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Special Issue Forward

SUSTAINABLE PLACES 2016 June 29-July 1, 2016 Anglet, France

Innovative business models and renewable energy technologies nowadays suffer from hindered market uptake in the construction and manufacturing sectors, which have intrinsic negative impact on society, economy, and the environment. Meanwhile, the impact of adding novel products & services to the product portfolio of construction and manufacturing companies has been shown to increase profitability by up to 5.3% and employment by up to 30% [CEPII, 2015].

The Sustainable Places (SP) series of annual conferences brings together scientists, researchers, and engineers, from research institutes and the industry, around one of the greatest challenge that our societies have ever faced: ensuring long-term environmental sustainability of ever-growing, densifying urban areas, in a resource-constrained world. Sustainable Places 2016 (SP2016) scope was centered specifically on the topics of sustainable buildings, districts, and communities. There was an extra focus on the entrepreneurial aspects of bringing new solutions to markets, and bringing market actors directly to those solutions.

SP2016 successfully fostered the scientific valorization of European-funded research projects and commercialization of innovative technological products and services towards sustainable built environments and next-generation entrepreneurship. Networking was integral to the conference objectives, resulting in stakeholder being informed of relevant market-ready solutions available for investments.

SP2016 was an official Energy Day of the EU Sustainable Energy Week. It was held in Anglet, France from 29th June – 1st July 2016, and was hosted at University of Pau and Pays de l'Adour (UPPA) by a leading technology transfer agency, Nobatek. As well as the 12 accepted Entrepreneurial and Sustainability Issues (ESI) journal articles, there were also 10 thematic sessions, 2 special interest group meetings, 6 scientific posters, 10 keynote speeches including a welcome from the Mayor of Anglet - Claude Olive, and 4 pilot site visits offering live demonstrations of simulation tools, energy-efficient buildings (EeB), and an eco-district in Bayonne, France.

The objective of the (ESI) special issue from SP2016 was to help advance the state-of-the-art of EeB & Smart Grids through research contributions, tutorials, and position papers that address the broad challenges faced in analysis and processing of grid-connected EeB with high penetration of renewables deployed. 12 original, peer-reviewed papers describe completed and unpublished work that are not currently under review or published by any other journal/magazine/conference/special edition. They represent 10 European projects, a University in Italy, and a technology institute in Luxembourg. We appreciate the collaboration, enabling the dissemination of scientific results.

A warm thank you to goes to the RESILIENT and PERFORMER projects, Nobatek, and UPPA, and especially to the 150 guests who contributed to the success of SP2016 and the ESI publication

Sylvain Robert

International Centre for Entrepreneurship Research

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Guest Editor-in-Chief

Robert Sylvain

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The *Entrepreneurship and Sustainability Issues* ISSN 2345-0282 (online) is a peer-reviewed journal, which publishes original research papers and case studies. It is international journal published cooperating with universities, social companies, consultancies and associations indicated on the cover of the journal. It is published quarterly.

Areas of research include, but are not limited to, the following:

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Editorial correspondence including manuscripts and submissions:

Prof. dr. Manuela Tvaronavičienė
Tel.: +37068783944
E-mail: submissions@jssidoi.org or manuela.tvaronaviciene@vgtu.lt

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TOWARDS SUSTAINABILITY THROUGH ENERGY EFFICIENT BUILDINGS' DESIGN: SEMANTIC LABELS[1]

Roberto Traversari[1], Martjan. Den Hoed[2], Roberto Di Giulio[3], Freek Bomhof[4]

[1,4] TNO, Van Mourik Broekmanweg 6, Delft, The Netherlands

[2] De Jong Gortemaker Algra Architecten, Rotterdam, The Netherlands

[3] Department of Architecture, University of Ferrara, Ferrara, Italy

E-mails:[1] roberto.traversari@tno.nl; [2]martjan.denhoed@djga.nl; [3]dgr@unife.it; [4]freek.bomhof@tno.nl

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Abstract. When designing buildings, it is a challenge to take into account Energy Efficiency in the early design stage. This is especially difficult for hospital designs, because these buildings comprise many different room types and functions. This greatly increases the number of design directions available. Choices made early on in the design process have a large impact on the final performance of the building. However, the lack of detailing available in early designs makes it hard to evaluate them in terms of Key Performance Indicators. The Semantic Labels developed as part of the STREAMER project provide a way to address this problem, by allowing structured capture of the most relevant aspects of the Program of Requirements. Using this method, design rules can be applied to early building designs to detect and correct inconsistencies or suboptimal solutions. Also, using default values for label values, an early design can already be evaluated using simulation tools. The Semantic labels describe standard values for Construction (floor height and strength, accessibility), Hygiene class (from public spaces to operational theatres), Equipment (electric power requirements, safety), User profile (when the room is used), Comfort class (like daylight) and Access security (who can enter). Design rules may express conditions like the preferred spatial separation between rooms, or whether rooms should be placed at outer walls, but may also highlight incompatibilities in e.g. access requirements and user profiles.
The Early Design Configurator, also under development as part of the STREAMER project, uses the Semantic Labels to allow automatic conversion of a Programme of Requirements, into an initial Building Information Modeling (BIM) design proposal that respects the design rules.

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[1] *This research was supported by the STREAMER project, which has received funding from the European Union's 7th Framework Programme under grant agreement No 608739.*

Keywords: sustainability, energy efficiency; BIM; early design; semantic technology; design rules

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JEL Classifications: L86, L74, Q56
Additional disciplines: Architecture, Design Methods

1. Introduction

Innovative solutions for sustainability is an area of scientific interest, which will maintain its urgency for the nearest decade, at least (e.g. Rezk et al. 2016; Šimelytė et al. 2016; Strielkowski et al. 2016; Razminienė et al. 2016). Energy efficiency in the built environment is an important part of this.

Designing complex buildings involves the integration of many stakeholder group perspectives, and requires optimization against a large number of Key Performance Indicators (KPIs). This is especially true for hospitals, where functions that include a wide range of different requirements have to be integrated into a single design solution. Energy efficiency is an important requirement: hospitals use on average 2.5 times more energy per square meter of gross floor area than a typical office building. This is due to the high rate of ventilation required as well as the round-the-clock nature of many healthcare processes (Health Building Note 00-10, 2013). Quality is another important area where designs have to meet or exceed KPIs. This group of KPIs generally includes requirements on the salutogenic performance of the built environment (Evidence Based Healthcare Design, or Healing Environment (Fotler et al. 2000), as well as operational quality requirements in terms of logistics and safety. A third group of KPIs relates to construction and operational costs.

Design decisions influence the values attained for these KPIs. It is generally recognised that decisions with the greatest impact on eventual building performance are taken in early phases of the design process (Guruz et al, 2014). In later design stages, design freedoms are increasingly constrained and it becomes more and more difficult to change key aspects of the design. It is therefore important to be able to assess the building's expected performance in terms of KPIs as soon as possible, and to be able to compare different design alternatives in those terms.

Where the configuration of rooms in a building influences its overall KPI performance, choices in building typology and building envelope technology impact on energy efficiency. Requirements for new build or refurbishment projects typically contain: the number of treatement rooms, offices, hotel rooms etcetera is however often specified in the early design. The starting point for creating early designs is generally a specification of the number of different types of rooms required, in the form of a Programme of Requirements. However, this type of document generally includes very limited performance data at room level.

A major problem in early design generation and assessment is that names assigned to spatial elements during the initial phase of a design, do not define either the properties or the performance values for that spatial element. Another problem is that creating different designs and comparing them in terms of energy efficiency, quality, and cost is very labour-intensive.

In this paper, we introduce a method that facilitates the generation and evaluation of different design alternatives in early stages. The work is based on the results of the FP7 STREAMER project, EU Grant 608739. The STREAMER project addresses the design of energy-efficient healthcare districts, addressing the design stage, especially the early design, where decisions are made with respect to topology and system choices, that have large effects on the resulting building performance. The approach in the project is to create different design alternatives that can be evaluated on the basis of KPIs for energy performance, cost and quality.

The names assigned to spatial elements (rooms) provide only very cursory information about the function of that spatial element (room) and the allowed or possible values for its properties. This can vary from country to country and even from region to region. Historical development of healthcare and hospitals, climate differences and differences in legislation all contribute to this. However, to use an automated early design process and to perform an evaluation, at least (some) properties of spatial elements, construction elements and systems need to have values assigned.

The proposed approach makes use of semantic labels. The basic idea is to assign labels to the room names or functions. These labels provide structured information on the types of properties and performance value associated with that room. Thus, allocation of allowed or default value ranges for properties can be done in an easy and structured way during the early design stage. Default values can be replaced with more detailed information as and when this becomes available during the design process, gradually enriching the design and allowing for more precise assessments of various KPIs. If the semantic labels of a spatial element in the design are known, the values assigned to its properties can easily be checked for compliance with the range of allowed values associated with this semantic label. Additionally, the semantic labels enable the definition of design rules that can be created to make tacit knowledge of various stakeholders (designers, users) explicit.

