Journal of Urban Design

ISSN: 1357-4809 (Print) 1469-9664 (Online) Journal homepage: https://www.tandfonline.com/loi/cjud20

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To cite this article: Maurizio Sibilla & Esra Kurul (2020) Assessing a simplified procedure to reconcile distributed renewable and interactive energy systems and urban patterns. The case study of school buildings in Rome, Journal of Urban Design, 25:3, 328-349, DOI: 10.1080/13574809.2019.1638238

To link to this article: https://doi.org/10.1080/13574809.2019.1638238

JOURNAL OF URBAN DESIGN
2020, VOL. 25, NO. 3, 328–349
https://doi.org/10.1080/13574809.2019.1638238

Routledge
Taylor & Francis Group

Assessing a simplified procedure to reconcile distributed renewable and interactive energy systems and urban patterns. The case study of school buildings in Rome

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ABSTRACT

Distributed, Renewable and Interactive energy Systems (DRIs) are revolutionizing the concept of infrastructure by introducing a set of new properties. The implications of the new system properties in the realm of Urban Design are often neglected. This paper proposes a procedure to reconcile DRIs and urban patterns. This procedure is tested on 23 school buildings in four urban regions of the *Ostiense* district in Rome. Findings suggest that the identification of existing buildings as active, neutral and passive nodes in DRIs can make a contribution to Urban Design decisions to exploit the renewable energy production capacity inherent in urban patterns.

Introduction

In recent years, the distributed and renewable energy systems (DRIs) have emerged as a valid alternative to the fossil-fuel-based and nuclear energy systems for developing Low Carbon Cities (LCCs) (Baños et al. 2011; Bernstein et al. 2015). These systems are described as small units, directly connected with the place of consumption and assembled in a sequence of nodes in order to organize a micro-energy network (Ackermann, Andersson, and Söder 2001). These micro-energy networks are revolutionizing the sense of making infrastructure.

Furthermore, the Smart Grid and Smart City concepts are becoming a key instrument for exploiting the interactivity associated with the distributed and renewable systems for energy provision. Interactivity is a new property of these systems (Angelidou 2015; Zanella et al. 2014; Hashem et al. 2016), which describes their capacity to manage energy and information flows in real time to optimize energy production, storage, consumption and cost (Luthander et al. 2015). Thus, the interactivity permits the node's association with different energy demand profiles, balancing energy flow exchanges with the support of appropriate computerized protocols (Siano 2014).

Hence, there is a growing body of literature that recognizes Distributed, Renewable and Interactive systems (DRIs) as micro infrastructures involving all components of the Urban Pattern as nodes of DRIs. This study takes into consideration the concept of Urban Pattern in line with Alexander's definition (1966), drawing attention to the geometric properties of buildings and urban spaces in relation to DRIs.

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Recent studies have stressed the need to combine spatial and energy planning to realize new urban energy landscapes involving new forms of technologies and local governance (Karvonen and Guy 2018; Moussa and Mahmoud 2017; McLean, Bulkeley, and Crang 2016; Guarino et al. 2016). In detail, Cajot et al. (2017) have pointed out the opportunities of investigating energy issues beyond the single building scale, while Wu et al. (2018) have emphasized the necessity to take into account the urban spatial structure when the integration of the distributed energy systems is applied to a neighbourhood-scale. Furthermore, other studies have suggested that the spatial organization of urban energy systems shapes potential trajectories of change for the urban energy transition (Broto 2017). Urquizo, Calderón, and James (2017) have shown an important link between energy-reducing and energy-increasing effects of urban morphology. Caird and Hallett (2018) have argued that the new infrastructural generations are integrating digital, human and physical systems in the built environment; in addition, an interesting analogy between the urban structure properties analysed by Alexander (Alexander 1966) and the current decentralized urban infrastructural systems has recently been revealed (Derrible 2017).

These studies mainly indicate that the combination of shape, size, building age, type and orientation identifies specific patterns impacting on energy consumption in different ways and that the urban configuration influences the system conformations and their energy load profiles. Research has so far tended to focus on Urban Patterns mainly in terms of energy consumption. The role of Urban Design in energy infrastructure evolution has been overlooked (Khan et al. 2014), due to two main reasons. Firstly, these studies lacked a systematic understanding of how DRIs work and interact within Urban Patterns. Secondly, traditional energy infrastructures have been considered immutable until recently.

This oversight is a significant barrier, given that the most advanced approaches to Low Carbon Cities are founded on a co-evolutionary process (Foxon 2011). They interlink the technical systems and urban patterns (Geels 2005), and involve a radical change in the Technology Support Network, which comprises work rules, requisite skills, work contents, standards and measures, culture and organizational patterns (Zeleny 2012).

The relationships between the urban morphologies and energy infrastructure have historically been established (Bijker, Hughes, and Pinch 1987; Choay and Magnaghi 2008). Such relationships are a fundamental part of human culture (Maldonado 1997); the dynamics among energy and information flows are substantially linked to the material components of the urban environment (Knowles 1974, 2003). Nevertheless, DRIs vision needs to be explored with regard to urban and architectural qualities since a strong contradiction comes to light. DRIs are composed of urban and architectural components, but the relationships between these components and the DRIs organization process are substantially neglected. Hence, the literature overlooks DRIs' significant contribution to the transition to Low Carbon Cities.

Consequently, embracing a co-evolutionary process, this paper focuses on the following research question: to what extent can DRIs facilitate the reconciliation of urban patterns and the evolutionary energy infrastructure as part of the Urban Design process? In order to answer this question, a simplified procedure has been developed. It integrates the urban and architectural qualities into the organization of DRIs. This procedure, which can be adapted and implemented in different urban contexts, has been tested within the context of the public school buildings of *Ostiense* district in Rome.

The main purpose of this procedure is to explore the potential relationships between urban patterns and DRIs features. Specifically, the procedure seeks:

(i) To disseminate knowledge on the operational aspects of DRIs among urban and architectural designers;
(ii) To integrate the urban and architectural qualities with the advanced concepts of smart grid and smart cities by promoting the spatial organization of the DRIs;
(iii) To identify potential active, neutral and passive nodes in order to make Urban Design decisions for exploiting the renewable energy production capacity inherent in urban patterns.

The initial results provide insights into the role of DRIs in enhancing the energy, architectural and urban qualities of the built environment. New research avenues in technical and cultural urban innovation for delivering Low Carbon Cities emerge. This study thus contributes to the current debate on energy transition and the role of urban form to foster such a process.

This paper is organized as follows: section 2 describes in detail the simplified procedure; section 3 presents the case study and its main findings; Section 4 proposes a discussion on the relationships and the implications of DRIs organizational process and Urban Design realm.

