities.

*B. Next steps*

The study presented in this article confirms the interest of the "District template" approach. This first attempt must now be scaled up and replicated:

*1) Scaling up:*

Scaling includes geographic scaling up and scaling up in terms of functionalities:

- The segmentation into districts and their simulation will be extended to the whole city of Bolzano (only 50% of buildings have been covered so far);
- Additional components that were not taken into account in this first version will be simulated (e.g. local generation by photovoltaic panels and district heating, energy consumption by other uses than heating);
- New functionalities will be added to the CROCUS tool to strengthen the "District template" approach.

*2) Replication:*

The replicability of this approach will be tested by TECHNOFI with the Early Adopters Cities of SINFONIA: Borås (Sweden), La Rochelle (France), Rosenheim (Germany), Paphos (Cyprus) and Seville (Spain), starting with Borås and La Rochelle.

With regard to the upgrade of CROCUS, the following functionalities are being integrated and will soon be implemented:

- *Economic calculations*: a database of typical costs of building refurbishment measures and energy prices has been incorporated to the tool. It will enable the calculation of various economic indicators, such as: the Net Present Value, the Discounted Payback Time and the Internal Rate of Return, in order to characterize the profitability of the investment, for each district type. These economic indicators will complete the district template database with indications on the best refurbishment measures in terms of energy savings / cost efficiency.
- *Refurbishment plans*: the way the district refurbishment measures should be prioritized and scheduled so as to achieve maximum savings in a cost efficient manner will be a key input for CROCUS. The user will be able to define different refurbishment plans, which consist in the successive refurbishments of the 'priority' districts, and assess their respective impacts in terms of energy savings, $CO_2$ emissions and global cost

These new functionalities imply an increased involvement of the city users in a collective way. Scenarios for the long-term vision of the city (which will drive the available economic incentives and local energy strategy) and potential refurbishment plans must indeed be defined with all concerned experts within the city departments, which requires their buy-in and trust in the provided approach and tool.

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## REFERENCES

[1] TABULA webtool: http://episcope.eu/building-typology/webtool/

[2] CITIES AND ENERGY: Urban Morphology and Heat Energy Demand, Final Report. The London School of Economics and Political Science and EIFER. 2014

[3] Morello E., Gori V., Balocco C., Ratti C., 2009, "Sustainable urban block design through passive architecture: A tool that uses urban geometry optimization to compute energy savings", Proceedings of the 26nd International Conference on Passive and Low Energy Architecture , Quebec City, Canada, pp. 146-151

[4] E. Troglio, T. Haas, T. Martschenko & S. Pagluila, 2012, "The energy transect; including sustainability issues in urban morphology analyses" WIT Transactions on Ecology and The Environment, Vol 165

[5] Maïzia, M., Sèze, C., Berge, S., Teller, J., Reiter, S., Ménard, R., Energy requirements of characteristic urban blocks, Proc. of CISBAT 2009 - Renewables in a changing climate - From Nano to urban scale

[6] Energy demand assessment of European urban structures based on a multi-scale approach. European Institute For Energy Research (EIFER), Karlsruhe, Germany, Florian Rapp, Christian Keim, Pablo Viejo Garcia, Markus Peter, presented at the 45th ISOCARP Congress 2009.

[7] Ratti, C., Baker, N. & Steemers, K. 2005. Energy consumption and urban texture. Energy and Buildings, 37, 762-776.

[8] Fredrik, L. 2007. Modelling the urban climate using a local governmental geo-database.

[9] http://www.izuba.fr/

[10] Riederer, P., Partenay, V., Perez, N., Nocito, C., Trigance, R. and Guiot, T. Development of a Simulation Platform for the Evaluation of District Energy System Performances. Fourteenth International IBPSA Conference, 2499-2506

[11] Partenay, V, Riederer, P., Caccavelli, D. Energy Refurbishment of a Scientific & Technology Park using a District Simulation Platform: Case Study of Sophia-Antipolis. ClimaMed 2015

[12] Perez, N; Riederer, P.; Inard, C. District Energy System Modeling and Simulation: How to Define the Appropriated Level of Detail. *International Building Simulation 2015*

[13] https://github.com/sp-etx/friendlysam

[14] D.Exner, V. D'Alonzo, G. Paoletti, R. Pascual, R. Pernetti. Building-Stock Analysis for the Definition of Energy Renovation Scenarios at Urban Scale – Green Energy and Technology 2016

[15] G. Paoletti - Analisi del patrimonio edilizio residenziale del Comune di Merano - Project Open Energy