2. Earlier work

Performance expectations for healthcare buildings are changing rapidly. The development of new technologies often results in the need for new room types. Hybrid operating theatres are a case in point. Here, new imaging techniques have led to the development of new types of surgical procedure, predominantly minimally invasive techniques. These techniques lead to improved treatment outcomes, but also place new requirements on operating theatre equipment, which in turn lead to new demands on spatial and technical configuration. This example shows that it is virtually impossible to develop a functional and technical room definition on the basis of its name only.

Previous work has been done in the field on definition and classification of room names in a hospital setting. These studies have, however, been limited to one country each (e.g. Sweden, Great Britain (Health Building Note 00-10, 2013), and have tended to focus on developing definitions for the room names themselves. They have not addressed the functional requirements of a specific room type.

Several room classification systems are available (e.g. OmniClass (Likhitruangsilp et al. 2014, Abdirad et al. 2015, Knopp-Trendafilova et al. 2009) and UniClass (Ei-Diraby et al. 2005, Maradza et al. 2014, Dael et al. 2006)). These classification systems have been mainly developed for the benefit of the construction industry. They are useful for many purposes, from organizing project library materials, product literature, and project information, to providing classification structures for electronic databases. The classification systems are rich in product level, and are a way of standardising available information. It is possible to define spaces or rooms using the structure these systems provide. The OnmiClass system defined a number of spaces in hospitals. However, spaces and rooms need to be defined on the basis of room type (room name) and the classification systems do not allow for standardisation for all hospitals in all countries.

Besides classification systems focused on products, systems are also available that manage and facilitate the development of a programme of requirements at room level. Briefbuilder (Van Ree et al. 2006) and dRofus (dRofus) are examples of such systems. These systems support key activities in the design phase of a project such as planning and mapping of spaces and functions, as well as registration and verification of the requirements for each space.

These systems also support data exchange through the IFC (Industry Foundation Classes) standard, and provide a databases with pre-defined rooms. These pre-defined rooms can be adapted for a specific (hospital) project.

However, to do so accurately a lot of detailed information is needed that is generally not yet available in the early design phase.

The Netherlands Board for Healtcare Institutions developed the so-called layers approach to hospital design (Netherlands Board for Healthcare Institutions, 2007). This approach was mainly focused on reducing the investment and operational cost of a hospital. The approach allocates functions to four different spatial environment typologies based on their functional and technical characteristics. These tyopologies are referred to as "layers": 1) hot floor environment, 2) hotel environment, 3) office environment and 4) industry environment.. Important drivers in applying the layers approach are simplification of the design challenge, reduction of investment and operational costs, and improvement of use flexibility.

In its strictest typological application, each layer constitutes a separate building block with functional and technical specifications optimized for that layer (e.g. ceiling height, build quality, type of HVAC equipment, operatining hours and the expected life span of the building block). Nowadays, many architects in the Netherlands use this approach to cluster functions based on their building characteristics. In practical application assignment of functions to layers is done more pragmatically, taking into account logistical and medical operational requirements as well as typology. This approach is very suitable for defining the functional areas and departments, but has limitations for application to room level design specifications. Any room may have a different set of specifications according to the typological environment within which it is situated.

Based on the survey of earlier work outlined above, we concluded that there is no consistent system available to define rooms based on the requirements in a hospital setting that could be used during an automated early design process. We also concluded that the OmniClass and UniClass system, Briefbuilder and dRofus are too detailed and the layer approach too generic for use during the early design phase.

3. Semantic labels

Once the strategic decision to build or rebuild a hospital or part thereof, the initial input for a design process generally consists of an estimate of the specific floor area required, based on the expected volume of activities. For the latter, some high-level estimate is usually employed, based on the expected annual number of patients, the size of the catchment area, or another production related figure. At this very early stage, the number of different rooms and their sizes are not defined clearly. Only the logistical relations with the other parts of the hospital are specified. In the subsequent phase, room types and numbers, are defined without, however, information being specified on the properties needed for the rooms. The resulting initial layout may be inefficient, because a number of aspects contributing to a balanced design decision – such as energy considerations - are as yet unspecified. Pushing the design process forward on the basis of spatial relationsip requirements alone, often causes problems during the more detailed design when it transpires that these spatial relationship driven design choices negatively affect other (technical) properties.

The use of semantic labels can be a valuable tool in the early design phase, allowing designers to assign additional properties and values to spatial elements (room) with a view to developing a proposed clustering of spatial elements (rooms) on the basis of a more balanced set of performance requirements. Thus, for instance, functions could be clustered on the basis of their energy consumption and operational hours as well as on their spatial relationship requirements.

Additionally, the semantic labels can help evaluation of early designs. The labels provide allowable value ranges for properties against which early designs can be checked. This step can be repeated for each newly created design in any design phase to verify if designs are still valid and continue to comply with the fundamental requirements.

Thus, semantic labels are both helpful during the early design stage and continue to be useful as the design process progesses, as more properties and/or requirements can be added to the properties of a spatial elements (rooms), and/or default values and requirements defined in the semantic labels can be overwritten as more accurate or detailed information becomes available.

A central concept used in the STREAMER project is the healthcare district (HD). A HD describes the specific area where a hospital is (or will be) located, taking account of the hospital's interactions with other functions within this area. A HD provides the opportunity for a hospital to align its energy needs and consumption patterns with those of the surrounding area, for instance capitalizing on temporary peaks and troughs in energy demand. This helps create more energy efficient and sustainable healthcare districts. When considered in its full extent, the concept of semantic labels addresses all the elements that define a healthcare district (HD) at its various levels. It must be noted that although the labels convey semantics (on the expected use or requirement), the labels are not stored in an ontology structure.

Taking into account the spatial and functional organization of healthcare districts and the possible configurations of existing typologies, four different levels can be defined (De Hoogh et al. 2014):

a. District level. A district consists of several buildings. This level can be further partitioned or organized, depending on its administrative, functional or technical characteristics. Accordingly, the structure of a HD can include: compounds, centres, departments, etc.Application of semantic labels at this level is indirect only, that is by inference of the consequences at district levels of the application of labels at lower levels.
b. Building level. Properties and energy-related features of the buildings may be related to their typological and technical characteristics, to their functions or to their shape. At building level, the applicable labels include different scales on which the building can be scored. At this level, the semantic model includes only one object: the building.
c. Functional area level. A functional area is a group of spaces exhibiting strong interdependencies between functions and spaces (wards, operating theatre blocks, etc.). A functional area can be classified considering both its functional and technical properties and characteristics, including the energy-related features of the latter.
d. Room level. Rooms are the lowest level spatial entity that can be identified by specific functions and properties (e.g. operating rooms, patient rooms, nurse offices, etc.). Spaces can be classified considering both their functional and their technical properties and characteristics, including their energy-related features.

For the building level, functional areas level and room level, the set of labels that can be applied depends on the consistency between the nature of the labels and the specific characteristics of the objects. For example an operating theatre belongs to the hot floor functional area. It must accordingly be situated in a building that complies with these requirements (see Tabel 2). This implies, high levels of cleanliness (e.g. hygiene meaurures and wipable surfaces), controlled access for staff, patients and visitors and a high performance level in terms of specific equipment. Since special air treatment equipment (HVAC) needs to be in place, specific requirements in terms of ceiling height apply. These requirements affect not only on the design of the room itself but also of the functional area and even the building in which it will be located.

Although the semantic labels at space unit's level are developed for rooms, these labels can also have values when applied to functional areas. The philosophy behind the application of semantic labels is identical at both levels. If no independent information regarding properties at the functional areas levels (office, hot floor, industry, hotel (Netherlands Board for Heathcare Institutions 2007)) is available, the semantic labels for the space units can be used to infer these in the early design stage.

Table 1. Streamer labels.

Streamer labels	Description	Label categories
Hygienic Class	Level of cleanliness of the room e.g. toilet, office, treatment room, operating theatre.	H1 – H5
Access and Security	How the access of the room is controlled e.g. publicly accessible, only accessible for medical staff.	A1 – A5
User Profile	Period of the day the room will be used e.g. mon-Fr from 8:00 – 18:00, 24 * 7	U1 – U4
Equipment	Level of electric power needed e.g. level of an office, Special equipment and requirements regarding safety	EQ1 – EQ6
Comfort Class	Level of comfort in the room e.g. level of a corridor, level of a patient room	CT1 - CT8
Construction	Typology of the construction ea. floor height, floor strength	C1 – C6

Source: FP7 STREAMER project

The label categories specify parameters in three areas: 1) parameters required for the early design configurator, 2) parameters for the selection of a Mechanical, Electrical and Plumbing (MEP) system and 3) parameters for the selection of an Energy efficient Building (EeB) solution.

Table 2. Streamer labels for different layers.