Methods

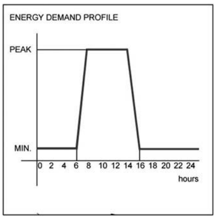
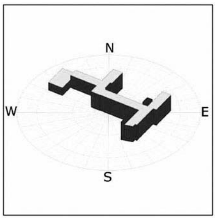
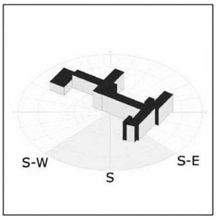
To date, various methods have been developed to measure the energy qualities of the urban environments. In most recent studies simplified procedures have been developed to certify the environment and energy qualities of urban and building transformations (Asdrubali et al. 2015; Andaloro et al. 2010; Alshamrani, Galal, and Alkass 2014). These procedures are particularly useful in the evaluation of the impact of several factors on the energy profile of different urban areas. These factors include urban morphologies, availability of renewable energy, building energy performance and energy demand.

A simplified procedure to categorize existing buildings as active, neutral and passive nodes will be developed. It has a number of advantages. Firstly, they allow professionals to idenfity the role selected buildings and their urban contexts can play in a DRI. Secondly, it can easily be adapted, scaled and utilized according to locally availabile data, technical and economic resources. Thirdly, indexes and graphs to promote a discussion on energy qualities of different buildings amongst technical and non-technical audiences can be produced.

In this paper a case-study approach was adopted to assess the effectiveness of a simplified procedure as a tool to reconcile DRI energy systems and urban patterns. In order to address this issue, the following stages were examined: 1) Defining the reconciliation criteria; 2) Gathering renewable energy data; 3) Assessing environmental design indexes; 4) Elaborating a hierarchical classification of DRI nodes; 5) Visualizing DRI clusters. These stages are discussed in the following sections.

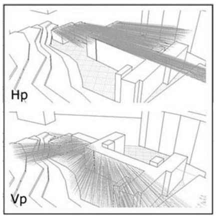
Before this discussion, it is necessary to introduce the main indicators and their definitions used in this work. Table 1 provides readers with the essential energy lexicon in the context of this study.

Table 1. DRIs and urban patterns: indicators and their definitions.

Indicator	Acronym		Description
Homogeneous Building Group	HBG		A Homogeneous Building Group includes buildings with the same hourly energy demand profile. These buildings are compared using the simplified procedure to determine those that can become active nodes. Different HBGs include buildings that have different energy demand profiles. The final configuration of DRIs includes several HBGs to reconcile the energy loads of individual buildings.
Homogeneous Urban Units	HUU		Homogeneous Urban Units are urban areas with similar characteristics, e.g. urban morphology. They can be existing areas, e.g *toponomi* in Rome. Alternatively, an HUU can be defined by using relevant urban design criteria, e.g. building typologies, natural elements. The active, passive, neutral nodes must be highlighted in the HUUs and utilized in making decisions regarding urban design.
Transformability Class index	T_{CL}		Transformability Class signals the compatibility of the urban area and the building(s) with the DRI system. The potential constraints due to environmental or landscape conditions (e.g. nature protection area, listed buildings) are assessed. Such constraints may necessitate further detailed investigation of the building characteristics before a decision is made.
Horizontal Oriented Surfaces	Hs		Horizontal Oriented surfaces (Hs), which are shaded grey; identify all surfaces which absolve the role of a roof. This indicator permits us to take into account the impact of the floor-plan in the DRIs organization. In this preliminary procedure, only surfaces more than 25 square meters, which is the minimum surface to produce a significant amount of energy using current technology, were taken into account.
Vertical Oriented Surfaces	Vs		Vertical Oriented surfaces (Vs) identifies all surfaces which lay in the South-South/West-South/Est solar quadrant. This indicator permits us to take into account the impact of the form of the building in the DRIs organization. In this preliminary procedure, only surfaces major of 25 square meters were taken into account.

(*Continued*)

Table 1. (Continued).

Indicator	Acronym		Description
Solar Gain on Oriented Surfaces	Hp Vp		Solar Gain on Oriented Surfaces refers to the potential solar irradiation in terms of energy generation. Several simplifications were adopted as this is a simplified procedure. Possible over-simplification can be addressed in the future phases of this study. The analysis was conducted on 21 December which represents the worst case scenario for solar gain.

Defining reconciliation criteria

Three qualitative criteria are fundamentally taken into consideration to evaluate whether and how the urban environment and DRIs are interlinked.

The first criterion establishes the parameters for the Homogeneous Building Group (HBG). Buildings have to be comparable in terms of their energy demand profile in order to classify their potential rank, i.e. an active node (the renewable energy production from the building is greater than its consumption); neutral node (renewable energy production meets the building's consumption); passive node, (renewable energy production is less than the building's energy demand).

The second criterion defines Homogeneous Urban Units (HUU). HUU are identified in terms of landscape features, such as historical matrix, urban morphology, buildings or natural features. HUU boundaries may be outlined as an overlap between one or more landscape and environmental features (e.g. density, morphology, microclimate and natural elements).

The third criterion refers to the Transformability Class index (T_{CL}), which is strictly related to the local regulatory framework analysis. This index signals the urban and building compatibility with the DRI system, assessing the potential constraints due to environmental or landscape conditions (i.e. protected area or listed buildings). In this preliminary stage, the procedure follows a precautionary principle. Consequently, two Transformability Classes are defined: T_{CL}(1)-without constraints; T_{CL}(0)-potential constraints. Buildings with T_{CL}(0) are automatically designed as passive nodes of the grid. The precautionary principle can be overcome only by a more detailed investigation, which is not within the scope of the present study.

Gathering renewable energy data

For the purposes of this analysis, it is important to examine the renewable energy technologies, which are integrated with the urban settlement producing physical and perceptive alterations of the urban spaces and building forms. To start with, this procedure focuses on solar energy, which is a resource widely available in Europe (Huld, Müller, and Gambardella 2012). Therefore, photovoltaic technologies are evaluated in this paper. The potential offered by wind (i.e. micro-turbine technologies) will be investigated in the future phases of this study. The weather data is obtained from the Energy Plus database (EnergyPlus 2016).

Assessing environmental design parameters

A considerable amount of literature has dealt with solar analysis on the urban and building scales (Lindberg et al. 2015; Hatefnia et al. 2017; Freitas et al. 2015). Consequently, a multitude of qualitative and quantitative methods and tools are available to analyse solar gain within the built environment.

This study utilizes a simplified energy modelling approach in a computer environment, using Ecotect software. The solar gain that the different components of the urban environment can accrue is assessed using this approach, which is similar to those reported in Yang, He, and Ye (2014); Fallahtafti and Mahdavinejad (2015); and Liang et al. (2015).

In detail, this procedure takes into account the concept of solar oriented surfaces, which are divided into two categories: Horizontal (Hs) and Vertical (Vs) as described in Table 1. By doing so, it is possible to assess both the dimensional and morphological impact of each building on its energy performance (Figure 1). Solar gain analysis applied to these categories of oriented surfaces shows the value of the potential solar irradiation in terms of energy generation (i.e. Hp and Vp energy performance of Horizontal and Vertical surfaces respectively).

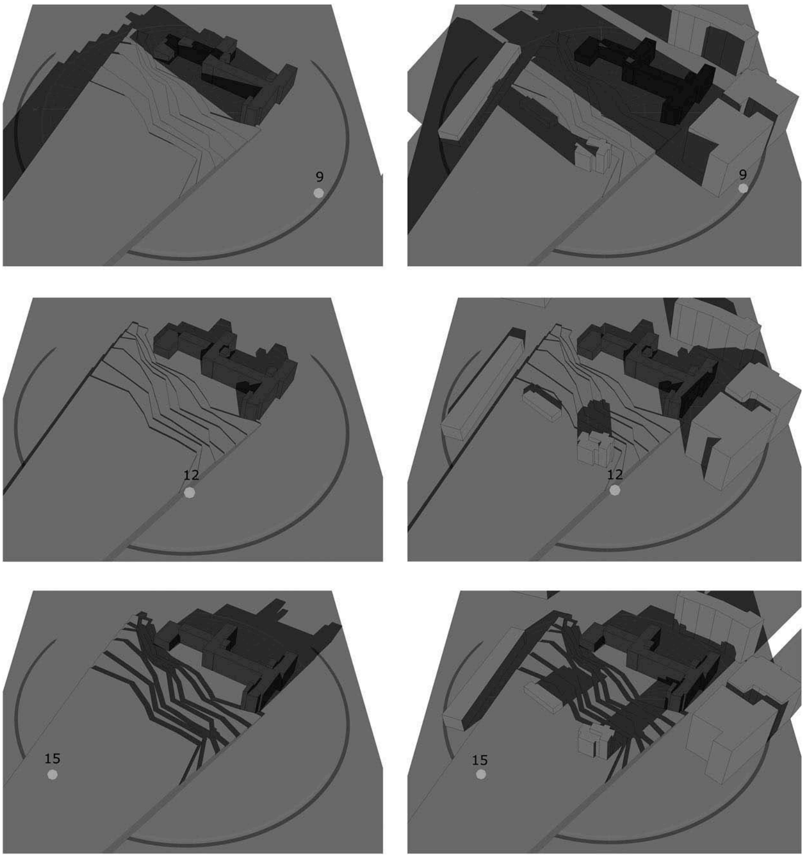


Figure 1. Example of the solar gain assessment which takes into account both the dimensional and morphological impact of each building and its own urban context.

In this research, several simplifications were adopted. Solar incident calculation refers to the monthly total, and it only weighs up the direct radiation; ground reflection was neglected and the radiation absorbed by each building was considered to be the same. In addition, the influence of the vegetation on solar gain was bypassed. A detailed analysis can be conducted in the next phase of this research to focus only on those buildings and urban contexts which fulfil the criteria to become an active node of the energy grid, as demonstrated by this simplified procedure. These criteria include both the dimension of surfaces and their solar exposure, which are affected by the urban context and the building form itself. The energy performance of the building envelope is also excluded at this stage. These restrictions may be considered admissible here since the present study aims at comparing the urban patterns with the DRIs features, without claiming to deliver analytical solutions.

Elaborating a hierarchical classification of DRI nodes

Once all parameters are defined, individual buildings are hierarchically organized as components of the DRI system. The hierarchical organization facilitates the visualization of the main urban and architectural factors involved in the process and allows for the identification of the buildings that have more potential to become part of a DRI.

Before elaborating the hierarchical organization, all indexes have to be normalized. Consequently, Hp and Vp (i.e. energy performance of Horizontal and Vertical surfaces) are normalized to obtain a range of values from 0–1 for each building. Hence, each building is considered within its own Homogeneous Urban Unit. The Transformability Class index is equal to 0 or 1. Hence, it does not need to be normalized.

This procedure uses a Relative Normalization formula:

$$N_i = K \times (X_i - X_{min})/(X_{max} - X_{min}) \tag{1}$$

Where, N_i is the new value (from 0 to 1), K is the maximum value of the range (in this case, it is 1), X_i is the building index, X_{max} and X_{min} are respectively the maximum and minimum index values calculated within the examined Homogeneous Urban Units. The potential role of each building as a DRI component is therefore determined.

Visualizing DRI clusters

The software Cluster 3.0 is used to analyse the Similarity Matrix, with the rows representing the buildings/components and the columns the examined factors (Hp, Vp and T_{CL}). It is well-established that similarity is a statistical calculation, often used in ecology to measure the differences among groups. The Similarity Matrix calculation is elaborated referring to the Euclidean distance with a cut-off of 0.1. The software Java Tree View is used to produce the graphical visualization of the Similarity Matrix. Buildings are categorized into clusters which take into account local renewable energy resources, building dimensions, building orientation, and urban and building morphologies to promote further investigation within a shared vision.

Case study

Recently, some studies have pointed out the high energy and environmental impact of school buildings (Gaitani et al. 2010; Lassandro, Cosola, and Tundo 2015; Alshamrani, Galal, and Alkass 2014; Santamouris et al. 2007; Wang et al. 2015). In Italy, the current state of these buildings has been recognised as a national emergency (Antonini et al. 2015). Particularly in Rome, the school buildings are part of the built heritage and legacy. There are 1.200 school buildings, and about 40% was built before 1970 (Cuccaro 2005). Hence, they have a high impact on the energy consumption of public buildings.

Furthermore, Remiddi and Bonavita (2005) have highlighted that school buildings in Rome are extremely important components of the urban pattern. The authors have illustrated technical and non-technical information on historical, architectural and urban qualities of 214 school buildings in seven districts of Rome, underlining the role of these buildings as important elements of the identity of the Eternal City. This paper introduces and evaluates the increasingly important urban and energy qualities of these buildings by using the Ostiense district as a case study. Hence, it moves the discourse towards the integration of energy issues with those that relate to architectural identity and quality.