Layer	Description	Streamer label categories
Hot floor	Accommodates the high-tech, capital intensive functions that are specific for hospitals e.g. operating theatres, isolation rooms, emergency	H4, A5, U4, EQ4, CT7, C3
Hotel	Comprises all functions for accommodation of patients e.g. patient rooms, general nursing, day nursing,	H3, A2, U4, EQ3, CT4, C1
Office	Accommodates the office facilities e.g. staff accommodation, accounting and management	H2, A4, U1, EQ2, CT3, C1
Industry	Accommodates all medical supporting and facilitating functions e.g. production pharmacy, laboratories, imaging centre	H5, A5, U3, EQ6, CT6, C4

Source: FP7 STREAMER project

Not all information explicit in the semantic labels and label levels at room (object) level is explicitly stated, but a lot of information can be derived from what is stated explicitly. Design rules, explained below, play an important role in enabling this inferral process to take place.

The structure of the labels itself is flexible. If deemed necessary for the purposes of a specific project, additional label categories can be introduced. Additional performance levels within label categories may also be defined . However, too many label categories and levels are hard to deal with. Designs should use a “minimal required set” approach to ensure manageability of semantic labels. New label categories and label levels should only be introduced if they add specific new (semantic) information to be used in the design process. To justify introduction of new categories and/or levels, this information should also be expected to lead to different choices based on related design rules.

4. Design rules

The purpose of design rules is to formalize the logical thinking employed when organizing rooms in a design proposal. They bring to light and structure tacit knowledge used by designers. Thus, design rules are captured rather than formulated.

The design rules concept used in the STREAMER project has been inspired by the packing approach developed for the early stage design of marine service vessels (Van Oers 2011). In this approach naval engineers created a methodology for the optimal placement of objects which needed to be transported by marine vessels. The descriptions of these objects were data technically enriched with metadata, which is used to support decision making on optimal placement of the objects inside these ships. The methodology allows for the use of metadata like size, weighing loads, and on-board presence periods in algorithms to generate and evaluate proposals for possible placement of these objects.In optimizing the early design of buildings for energy efficiency, the design rules methodology similarly not only creates and evaluates alternatives based on different outer shell layouts, but bases its design proposals also on different groupings of activities taking place in the rooms described in the Program of Requirements (PoR). For this purpose, the PoR is enriched with activity and building labels. On the basis of a PoR enriched in this fashion, design proposals can be generated.

An example: a design rule could be that all rooms with the activity label U1 (opening hours 08:00-17:00, weekdays) should be clustered together. Activity label U1 signifies weekday operating hours form 08:00-17:00 with weekend closure. Energy efficiency in a design following this design rule would profit from the possibility of switching off its energy systems outside operating hours. In terms of quality and safety, the design would profit from improved security and access management.

Other design rules could apply to spatially grouping rooms with similar access restriction profiles and/or placing constraints on the possibilities for spatial contiguity of rooms and areas with different access restriction profiles.

To show that design rules can apply to all three parameter areas, note for instance that high hygienic class levels, will prohibit (or at least strongly discourage) the use of radiators for heating, as these systems are not easily cleaned. To demonstrate that part of the semantic information is implicit, note that rooms with high specified hygienic class levels implicitly require easily cleanable wall and floor coverings even where these are not explicitly specified.

The generic form of a design rule is:

Object X having property A has relation R with Object Y having property B

Based on this template an infinite number of rules can be created based on a limited number of relationship types. The relationship types determine the generic relation between two objects. Examples of relationship types include for instance: clustering, embedding, minimum or maximum distance between one and the other, must be directly above or below another object, must be on the same storey, et cetera The properties in an early design are defined by the different label categories, table 1. The objects the design rules pertain to are the rooms, the outer boundary, the levels and later on the entrance. The properties of the objects that can be referred to are the labels, the name of the Functional Area or the Room Type. By changing the objects or the properties multiple design rules can be created within the same relationship type.

Inclusion of semantic labels in BIM

The room descriptions in the PoR are enriched with activity and building labels. The BIM exchangeable file format IFC also uses room objects. The semantic labels can easily be added to these IFC objects as specific property sets.

Standard BIM modeling software can work with the IFC files, and in the STREAMER project a number of tools has been created that work specifically with the labels that are stored in this way within IFC files. The project will start standardization activities to promote the broader use of semantic labels.

The design rules are not hard-wired into the BIM model. They provide information about the compliance or otherwise of a spatial lay-out with the rules, but are not themselves part of that lay-out specification. Hence, the rules are not a part of the semantic model, but a way to store experts' semantic knowledge, and possibly also information on regulations. Semantic technologies, including domain ontologies, may additionally be used to analyse the designs for specific other aspects, but currently this is not yet elaborated.

Relation to MEP systems

The design rules methodology also helps select appropriate MEP solutions. Design rules specifying the constraints on possible MEP systems from certain label values are introduced into the software. Using this design rule, for each room a shortlist of permissible MEP systems is generated from the longlist of all available MEP systems. Currently, research is underway to ascertain whether MEP systems characteristics can also be summarized in a specific 'MEP label' system.

Selection of MEP solutions appropriate to an area, department, level or building wing, or even to a whole building is normally done by a specialist MEP advisor, but here too additional design rules that capture tacit designers' knowledge can be created.

5. Practical applications

Semantic labels and the programme of requirements (PoR)

The development of a PoR will precede any design activity on new build lay-outs and retrofitting solutions. The next step will be the definition of the building-related labels values as defined in the PoR. Once compatibility has been assessed at building level, the next steps are to look up the label values of the new functional areas and rooms proposed and compare these label values to that of the building. This requires that an initial estimate be available of the number of rooms, the functions assigned to each room and the floor area for each room. The semantic labels are assigned to the different rooms and functional areas based on their proposed functions.

An adapted version of the Briefbuilder software tool that allows PoR designers to attach semantic labels is available on the market. The output of this tool can be processed by the Early Design Configurator.

Early Design Configurator (EDC)

The Early Design Configurator (EDC) is a tool that is being developed as part of the STREAMER project. It uses genetic programming methodologies for generating multiple design proposals that progressively satisfy the PoR and design rules. Besides the PoR and design rules, the EDC uses the outer shell layout of the building, and the activity and building labels to generate its design alternatives.

Different design rules may be partially or wholly incompatible or even contradictory. In recognition of this, the EDC methodology is probabilistic: it will apply design rules in such a way as to maximise the likelihood of a layout alternative satisfying a certain rule. This means that solutions generated through the EDC will often not satisfy all rules, and/or satisfy some rules only partially or sub-optimally. Not all rules are equally important, nor do all rules follow the same format. For some, satisfying the rule will be a binary Yes/No assessment, while other rules will employ a gradual scale. To improve user control over design compliance with crucial rules, the EDC allows users to assign relative priorities to different design rules. The higher a priority assigned to a design rule, the more the alternatives generated by the EDC will be geared towards satisfying that particular rule. Different design proposals can be created by changing design rules, or by applying different priority weights to design rules.

During the early design stage, i.e. before proceeding to more detailed definition of technical and functional solutions, an important question to be addressed is whether a proposed or available building (structure) can accommodate certain crucial functional areas. This question is especially relevant when a hospital is considering to retrofit an existing building: in such cases a basic assessment of a building's utility for different healthcare functions is essential.

The relationships that determine the spatial layout are often complex and may be contradictory to each other. For EeB design, the EDC approach is to favour alternatives that include those relationships that, on the basis of the information available in the early design phase, are most likely to improve energy efficiency. The EDC will, for example, favour designs which tend to cluster rooms with the same operational temperature range requirements, as reducing energy flows between rooms reduces overall energy consumption.

Design validation

The EDC output is designed to support manual comparision of alternatives by experts. Its main supportive feature in this respect is conditional colourisation of rooms on the basis of the values in the enriched data linked to the room objects. For example it is possible to show all the 'U' labels to visualize all the rooms with the same U label value. Such a visualization helps in identifying inconsistencies or serious flaws in a design alternative. Multiple labels can be visualized concurrently, using different colour spectra.

Design alternatives may be validated through a design validator. This separate module is under development for this, as the EDC output proper is insufficient for this purpose: although the EDC provides a "satisfaction score" for each layout generated, this is based solely on the placement of rooms, the width/depth ratios of the rooms, floor areas of the rooms and the overall degree of satisfaction of design rules. This does not provide information on which specific design rules are fulfilled or violated in the spatial layout generated. The validation tool will use the same rules as used for input in the EDC, and will allow validation of the fulfillment of each individual design rule.

The manual input from the designer is still required to apply the relations of the PoR, the building regulations and his or her own interpretation. This concept will be "scraped and sanded" into a layout which is more and more in line with the regulations, wishes and budgets, and of course the PoR. Manually updated designs can be validated, evaluated and visualized again.