Homogeneous Urban Units

The case study involved 23 school buildings in Rome. The Homogeneous Buildings Group has been defined in terms of each building's energy consumption profile. Subsequently, Homogeneous Urban Units were defined considering the definition of *Toponimi*. Rome has a multitude of *Toponimi*, which are homogeneous parts of the settlement since they reflect the historic urban stratifications. Therefore, *Toponimi* are closely related to urban and natural features rather than administrative boundaries. Homogeneous Buildings Group is distributed among four *Toponimi* (Figure 2): *Garbatella; Navigatori; San Paolo; Valco San Paolo*; which are all part of the *Ostiense* administrative district.

The *Carta della qualitá* (Quality Chart), which is one of Rome's Master Plan documents, is used to establish the Transformability Class index. In particular, the Quality Chart G1-b identifies the urban, architectural and environmental qualities of the listed buildings. For these buildings, a specific Listed Building Consent is necessary to make alterations, and the integration of renewable energy systems is not often permitted.

As described in Section 2, in this phase two classes were analysed: $T_{CL}(1)$-without constraints; $T_{CL}(0)$-potential constraints. Information about Transformability Class is integrated with Figure 1. In this case, four listed buildings were identified, all of them being in the *Garabatella* Homogeneous Urban Units.

Solar data

Solar energy is an important renewable resource for Rome. Considering the energy potentiality of the Horizontal and Vertical oriented surfaces, the architectural integration of photovoltaic systems may constitute an important opportunity for renewable energy infrastructure in Rome. Solar data for vertical surface in Rome shows the range of the total annual collection of solar radiation shifting from 707.76 kWh/mq per year, for the Southerly surfaces, to 564.81 kWh/mq per year for South-Easterly surfaces and

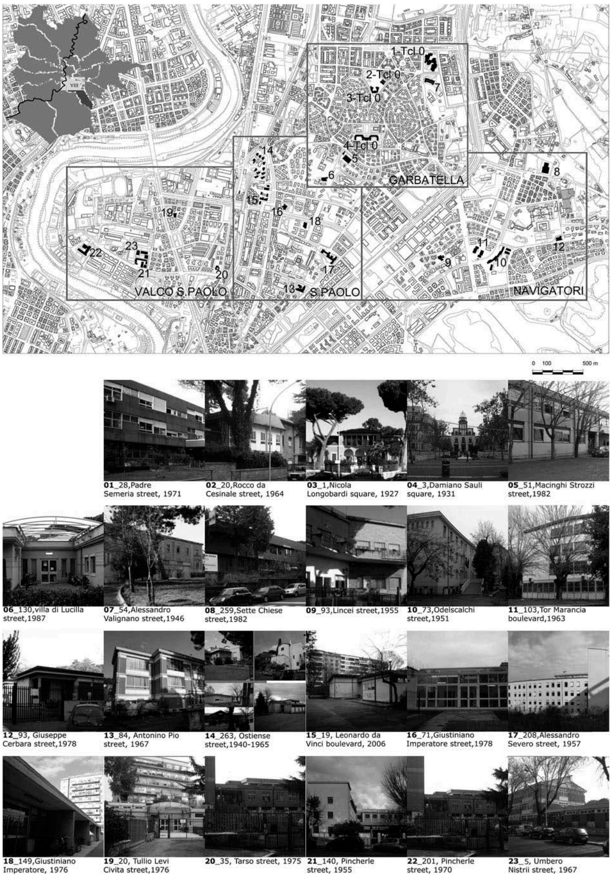


Figure 2. Homogeneous urban units and the distribution of the homogeneous buildings group (i.e. school buildings).

789.71 kWh/mq per year for Westerly surfaces. This value is 1.621,45 kWh/mq per year for a Horizontal oriented surfaces (EnergyPlus 2016).

Nevertheless, solar availability may be drastically reduced because of the spatial organization of the urban context and the building morphology. Therefore, the next section examines the real urban conditions in order to determine the actual solar gain.

Assessing solar gain

Figures 3 and 4 compare four Homogeneous Urban Units in terms of interactions between solar gain and urban and building morphology through a qualitative representation. Figure 5 shows a selection of buildings façades, as examples of vertical surfaces represented in the simulation.

Interestingly, the urban and building morphologies influence solar gain in different ways in relation to Homogeneous Urban Units. For example, Figure 3 shows the compactness of the urban surroundings of school n.4, while schools n.9 and n.20 are placed in a more sparse urban tissue and school n.14 is typified by a complex urban topographic context.

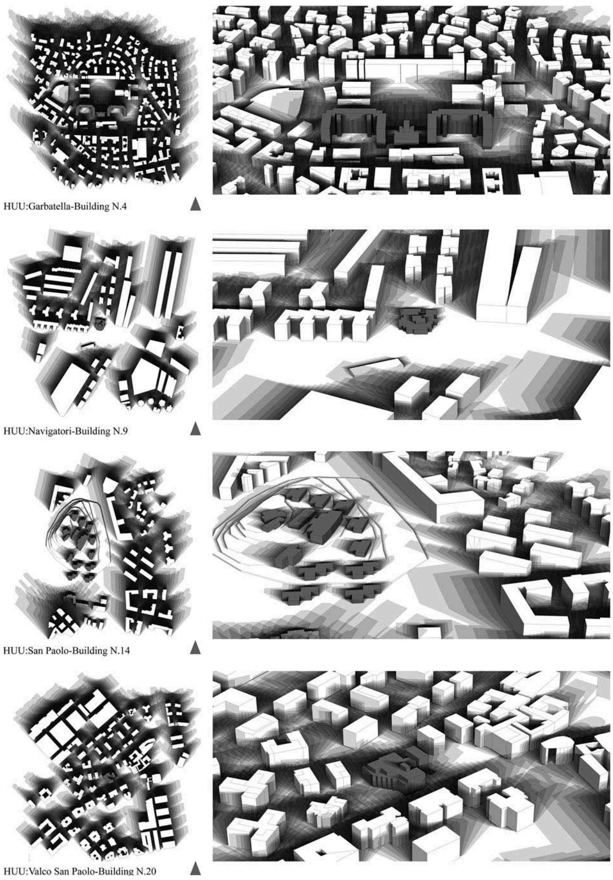


Figure 3. Solar gain and urban and buildings morphology interactions. Schools: 04, 09, 14, 20.

In addition, the differences among the building morphology become clear. School n.4 is a listed building (it was built in 1931), which plays a significant role in the spatial organization of the urban area. In contrast, schools n.9 (1955) and n.20 (1975) represent the typical post-war building block. Finally, school n.10 (1940) is an example of integration of the original building with a complex of pavilions (1965), due to the topography of the context.

In association with the above-mentioned qualitative analysis, Figure 6 provides the results of the quantitative solar analysis. This Figure 6 is quite revealing in two ways. Firstly, it includes the dimensions of both Horizontal and Vertical oriented surfaces in each building. Secondly, it reports on the energy performance of these oriented surfaces, taking into account the reductions in the annual solar gain in Rome due to morphological factors.

From this data, it is possible to establish that for the Horizontal oriented surfaces the solar radiation average is 34.67% of the total annual solar gain (with a minimum of 9.74% in the case of school n.2, and a maximum of 42.44% in the case of school n.11). Thus, with the exception of schools n.2, 3, 19, 22, where solar radiation is under 30%, the other schools present a very similar range.

With reference to the Vertical oriented surfaces, the solar radiation average is 14.73% of the total annual solar gain (with a minimum of 6.00% in the case of school n.23, and

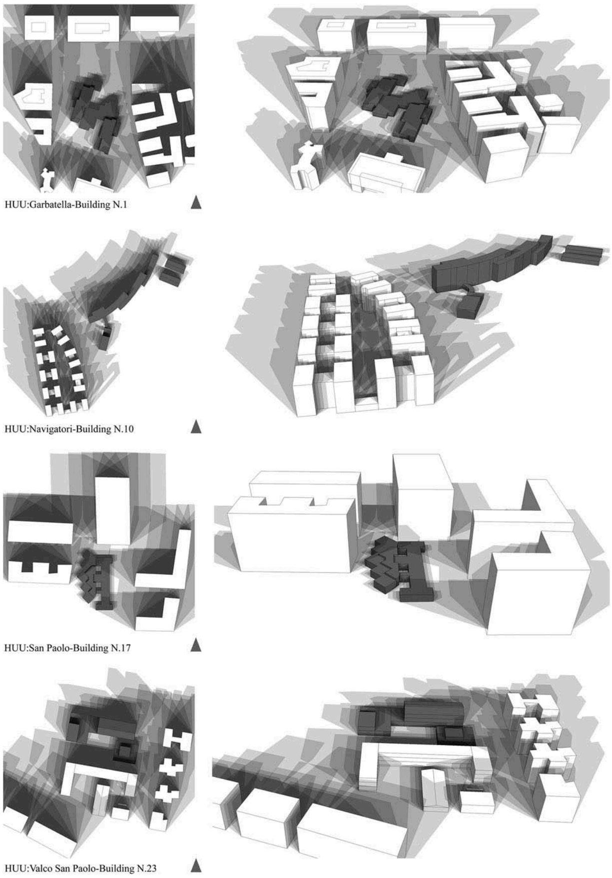


Figure 4. Solar gain and urban and buildings morphology interactions. Schools: 01, 10, 17, 23.

a maximum of 18.70% in the case of school n.5). In this case, eight schools (n.1, 2, 4, 12, 17, 18, 19, 23) are not in line with the average.

Furthermore, Figure 6 shows that the range of dimensional factors (i.e. size of the solar-oriented surface) is significant. Indeed, a building with good solar exposure but with a limited area of surfaces with high levels of solar gain cannot become an active node. Nevertheless, it can function as a neutral node.

Schools n.5, 8, 9, 10, 11, 13, 14, 15, 16, 20, 21 show optimal values of solar gain, even if some of them have very small solar surfaces (e.g. schools n. 8, 9, 16, 20) to be used as active nodes within the Homogeneous Urban Unit.

The next section introduces the normalization process to establish each building's potential within the Homogeneous Urban Unit.

Elaborating a hierarchical classification of DRI nodes

Figure 7 presents, for each Homogeneous Urban Unit, an example of hierarchical classification of the school buildings examined herein. The results establish each Homogeneous Urban Unit's hierarchical classification based on the reconciliation criteria

Figure 5. Examples of buildings façades.
(source: authors).

analysed in the prior phase (Hp, Vp, T_{CL}). Therefore, potential active nodes are suggested within each Homogeneous Urban Units.

For example, the hierarchical classification is not homogenous since each Homogeneous Urban Unit (HUU) presents a critical gap between the first range and the others. Focusing on the single Homogeneous Urban Unit, within Garbatella HUU, school n.4 has the greatest potential, but its Transformability class is 0 (i.e. potential constraints due to historical value), while the other schools show a low range of performance in terms of potential solar gain. As a result, in Garbatella HUU there are no schools able to perform as an active node.

While, school n.10 is the best performing in Navigatori HUU, in the case of Valco San Paolo HUU, the results identify a similar condition for schools n.21 and n.22 to become an active node. In relation to San Paolo HUU, it is interesting to point out the difference in terms of performance between the Horizontal and Vertical surfaces. Indeed, school n. 17 has the maximum Vp, while school n. 14 has the maximum Hp; only one school (n.15) presents the optimal ratio between the two factors. (0.9 Hp and 0.7 Vp). As a result at this level of investigation, school n.17,15,14 may be considered as candidates to become an active node for San Paolo HUU.

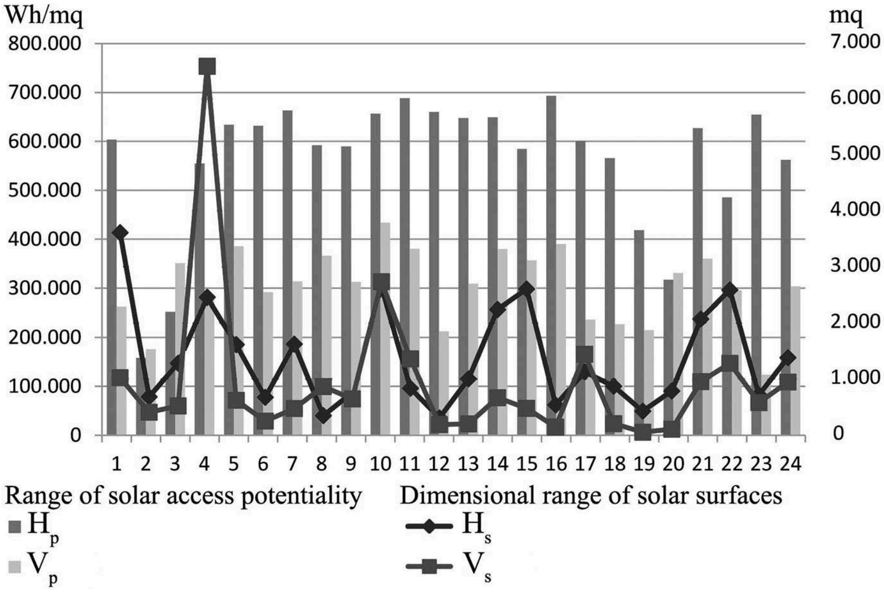


Figure 6. Dimensional range and energy performance of the Horizontal and, Vertical oriented surfaces (i.e. South-South/West-South/East quadrant).