Design evaluation

When a design has been validated (checked against design rules and Program of Requirements), it needs to be evaluated in terms of KPI scores. The advantage of semantic labels in doing this is that default values for parameters can be derived, which can be used as input for simulation tools modelling KPI performance. The STREAMER project focusses on simulation of energy performance, but other need to be assessed as well; cost KPIs (Life Cycle Costing) and quality KPIs are estimated during design evaluation.

Design process

Figure 1 shows the process of the early design with the Streamer semantic labels methodology.

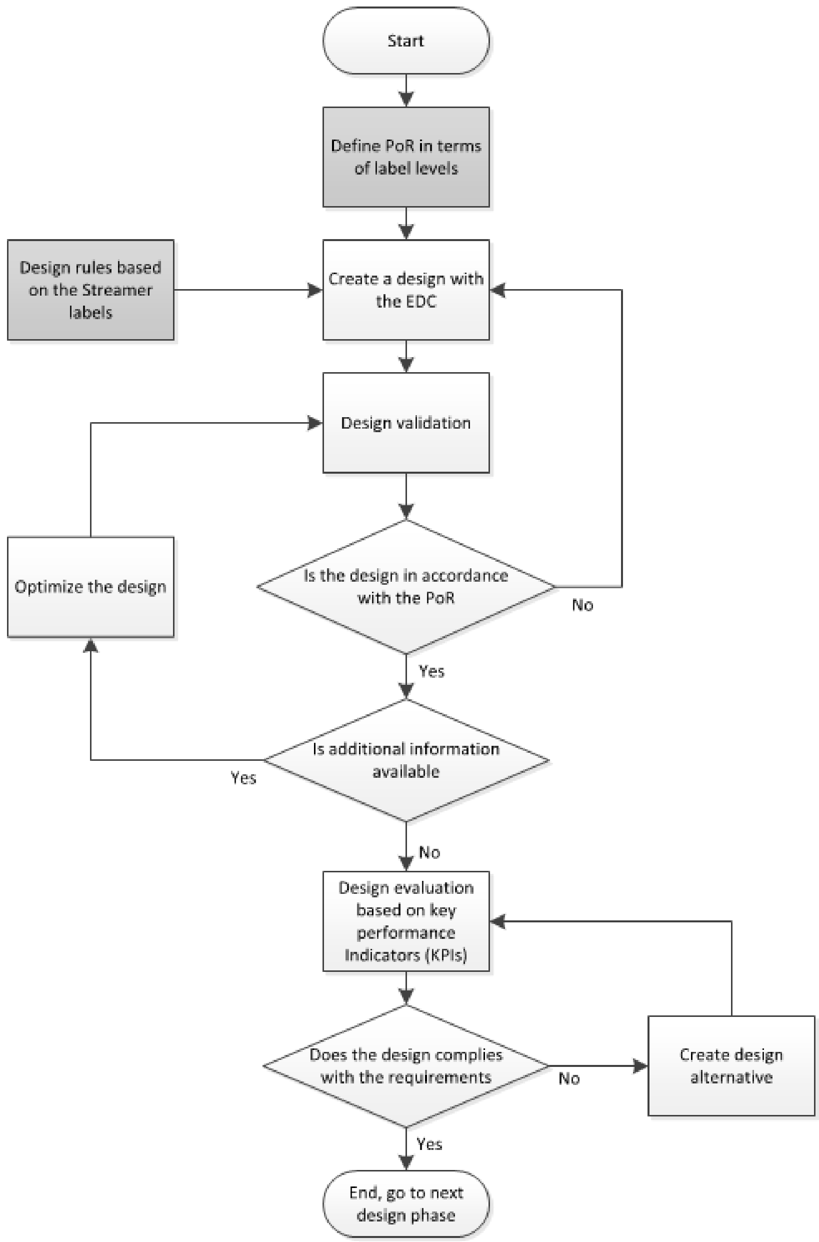

Figure 1. Process scheme of the early design process with the semantic labels.

Assessment of designs by the authorities often takes place at a very late stage in the design process. This may lead to problems, for instance when non-compliance with laws and building regulations comes to light and necessitates major design changes, often leading to substantial cost increases and delays. Use of the tools in development in the STREAMER project addresses this problem both prospectively and retrospectively. Prospectively, our methodologies allow for more accurate early prediction of performance; retrospectivelythey make it easier to go back to previous design stages, to reconsider the other compatible solutions and to find the most convenient way of dealing with the changes requested.

Semantic labels and refurbishment

For a variety of reasons refurbishment approaches are often selected over new build options. The semantic labels approach is very suitable for refurbishmen projects. Naturally, the existing configuration needs to be assessed and the appropriate labels need to be identified for each room. If the labels of a room are known it can be checked if this spatial unit (room) could be used for other functions, provided the requirements for this new function are known as well. This can help designers during the retrofitting of a building or part of a building to find out quickly if spatial elements can be used for other functions as well. Compatibilities and conflicts within the labels (existing ones vs new ones) will define feasibility and costs of the retrofitting interventions.

Testing the approach

Currently the first step (attaching semantic labels to rooms as defined in the Program of Requirements) has been validated in practice. This test has led to some refinements in the label values. It turned out that the labels could be attached to rooms in a consistent way. Also, it appeared that an 80/20 rule applied: the majority of the rooms could be assigned by using a limited combination of label values. The steps following this first one (using the Early Design Configurator, the validation and evaluation) are planned.

6. Conclusions, discussion and future work

Semantic labels have already proven to be a promising approach in early design phases of complex buildings like hospitals. They provide the design team with structured information that can easily be related to the PoR, and that can be extended and revised as the design process continues. The labels enable the capture and application of design rules that formally structure implicit designer knowledge, and allows the creation and evaluation of different design alternatives. Semantic labels play an important role in identifying problems and optimization opportunities. They provide a common language for different groups of stakeholders to communicate abour properties of functional areas and individual rooms in a common and unambiguous way.

In the STREAMER project, the semantic label approach has developed into a central concept for addressing energy efficient building design issues. On the basis of the central concept, a number of tools around the concept is being created to leverage the methodology. These tools have been created and initial tests have been performed, but they are currently at the Proof of Princple stage and need to be elaborated further.

While the semantic labels show promising results in supporting the early design phase for Energy efficient Building design, there is a number of topics that needs to be addressed if the methodology is to be applied more broadly.

Future research should address the problem of how to identify which sets of default values are appropriate when applying the semantic labels in different countries. Climate conditions, regulatory environments and construction practices vary considerably from country to country, and it is extremely unlikely that one single set of default values will be able to capture all this variety.

Another topic for future research is the scope for expansion of application domains for design rules that use the semantic labels as a basis. While it has become apparent that important parts of architects' tacit knowledge can be expressed using design rules, it is still an unresolved question what additional design rules are needed to reflect the state of the art in EeB design. One research direction in this area is the inclusion of MEP design in the approach. In principle this should yield good possibilities for further energy efficiency gains because the selection of MEP systems has a large impact on energy performance. The use of semantic technology may provide additional means to analyse a design in early stages.

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Biographical notes about the contributors:

A.A.L. (**Roberto**) **TRAVERSARI** has a degree in engineering and is Master in Bussiness Administration and working at TNO. His main focus is on research and consultancy in the field of the critical technical ingfrastructure of hospitals and energy and sustainability in hospitals. He was also involved in the RES (Renewable Energye Systems) hospital project and is now involved in FP7 STREAMER project.
ORCID ID: orcid.org/0000-0001-9116-3849

R. (**Roberto**) **DI GIULIO** is an architect, Phd in "Technology of Architecture", Full Professor at the University of Ferrara, Dean of the Department of Architecture. His studies cover a broad range of issues from building design methodologies to investigation on innovative technologies for a sustainable built environment. He is involved in FP7 STREAMER project with Ipostudio Architects, a planning and research organisation operating in the fields of architecture, design and research, in Florence since 1982.
ORCID ID: orcid.org/000-0002-8569-1271

M. (**Martjan**) **DEN HOED** is operations director and architect with De Jong Gortemaker Algra architects in Rotterdam. He graduated from Delft Universityof Technology in Construction Engineering. He has been a pioneer in the adoption of BIM in the Dutch construction sector, and he is board member of the Revit user group, responsible for the Dutch Revit Standards.
ORCID ID: orcid.org/0000-0002-0596-5042

F. W. (**Freek**) **BOMHOF** is the coordinator of the FP7 STREAMER project. He has extensive background as a consultant and project manager in ICT research. He graduated from University of Twente in 1990 in the field of Pattern Recognition and since then held various positions at KPN (the Dutch national telco) and then joined TNO where he is now in the Data Science department that focuses on applied research in the field of data analysis and semantic technology.
ORCID ID: orcid.org/0000-0002-1498-6873

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TESTING INNOVATIVE TECHNOLOGIES FOR ENERGY-EFFICIENCY: COVENTRY UNIVERSITY AS A LIVING LAB[2]

Abdullahi Ahmed[1], Danny McGough[2], Monica Mateo-Garcia[3]

[1, 2,3] Coventry University, Priory Street
Coventry, United Kingdom
CV1 5FB

E-mails: [1] abdullahi.ahmed@coventry.ac.uk; [2]danny.mcgough@coventry.ac.uk; [3] monica.mateogarcia@coventry.ac.uk

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Abstract. Retrofitting Solutions and Services for the enhancement of Energy Efficiency in Public Buildings (RESSEEPE) is an EU funded project which aims to bring together design and decision making tools, innovative building fabric manufacturers and a programme to demonstrate the improved building performance achievable through the retrofit of existing buildings at a district level. The RESSEEPE framework is being validated by a strong demonstration programme, envisaging the renovation of 102,000 square metres of public buildings. The core idea of the project is to technologically advance, adapt, demonstrate and assess a number of innovative retrofit technologies implemented on several pilot cases with different climate conditions across Europe (Coventry-UK, Barcelona-Spain and Skellefteå-Sweden) to ensure a high potential replication of the retrofit solutions. The three demonstration sites are involved as the main promoters of a very ambitious district level renovation, demonstrating a systemic approach to technology installation and evaluation, taking into account the benefits of a set of technologies, which properly combined in terms of cost effectiveness and energy performance could achieve reductions around 50% in terms of energy consumption.

Coventry University is acting as a Living Lab in order to test some advanced technologies already in the market and others developed specifically within the RESSEEPE project. Those innovative technologies implemented in the pilot case are: Vacuum Insulated Panels, PCM tubes, Ventilated façade with Photovoltaic Panels, Electrochromic windows and Aerogel Mortar. The main feature of this installation is that it acts as a testing bed for where to install different advanced technologies covering specific areas of the building, rather than refurbishing it as a whole.

This paper documents the testing of prototype technologies in a pilot case in Coventry University, analysing the process of selection of the different technologies and showing all the challenges faced during installation and coordination of installation activities. The installation process is shown and discussed, highlighting the difficulties, setbacks and challenges faced during the low carbon refurbishment. The key

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issues are related to technical and health and safety risks. Also, to financial, coordination, planning and legislation barriers etc. It will also show ways forward and solutions adopted. The study also analyses the process of monitoring the energy performance of the spaces retrofitted and the data obtained through the monitoring of the building before and after the installation of the different technologies. The idea behind the Living Lab pilot case is to monitor the performance of those installations in isolation in order to obtain results which allow us to make conclusions about the replicability of the technologies selected in other locations. Ultimately, what is discussed is the overall process followed. This discussion seeks to show the lessons learnt throughout the process and to obtain conclusions from the barriers and engagement issues faced during the installation when retrofitting a public building.

Keywords: Low-Energy Retrofit, Living Lab, Public Buildings, Stakeholder Engagement, Performance Modelling and Monitoring;

Reference to this paper should be made as follows: Abdullahi A., McGough, D., Mateo-Garcia, M. 2017. Innovative technologies for retrofitting: Coventry University as a living lab, *Entrepreneurship and Sustainability Issues* 4(3): 257-270. http://dx.doi.org/10.9770/jesi.2017.4.3S(2)

JEL Classifications: I23, O32, Q55
Additional disciplines: Ecology and Environment, Construction Engineering

1. Introduction

The urgency for Europe to transform into a low-carbon economy to meet climate and energy security targets is a fact. One of the most cost-effective measures to meet energy reduction targets, as clearly specified in the "European Economic Recovery Plan", is to address the existing building stock. Buildings account for 40% of European energy consumption and one third of GHG emissions (Directive 2010/31/EU). By 2050, the energy consumption in buildings could be cut with an amount corresponding to today's transportation and industrial sectors combined. In particular, the state of European building stock contains a tremendous improvement potential. Retrofitting Solutions and Services for the enhancement of Energy Efficiency in Public Buildings (RESSEEPE) is an EU funded project that focuses on the refurbishment of existing public buildings in three European cities: Coventry (UK), Barcelona (SP) and Skelleftea (SW).

RESSEEPE aims to develop and demonstrate an easily replicable methodology for designing, constructing, and managing public buildings and district renovation projects to achieve a target of 50% energy reduction in public buildings within specified districts. For this purpose, a demonstration and dissemination framework is developed with innovative strategies and solutions for public buildings, energy renovation at building and district level, based on the following pillars: three demonstration district retrofitting projects in three different countries representative of the breadth of EU climate conditions; cost-effective solutions for holistic energy performance improvement at building and district levels; systemic selection process to achieve optimal mix of intervention measures from a wide range of innovative technologies; mass customisation of the proposed business models and development of a strategy for large scale market deployment throughout Europe; market and replication deployment plan, in order to ensure the project impact at business level, and exploitation strategy suitable for achieving a wide impact.

The RESSEEPE project aims to develop new methodologies for the diagnosis of the potential public district refurbishment taking into account not only the structural and energy analysis, but also the potential problems with the end users in terms of social acceptance and financial constraints. This paper shows a Higher Education building case study used as a Testing Bed for innovative technologies developed specifically within the project framework, for the improvement of energy efficiency in buildings. All the technologies selected for the project are innovative or have new innovative features. They have varying properties ranging from absolute state of the art to more thoroughly tested intervention methods. These advanced technologies are not aimed at refurbishing the building as a whole, being applied just in some areas in order to evaluate the performance of the retrofitted elements in isolation. The idea behind the Living Lab pilot case is to monitor the performance of those installations in order to obtain results, which allow us to make conclusions about the replicability of the technologies selected.

2. Literature review

Buildings account for about 40% of total energy consumption in the European Union, there are indications that this will increase as the number of buildings increase over time to meet population growth etc. (Zero Carbon Hub, 2011). If the European Union is to reduce its energy dependency and greenhouse gas emissions, it is essential that the energy consumption in the built environment is reduced. The existing building stock across Europe offers one of the most significant challenges for meeting the energy and environmental targets. Annually new non-domestic buildings represent less than 1.5 percent of the total building stock, therefore the improvement and management of existing non domestic buildings offers significant potential for achieving energy and environmental savings compared to the construction of new buildings (Baker, 2009).

The European Union responded to this challenge by increasing building energy efficiency standards through the Energy Performance of Building Directives, which came into force in 2002. The aim of the EPBD is to reduce energy consumption in both the residential and non-domestic sectors by raising awareness of energy use through mandating Energy Performance Certification and Display Energy Certificates in Public building, mandating minimum standards, and requiring inspections of key plant. The EPBD also states 'Major renovations of existing buildings, regardless of their size, provide an opportunity to take cost-effective measures to enhance energy performance'(EPBD, 2010). The United Kingdom also set a legally binding target of an 80% reduction in greenhouse gas emissions by 2050 compared to 1990 levels (Climate Change Act, 2008) which sets out the government ambitions for greenhouse gas emission reduction. The UK construction strategy was developed to improve efficiency in the construction lifecycle of buildings (Government Construction Strategy 2011), which aims to reduce costs, improve and optimise the buildings processes and performance of the construction industry.

The retrofit in Coventry University is focussed on the University Buildings. The Association of University Directors of Estate (AUDE) commissioned and published a paper entitled "The Legacy of 1960s University Buildings" (AUDE 2008) The paper focuses on the refurbishment of post 1960 higher education buildings and highlighted a common issue that many universities are facing, which is the problem of building stock that is progressively becoming out of date and unfit for purpose. The choice that owners are facing is whether to condemn the buildings or refurbish them or carry out a full demolition and rebuild. As stated within the AUDE report, the "report considers one of the big issues in Higher Education today – how to renew a very large proportion of the property portfolio that was built in the 1960's.

Four key points that were identified as a significant part of the study;

- Academic buildings can often be refurbished more successfully than residential;
- While the financial case for refurbishment might look poor, with costs in some cases as high as 80% of a new build option, there are often significant environmental benefits from refurbishment; High standards of environmental performance can be achieved on refurbishment projects, provided that the objective is at the core of the design from the outset;
- Architectural excellence can still be achieved in refurbishment projects.

AUDE (2008) stated the need to re-evaluate how pre-assessments of higher education building refurbishments are carried out. An example of the demand for the project was expressed through the indication that the University of Bath alone had earmarked "£40M of investment decisions that will need to be taken which directly impact 1960's buildings." (AUDE 2008).

Technologies Review

There are a number of technologies that can be used to improve the energy and environmental performance of buildings. Figure 1 shows a number of technologies that are considered within the RESEEPEE project.