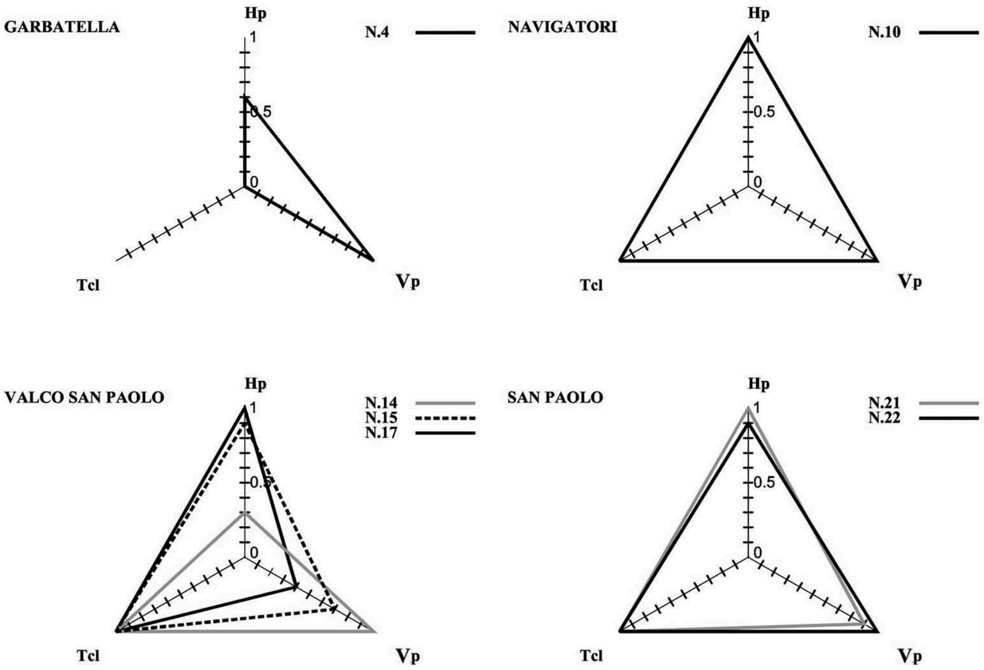


Figure 7. Hierarchical classification of potential DRI nodes.

Visualizing DRI clusters

Figure 8 illustrates, as a dendrogram, the results of the similarity analysis conducted first to organize the information collected and then to provide a tool to develop integrated urban design strategies.

The dendrogram shows a sequence of clusters based on the specific indicator examination, revealing significant information.

For example, the first cluster is represented by schools with Transformability Class index 0. None of these schools has good solar gain or sufficient amount of surfaces that are exposed to the Sun to be an active node. However, school n.4 is an exception. Indeed, this school benefits from high levels of solar gain and sufficient size of surfaces that benefit from solar gain. It is an exception both in its own Homogeneous Urban Unit and in the whole urban context, although its Transformability Class index is zero. The second cluster includes all those schools which have a Transformability Class index of 1. Hence, these schools could become active nodes, but they are not appropriate due to limitations on solar gain and the number of surfaces that are exposed. The third cluster includes all schools with a good range

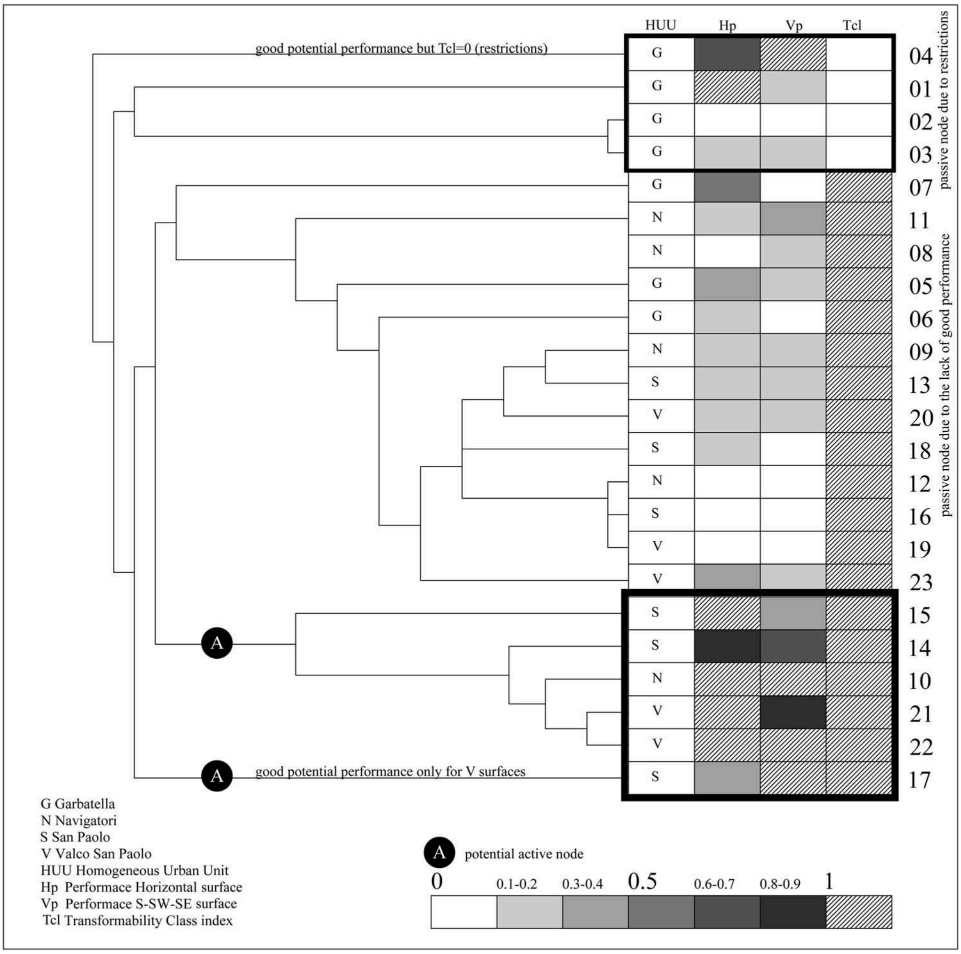


Figure 8. DRI clusters of the analysed school buildings.

of solar gain and a clear distinction between the Horizontal and the Vertical oriented surfaces. These clusters respectively show buildings with low, medium and high potential to become active nodes.

Discussion

This study has developed a simplified procedure to illustrate how Distributed Renewable and Interactive (DRI) energy systems may be spatially organized. The procedure has also introduced some preliminary criteria and indeces to disseminate knowledge among urban and architectural designers about how DRIs work. Furthermore, some relationships between changes in energy infrastructure and changes in the approaches to urban design are identified and discussed. This simplified procedure facilitates a new approach to devising energy infrastructure as part of the urban design process. This is achieved through two key steps: a) the identification of urban components, as active, neutral or passive nodes of the future energy network; b) the definition of an urban hierarchy of these nodes.

Figure 9 illustrates how these steps are put into practice to configure a complete DRI network. The suggested process is applied in the Garbatella Homogeneous Urban Unit,

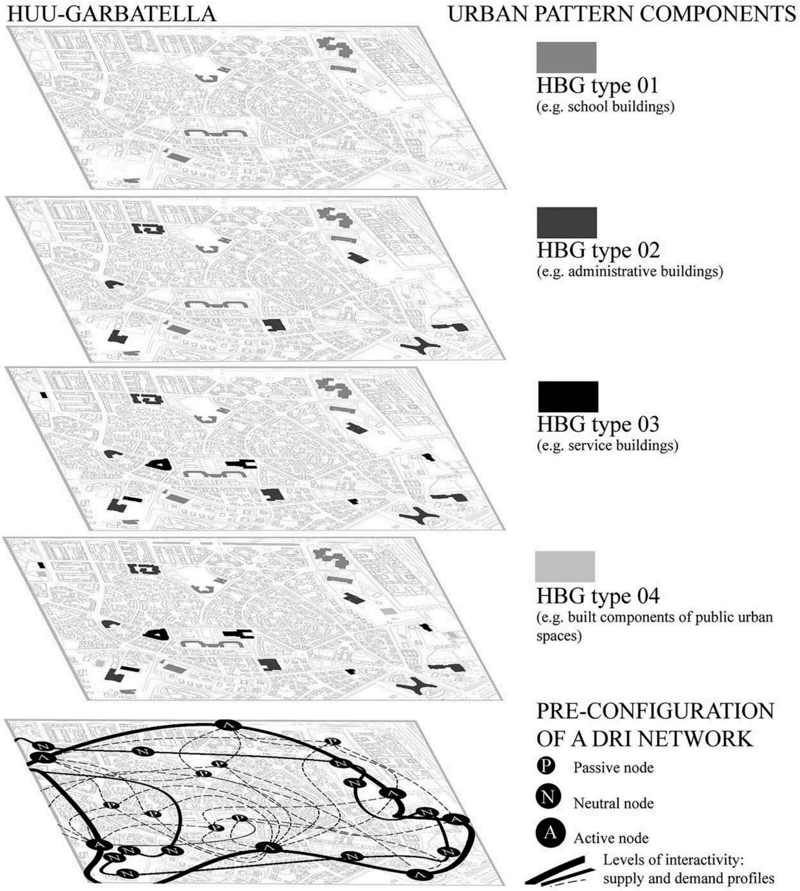


Figure 9. Process to configure a complete DRI network.

where none of the school buildings was identified as an active node. Hence, potential active nodes need to be short-listed among other Homogeneous Building Groups, e.g. public administrative buildings, public urban areas such as car-parks, in Garbatella. These buildings should have different energy profiles to reconcile different energy flows. The simplified procedure is then applied to all these Homogeneous Building Groups to identify potential passive, neutral and active nodes as denoted in HBG type 2 to HBG type 4 (Figure 9). This step culminates in the pre-configuration of a DRI network (Figure 9). Hence, this DRI facilitates the reconciliation of urban patterns and the evolutionary energy infrastructure as part of the Urban Design process. Integration of the appropriate urban components in a DRI network provides a new insight into urban design strategies. Table 2 highlights three new topics and associated processes, which emerged from this simplified procedure that promotes DRI as a tool for Urban Design.

First of all, there is evidence (e.g. image in Table 2) that the number of buildings and urban areas involved as components of the DRI network may be significant, if all the existing buildings are evaluated. This energy transition potential can only be exploited if the traditional urban design practices are reconsidered with specific reference to energy infrastructure.

For example, Homogeneous Urban Units and the Transformability Class Index could be defined in ways that prioritize the establishment of novel energy systems, which pay due attention to local urban features. Novel urban morphology analyses, which map the local urban features with regards to these systems, could be developed. The implementation of the reconciliation criteria at the local level, could potentially reverse the urban homogenization that results from heavy reliance on fossil-fuel-based energy systems.

It should be noted that participatory decision-making processes are required to identify Homogeneous Building Groups in collaboration with institutions and other parties that have a stake in the selected buildings and areas. The selection of these groups is not only concerned with energy profiles that are determined by the use class, but also with new approaches to participatory decision-making and co-creating novel urban governance systems. Urban designers and architects could become principal intermediaries for low carbon transition, acquiring new competencies and skills.

Furthermore, the proposition of the concept of buildings as ‘energy nodes’ is timely. It complements the EU initiatives that aim to reduce the environmental impact of buildings such as the Nearly Zero-energy Buildings Directive (European Commission 2010). This directive proposes a technical and regulatory framework, focusing on the building scale and leaves the concept of energy infrastructure unchanged. In contrast, the proposed procedure offers a possible solution, going beyond the state-of-the-art. It promotes a novel approach to synchronizing urban and energy regeneration processes by identifying buildings and their own urban context as energy nodes.

The clusters and the hierarchical classification, used in this preliminary procedure, help to identify the platform which can become the new infrastructure. A set of primary strategic measures can thus be implemented to deliver this platform. On the one hand, the morphological re-balance of urban settlements and buildings can be achieved through demolition, reconstruction, and extension of the existing fabric. On the other hand, active, neutral and passive nodes can be used to gradually build a novel energy network.

These strategic measures can be implemented within the short-term, augmenting solar gain (or other local renewable resources) and resulting in environmental benefits.

Table 2. Potential integration of Urban Design strategies and Distributed Renewable and Interactive Energy Systems.