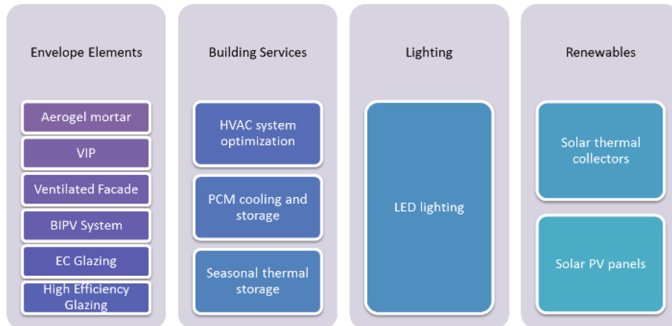

Figure 2. Technologies selected for RESSEEPE project

Aerogel mortar: It consists of a very porous ultra-light material that combines aerogel with cement to provide super-insulating properties. Due to its low density and small pores this material shows a remarkably low thermal conductivity (λ), typically on the order of 0.015 W m-1K-1. This property makes this product highly interesting for insulating applications in construction. This is an innovative application of aerogel as rendering because although there are examples of insulating renderings using aerogel aggregates, they are not based in cement materials and their application is for inside building walls (Stahl, T. *et al* 2012). Figure 2 shows the process of installation of the mortar on abrick wall.

Figure 3. Image of aerogel and aerogel mortar insulation

Vacuum insulation panels: Vacuum insulation panels (VIPs) can be described as 'evacuated open porous materials inside a multi-layered envelope'. They are considered to be one of the most effective insulation materials available. VIPs shown in Figure 3 consist of three components: the core, the envelope and getters (a reactive material to help maintain the vacuum, e.g. desiccants and opacifiers). The core of the plate is evacuated and determines the thickness of the plate. A foil envelope keeps the vacuum inside and avoids gas and moisture permeation into the core as long as possible (Livesey, K. *et al* 2013).

Figure 3. Image of a VIP and Final installation on-site

Ventilated façade with photovoltaic panels: Among the emergent advanced façades, double-skin façades (DSFs) are an efficient solution to control the interactions of indoor and outdoor environments. As a basic definition, "Double-skin façade is a special type of envelope, where a second "skin", usually a transparent glazing, is placed in front of a regular building façade" (Ghaffarianhoseini, A. *et al.* 2016). Double skin façades can efficiently reduce the overall HVAC consumption in buildings by absorbing part of the solar radiation during winter and preventing overheating during warm periods (Barbosa, S. *et al.* 2014). The ventilated façade proposed for the project shown in Figure 4 has a photovoltaic system (PV) as an outer layer. The different parts that compose the ventilated façade are: insulation layer of Vacuum Insulated Panels (VIP), steel substructure and photovoltaic modules fixed with aluminium clamps.

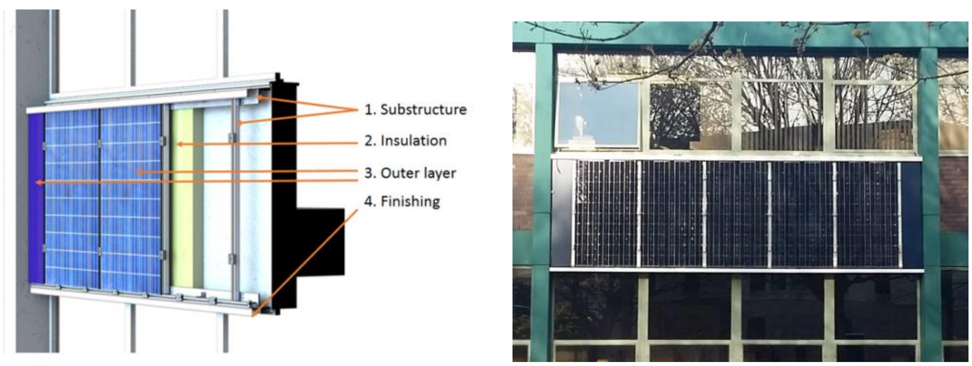

Figure 4. Ventilated façade (Model and Final Installation on-site)

Phase Change Materials Tubes: The thermal storage capacity of a material is a measure of its ability to absorb and store thermal energy and subsequently release it back into the environment after a period of time. There are two broad types of thermal storage materials, namely sensible and latent heat storage materials. Sensible heat storage materials include brick, concrete, rocks etc. The sensible thermal storage of these materials is as a result of the change in temperature of the materials. Phase Change Materials (PCMs) are material compounds that melt or solidify at certain temperatures to store or release large amounts of energy (Iten, M. and Liu, S.. 2014), (Iten, M. et al, 2016). They behave similarly to ice, in that the material 'freezes' and melts at a fixed temperature. PCM products therefore store and release thermal energy during the process of melting & freezing (changing from one phase to another). When such a material freezes, it releases large amounts of thermal energy in the form of latent heat of fusion, or energy of crystallisation. Conversely, when the material is melted, an equal amount of energy is absorbed from the immediate environment as it changes from solid to liquid. The sizing of PCM is carried out based on the performance specification of 1m long TubeICE provides 0.145 kWh (0.041 TRh) thermal energy storage (PCM Phase Change Material Limited).

The PCM installed in Coventry is a S27 phase change material, which is a salt hydrate that peaks at 27 C^{o}. In reality, the PCM may start the melting process at 25 C^{o} and be completely liquid at 29 C^{o}. In reverse, the PCM may show signs of solidification at 29 C^{o} and be completely solid at 25 C^{o}. The PCM Tubes are installed and respond to the surrounding temperature of the room (Figure 5). At the beginning of the day, the TubeICE are frozen. As the room heats up due to body heat, and heat from the sun, the PCM Tubes passively cool the room by absorbing the heat until completely melted. The duration of the cooling effect is dependent on the intensity of the heat being absorbed. I.e. the PCM will melt quicker if the ambient temperature in the room is 40 C^{o} compared to if the temperature is 35 C^o, much like a block of ice would. As the temperature cools over night, so does the PCM. The PCM effectively loses energy to the immediate surroundings, charging for the next day.

Figure 5. Phase change materials tubes (Final Installation on-site)

3. Research methodology

The Case Study at Coventry provides enough data and perspective to enable extrapolation to wider urban retrofit and living lab strategies. The case study building was selected due to the replicability of the building typology, which brought strong possibilities for the extrapolation of results and findings. The case study approach utilises descriptive data collection techniques. These techniques cover a number of practical interventions within the adoption of innovative technologies. As stated by Stake (2012), qualitative method is an iterative and reflexive process that begins as data is being collected rather than after the data collection has ceased. This strategy will be effective, as the aim is to provide a qualitative view of the case study at Coventry University. The process of adopting interventions within the case study into living lab buildings will lead the research into areas unknown from the outset. Descriptive analysis will be adopted to enable the research team to reflect on the challenges within the living laband adoption of state of the art technologies. Patterns, which describe the use of descriptive analysis, can be found as "descriptions of objects or phenomena, explanations of processes, and predictions on the future behaviour of the object of study." (Routio 2007)

A range of building performance evaluation protocols has been used to evaluate the performance of the building before and after retrofitting with a view to assessing three key factors, namely building and system characteristics, environmental factors and occupant perception (ASHRAE, 2010). The purpose of the building performance evaluation strategy is:

1. To monitor the objective measures of comfort within buildings (temperature, humidity, CO2)
2. To investigate building fabric performance, U-value and thermographic surveys;
3. To evaluate user satisfaction of key stakeholders;
4. To evaluate the installation process;
5. To model the current performance of the building;

Therefore the methodology followed will include: experimental monitoring, modelling, benchmarking of energy and environmental performance and surveys to key stakeholders and people involved in the installation process. Figure 6 summarises the strategy for stakeholder evaluation and engagement throughout the research project:

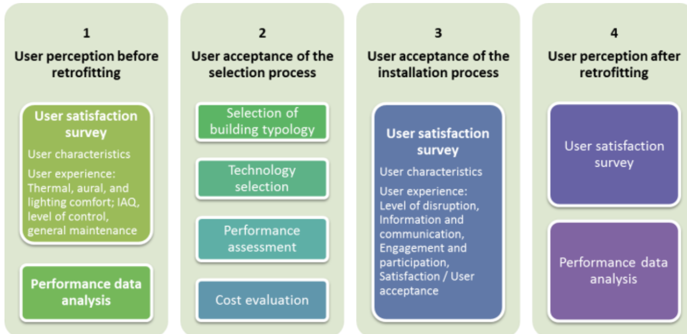

Figure 6. Evaluation of social acceptance

For the evaluation of user perception, user satisfaction surveys have been carried out before and after the retrofitting activities among the users of the building: students and academics. This provided a range of data set to compare the user satisfaction before and after the interventions. Stakeholder engagement events will be organized to get their feedback regarding the selection and installation process. Some interviews will also be done with the stakeholders involved in the installation process: technology providers, contractors, etc. Their views in conjuction with our personal assessment of the installation process will provide us with a solid material from which evaluations and lessons learnt from the process can be extracted. Detailed performance modelling and simulation will be carried out to predict potential energy and carbon savings from the retrofit process and intervention strategies for each demo site building, with the following steps:

1. Estimate the energy needs/consumptions before retrofitting
2. Evaluate the impact of the solutions on the energy demand/consumption
3. Justify the expected performance of the systems based on energy, economy, environment, comfort.
4. Retrofit some areas of a building, and extrapolate the results to the whole building to evaluate the overall potential savings in the building after its refurbishment.