A hypothesis of Distributed Renewable and Interactive Energy System organization for an Homogeneous Urban Unit based on a network of several Building Homogeneous Groups:	To reconcile Urban Patterns and the DRIs	
	New topics	New processes
	1. New criteria and parameters to identify Homogeneous Urban Units to associate energy implementation actions with local urban features.	Mapping urban areas, taking into account the local geographical conditions which need to be enhanced (e.g. topological overlap of morphological, historical, environmental and social features). By doing so, DRIs components will be locally defined.
	2. New decision-making process to assemble the set of Homogeneous Building Groups	Defining rules and parameters to manage the urban decision-making processes of DRI organization, which involves Institutions and stakeholders of the selected buildings.
HUU: Garbatella. HBGs: e.g. Type 1 + Type 2 + Type 3 + Type 4 (Figure 9)	3. New agenda for urban and energy regeneration process 2030–2050	Urban regeneration strategies integrated with the DRI vision that can be implemented in the short, medium and long term. These strategies should take the following into account: – Morphological rebalance of buildigns and urban spaces to improve exposure to renewable energy resources; – A set of urban and architectural design transformations to reconcile the energy supply and demand characteristics of active, neutral and passive nodes.

These benefits will only be exploited if the opportunities offered by DRIs are integrated into approaches to Urban Design. This opportunity can be achieved through increased comprehension of DRIs as a socio-techno apparatus.

Implications

In this work, DRI systems are not intended as a technological panacea for the resolution of the environmental imbalances in urban contexts. They are proposed as means to changes in the urban organization to deliver changes in energy infrastructure (Rutherford and Coutard 2014). The suggested procedure aims to go beyond merely energy efficiency at the urban and building scales. It re-introduces the local geographical condition into the decision-making process in order to make a 'difference' to the way energy is produced, transferred and consumed. This is a radical change.

As already stated, DRIs may be built using low carbon transition technologies other than solar. They are grounded in the spatial organization of the settlement and its local energy resources. They are implemented with the support of the socio-technical capacity of the local communities, who are called to manage the integration of this new technology in tandem with the main features of the urban environment. Urban Design can play a critical role in finding suitable socio-technical solutions for future energy infrastructures that balances the local energy generation and management capacities. Thus, a novel debate on the role of DRIs as potential tools for Urban Design to facilitate the co-evolution of urban patterns and energy systems becomes relevant. Within this debate, urban designers and architects are well-placed to generate programmes, plans and physical and social products based on simplified (or complex) procedures, which help to understand how energy provision and urban development can co-evolve.

This procedure has delineated some implications for this co-evolution. For example, it is now commonly accepted that the new energy systems are more efficient if they are conceptualized and implemented at the district scale (Guarino et al. 2016). Simply enlarging the scale of the analysis is not sufficient to describe the properties of the new energy systems. Indeed, this procedure highlights the difference between the Homogeneous Urban Units and energy districts, which are usually adopted in current approaches.

Energy districts propose an advancement of technologies without compromising the existing Technology Support Networks (Zeleny 2012). However, DRIs promote a review of both the structure of the organization and the technology components. They make it possible to operate in an alternative and more efficient way; and more importantly, to do new things (Sibilla and Kurul 2018; Zeleny 2012)

The novelty of this research is its conceptualization of the process through which the DRI systems are organized. Spatial design may play a key role in this process, and new reflections on spatial qualities are necessary for the evolution of the energy infrastructure (Khan et al. 2014). These new reflections specifically considered the relationships between the spatial organization of the urban environments and the components of the future energy network. The spatial qualities involve infrastructure (re)development, which in turn involve a socio-technological transition (*ibid*).

This process requires the integration of the qualitative and quantitative analytical approaches to:

- Avoid technologically deterministic views of the city (Carmona 2016);
- Quantify the environmental weight of DRI components (Karimi 2012);
- Embrace social acceptance of energy innovation (Wüstenhagen, Wolsink, and Bürer 2007), and;

- Enhance technological, organizational, social and institutional coevolution (Unruh 2002).

These analyses can no longer remain isolated in discrete professional domains. The new system properties of DRIs should be understood by all the built environment professionals, so that, they can make credible and creative contributions. These new system properties were described in this paper through a simplified procedure to demonstrate the possible interactions between urban design and energy infrastructure.

Conclusions

This paper has developed a simplified procedure to reconcile urban patterns with the new features and properties of DRI systems. This reconciliation seeks to contrast the homogenization of the urban form which emanates from the fossil-fuel-based energy infrastructure. This simplified procedure goes beyond the technical vision of the energy apparatus by focusing on the implications of the spatial and social dimension of an urban structure.

The concept of a DRI cluster has been proposed as a cognitive apparatus that can enhance the energy infrastructure and enable its co-evolution with the settlement. This cognitive apparatus may be seen as a useful tool both to implement a co-evolutionary process (Foxon 2011) towards Low Carbon Transitions and to promote the interconnections between technical systems and urban patterns (Geels 2005). Specifically, the research findings can be interpreted as a further contribution towards exploring the use of the urban context as a platform for developing a new generation of micro-grid projects. This contribution is made by providing a practical procedure that can tailor the DRI infrastructural system to the features of the local setting.

DRI clusters were presented as valid tools to synchronize urban transformations with the establishment of novel energy infrastructures at the local level. DRI clusters are based on morphological analysis of settlements and buildings, which is the core of urban design according to Macdonald (2016). The proposed procedure contrasts with the technical literature which is focused on balancing energy demand by using technological solutions in isolation. Furthermore, DRI clusters could facilitate the move towards a more holistic approach to urban transformation, where urban design strategies can be planned on a short, medium and long term basis to support the co-evolutionary scenario towards Low Carbon Cities and social transition towards sustainable living.

Understanding the DRI properties is necessary, given the growing experiments of smart cities and smart grids. The quantitative approach has significantly been simplified here to facilitate such comprehension. Any limitation of the current, simplified approach can easily be addressed by adopting more sophisticated analyses (e.g. increasing the level of detail of the 3D urban environment and taking into account the real building energy consumption figures).

This work opens a multitude of research paths as the simplified procedure can be adapted and implemented in different urban contexts. A future step might consider other case studies to improve the DRI system typologies. These new case studies could integrate other Homogeneous Building Groups (i.e. those presented in Figure 9) and take into account further energy resources (e.g. wind, water) and technologies (e.g., micro-turbine, micro-hydro-plant). Therefore, the challenge of the socio-technological organization of the DRI remains to be fully addressed. The core of the investigation is likely to continue to move towards the optimization of the methodological apparatus to implement DRI systems in short, medium and long terms. In conclusion, this exploration embraces Knowles'(1974, 2003) vision to develop a procedure to reveal the energy supply potential inherent in the physical aspects of a particular context and to reconcile energy infrastructures and future urban patterns. This is achieved by focusing on the role of DRIs as tools for implementing urban design strategies.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the H2020 Marie Skłodowska-Curie Actions [751376].

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