For the evaluation of the performance of the building fabric the key performance criteria should include the analysis of the existing constructive documents of the building in order to get the maximum information about the composition of the external walls, and the measurements of the actual building performance by using non-destructive testing. In order to obtain this performance the following strategies will be followed: definition of the existing building fabric composition, Thermal imaging camera, Infra-red and Heat flux sensors, light level sensors and Indoor Environmental Quality measurements (CO2, Temperature and Humidity). Further monitoring will be continued after installation to evaluate the benefit of the intervention. It's significant to note that part of the objectives of the RESSEEPE project will be to explore and test these products further, attaining clear results on performance, reliability and future possibilities. The building performance Evaluation Strategy will include, finally, a district scale performance evaluation, modelling the district level impact and extrapolating the results obtained for the replicability of the model.

4. Case Study Description

Coventry University is a large contributor to the city's economy, the university and the council own 90% of the land within the city centre. The current estate is part of an ongoing investment to rejuvenate a number of areas around campus with investment surpassing £150m in the last 5 years (Lynch 2008). The case study at Coventry University is focused on two selected buildings, Sir John Laing (JL) and Richard Crossman (RC) Buildings. The buildings were selected as part of a robust benchmarking of the current university estate, which was carried out early within the project (Montazami *et al*. 2014). Part of the planning for the city moving forward is the recognition of a living lab status, "Establishing Coventry as a test-bed, incubation hub and international showcase for low carbon innovations" (City Lab Coventry, 2016). The living lab status holds high relevance to this project, as the JL building will encompass a living lab ethos, acting as a live experimental environment for a number of innovative technologies.

Coventry University demo-site developed a dual strategy for implementation and testing of these technologies. The first strategy is based on a whole building level intervention. In this strategy, advanced established technologies were implemented at a large scale in RC Building. The second strategy is to design and implement a selection of innovative technologies in selected areas of an existing building (JL). This gives the project an opportunity to test these technologies in real buildings and climatic conditions while at the same time limiting the risk exposure for the university. These state of the art technologies are categorised into four groups: envelope technologies, services technologies, lighting and renewable technologies. Figure 7 shows the technologies selected to be implemented in John Laing Building.

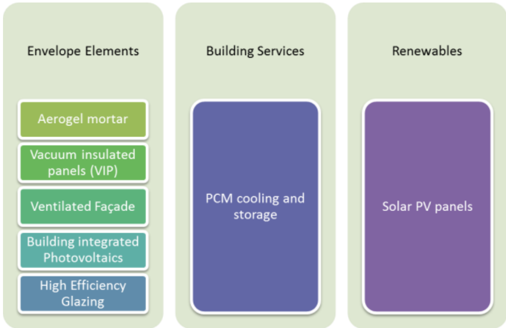

Figure 7. Technologies finally selected for John Laing Building

Technologies were selected for specific spaces within the case study building using a process of energy modelling simulation, user comfort responses and field lab testing opportunities. A viability analysis was also carried out to assess the final selection of the best mix of technologies. Table 1 shows the impact assessment of the individual retrofitting solutions. The assessment has been made considering the effect of only one solution implemented on the building. Yet to reach the objectives in terms of energy efficiency, the retrofitting project integrates combinations of several individual solutions, aiming at a maximum level of complementarity of the measures

	Solution	Ventilated façade system	Innovative Mineral Mortar ETIC	PCM	PV
Energy/CO2	Fuel gain (kWh/year)	160 000	40 000	80 000	0
	Electricity gain (kWh/year)	38 000	11 000	1 000	17 000
	Environmental gains (tonne of CO2/year)	61	17	20	10
Financial aspects	Instant financial gain (€/year)	14 000	4 000	4 000	3 000
	Investment (€)	110 000	130 000	80 000	30 000
	Maintenance cost (€/year)	3 150	0	0	1 500
Life cycle impact	Lifetime (Year)	25	30	25	25
	Fuel gain (kWh)	4 800 000	1 300 000	2 400 000	0
	Electricity gain (kWh)	1 150 000	320 000	40 000	510 000
	Environmental gains (tonne of CO2)	1 800	500	600	300
	Financial gain total (€)	450 000	160 000	150 000	0
	Global cost (Inv + Maintenance cost)	180 000	130 000	80 000	70 000
Return on investment	Payback (year)	10	24	14	19

Table 1. Impact assessment of the individual retrofitting solutions

3. Results and Discussions

The first major works at Coventry consisted of the installation of Phase Change Materials (PCM), ventilated façade with vacuum insulated and solar panels, and exterior insulation with aerogel mortar, Figure 8 shows the location of the various technologies on the building façade and internal spaces. The installation process was managed by the technical coordinators and the technology providers with support from Coventry University.

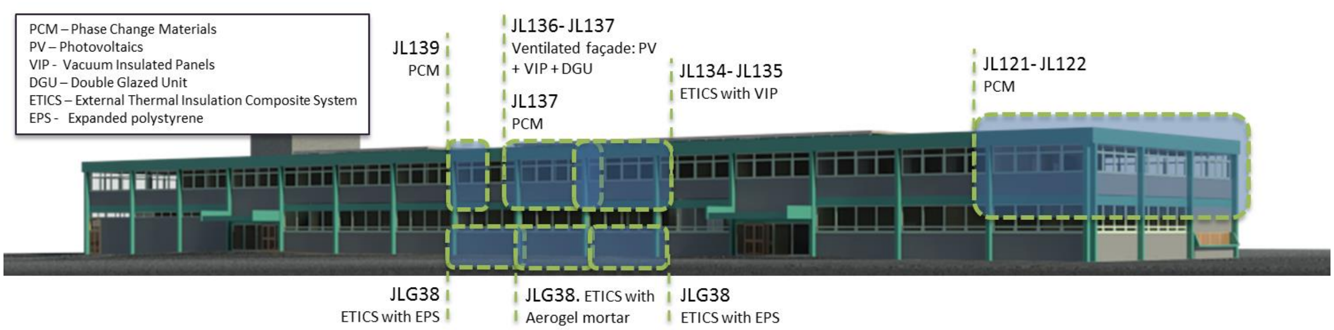

Figure 8: Location of the interventions

PCM was selected for use in the architectural studio space which is located in southern and south eastern orientation of the building to counteract specific overheating issues identified through user responses and simulations. The spaces are occupied by high student numbers over long hours during day and night. The architecture studio also has high internal gains due to density of computers and other heat emitting equipment. The space is naturally ventilated providing the ideal environment for testing a passive solution. To investigate different space use and and control mechanisms, PCM was installed in small office spaces (less than $20m^2$).The selected offices are located on the west façade of the building with high risk of overheating.

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VIP insulation has been selected on a west office to counteract the current poorly insulated cavity brick system. During the winter months users often report cold temperatures especially in the mornings. The VIP is intended to improve the overall insulation of the space without being invasive of the existing cavity. To further test insulation improvements ETICS with EPS and Aerogel mortar have also been implemented in neighbouring spaces providing a spread to the data experiments. A significant aspect of the interventions is the interaction combination space of JL137, which has been impacted by PCM and Ventilated façade (VIP and BIPV). This provides a critical zone where the interconnection of technologies can be analysed.

One of the challenges with installation was due to lack of experience and knowledge of PCM. A number of local contractors were approached to install but were put off by the increased risk of dealing with a new technology. Contractors have to consider the increased level of risk and liability that they will take on when dealing with technologies and installation procedures that they have little prior experience of installing. Prior to installation there were concerns over the integrity of the tubes and the risk of leakage of the PCM. The tubes were enclosed within a very robust structure, which reduces this concern. Once the contractor had been identified the installation was fairly straightforward. Certain protocols had to be adhered to such as a structural assessment of the space and an asbestos survey, both to ensure that firstly the structure could hold the increased loading of the PCM tubes and secondly to ensure that there is no risk of exposure to asbestos by both installers and users of the building. Figure 9 shows the PCM tubes were fixed using a standard tube fixing bracket system, which was fixed to the underside of the ceiling. The spaces and tubes will be monitored over the next year to evaluate performance of the system, both objective and subjective data will be used to compare rooms with PCM to selected controls rooms.

Figure 9: Installation of the PCM tubes

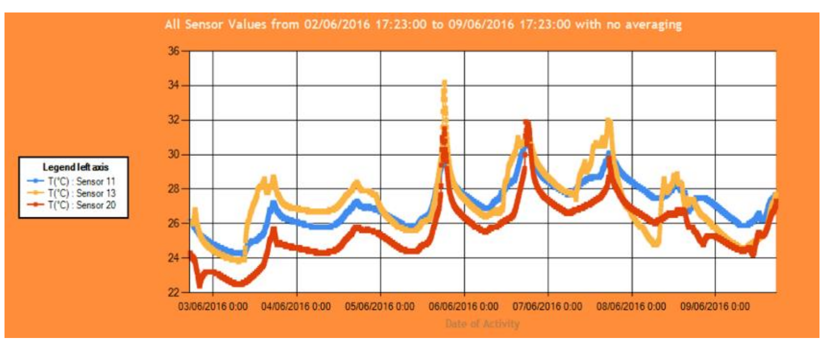

Figure 10. Indoor temperature of PCM rooms (11 & 20) and a control room (13)

Initial results from the indoor environmental monitoring suggest more comfortable internal environment compared with the control rooms. Figure 10 shows that the control room has a consistently higher peak indoor temperature over the 5 days monitoring period. This trend will be assessed over a long period and also evaluate the influence of user behavior in terms of opening and closing of windows. The result shows that there is a peak temperature difference of about 4K between rooms with PCM and the control room. The dirnal temperature variation is higher in the control rooms, 10.4K compared to two rooms with PCM with 6.4K and 9.50K diurnal temperature range.

The ventilated facade was conceived andmanufactured within the RESSEEPE project. The partners involved in the manufacturing of the structure and the assemblies of the system were from a different country, which implied a carefully designed installation process and the validation of the system beforehand. However, even with a very detailed assembly plan there were some logistic issues regarding the delivery of materials, lack of specific tools and lack of a Risk Assessment plan and disposal of the waste materials. The installation process was successful at taking into account all the challenges that were faced as mentioned above. Surface sensors were integrated into the different layers in order to get a real time performance of each material. Figure 11 shows the installation of VIP and Ventilated Façade and the completed system.

Figure 11. Installation of the ventilated façade

The aerogel mortar was tested and manufactured specifically for its application in Coventry University. Due to its innovative nature a theoretical and practical training was done by the manufacturer in order to ensure a good product application. The application of the aerogel mortar was done by hand instead of the spray system, this implied having to test different percentages of water-mortar ratio in order to get a good performance. During the construction a number of thermocouples were integrated into the layers of the façade systems, which will provide information on the thermal gradient through different layers of the façade. Figure 12 shows the installation process of the aerogel mortar.

Figure 12: Installation of the aerogel mortar

An international prototype installation requires an effort of understanding and cooperation. Having to coordinate the construction works from another country is very complicated and with a lot of logistic challenges such as bringing heavy tools & equipment as well as a language barrier. Some risk was assumed by the demo-site derived from difference in Health and Safety culture, waste disposal measures and damage to existing landscape. Additionally it could be argued that many of the problems were due to the impact of having no robust method statement and risk assessment. Many delays were experienced due to the lack of robust planning which resulted in extended disruption to CU day to day activities. As a result of some of the technologies being in developmental stage, it is essential for all the stakeholders involved to understand the risks associated with both installation and on-going maintenance challenges, which highlights the need for effective stakeholder engagement at an early stage of the project to explore the benefits as well as the potential risks associated with each technology and intervention strategy. Some of the setbacks could have been avoided if all the coordination had been done by just one company with experience of the construction culture and procedures in the pilot country. An initial stakeholder engagement provided a vital platform to highlight critical factors such as user comfort, consideration on local planning constraints and disruption to the useable areas. The engagement and communication of on-going interventions and disruptions to the users of the buildings was particularly vital for achieving the socio-ecomomic and environmental benefit of low energy retrofit.

At this stage it is too early to evaluate energy data in great depth as the in-situ monitoring study is still in its infancy. Additionally, user experiences will be evaluated over the next year before disseminating results. This approach will ensure that performance data is evaluated over summer and winter seasons. A period of 12 months of user experiences and monitoring will provide a robust level of data to establish greater generalisation and ensure higher quality analysis and extrapolation.

Conclusions

The RESEEPEE project aims to achieve energy reduction in the region of 50% through the use of innovative building fabric and systems to retrofit public buildings. The project developed a building selection process for retrofitting and a clear methodology for selecting technologies for implementation within selected case study buildings. The aim of this paper is to critically review the process of stakeholder engagement and evaluation and the process of technology installation. The paper reviews the relevant technologies and describes the process of stakeholder engagement. The challenges faced during installation of the various technologies shows that effective stakeholder engagement at different stages of the project life cycle is essential for maximising the socio-economic and environmental benefits of a low energy retrofit project. It is also essential that the installation process of the various technologies is centralised and coordinated by a single entity with experience of local culture and procedures to ensure efficient installation process. So far some results of the PCM performance have been presented which reveals very interesting trends showing that the PCM will be useful for alleviating discomfort, especially in the summer months. The installations will be monitored over the coming 12 months and detailed performance evaluation of the various systems will be evaluated. Additionally the stakeholder engagement process will continue post installation and in conjunction with objective measurement come up with clear performance metrics for each technology. Results from the demo-sites will be extrapolated to other public buildings in order to achieve potential urban scale retrofit analysis.

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Authors

Dr. Abdullahi AHMED is a Senior Lecturer in Built Environment with over 10 years industry and professional experience in the field of building physics and sustainable design. Dr Ahmed has participated in several funded projects over the last 3 years. He is leading Coventry University's contribution to the EU funded project RESSEEPE. Dr Ahmed is managing a number of PhD students in the area of BIM, Urban Resilience and Low Carbon Technologies. Dr Ahmed has skills and experience of building information modelling and the transient simulation of buildings and building systems.
ORCHID ID: 0000-0002-2143-9616

Mr. Danny MCGOUGH is a Lecturer in BIM at Coventry University and is leading the development and integration of BIM into Coventry University delivery of teaching and learning activities. Danny is an investigator on the current FP7 RESEEPEE project. Danny has also been involved in developing consultancy for companies within the West Midlands to develop BIMM systems and strategies within construction organisations. Danny is currently managing 2 ERDF KEEN projects that assist SME's to optimise their processes through the implementation BIM. Danny's particular research interest is in the retrospective application BIM in performance management of existing buildings stock.
ORCHID ID: 0000-0002-3020-9011

Dr. Monica MATEO-GARCIA is an Architect with over 8 years professional and academic experience. She holds a PhD in Architecture and Sustainable Urban Planning from the University of Alicante, Spain. In 2008, she moved from professional practice to academia, joining the University of Alicante as an Assistant Lecturer teaching modules in Construction and Energy efficiency in Architecture. In 2015 she joined Coventry University as a Research Associate in Low Carbon Refurbishment in the project EU FP7 RESEEPEE.
ORCHID ID: 0000-0001-7331-4818

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DEMAND RESPONSE IN BLOCKS OF BUILDINGS: OPPORTUNITIES AND REQUIREMENTS[3]

Tracey Crosbie[1], Michael Short[2], Muneeb Dawood[3], Richard Charlesworth[4]

[1, 2, 3] School of Science and Engineering
Teesside University, Middlesbrough, United Kingdom

[4]Siemens plc, Energy Management Division
RC-GB EM DG PTI
Princess Road, Manchester, United Kingdom

E-mails: [1]T.Crosbie@tees.ac.uk; [2]M.Short@tees.ac.uk; [3]M.Dawood@tees.ac.uk; [4]Richard.Charlesworth@siemens.com.

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Abstract. Increased Demand Response (DR) is essential to fully exploit European power systems, which in turn is an absolute prerequisite for meeting European targets related to energy efficiency and climate change. Essentially DR involves consumers reducing or shifting their electricity usage during periods of peak electricity demand in response to time-based tariffs or other forms of financial incentives. The opportunities for realising demand response vary across Europe as they are dependent on the particular regulatory, market and technical contexts in different European counties. Nevertheless successful DR programs are becoming increasingly common for large industrial customers. However DR programs aimed at small and medium scale customers have mostly failed to meet their expected potential. Blocks of buildings offer more flexibility in the timing of energy use, local energy generation and energy storage than single buildings and as such researchers and the energy industry are beginning to consider how blocks of buildings can operate collectively within energy networks to enhance the effectiveness of DR programs. This paper identifies the opportunities and technical, market and regulatory requirements for realising DR services in blocks of buildings in the European context. The work presented is part of an ongoing European Horizon 2020 project entitled Demand Response in Blocks of Buildings.

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JEL Classifications: P18 L94, L90, L98
Additional disciplines: environmental engineering; electricity electronic engineering; law

1. Introduction

The European 2030 climate and energy framework adopted in 2014 sets three key binding targets for the year 2030: At least 40% cuts in greenhouse gas emissions (from 1990 levels); at least a 27% share for renewable energy; and at least a 27% improvement in energy efficiency (European Commission 2016a). Increased Demand Response (DR) is an absolute prerequisite for meeting these European energy efficiency and climate change targets. Essentially DR involves consumers reducing or shifting their electricity usage during periods of peak electricity demand in response to time-based tariffs or other forms of financial incentives. The opportunities for realising demand response vary across Europe as they are dependent on the particular regulatory, market and technical contexts in different European counties. Nevertheless successful DR programs are becoming increasingly common for large industrial customers. However DR programs aimed at small and medium scale customers have mostly failed to meet their expected potential. Blocks of buildings offer more flexibility in the timing of energy use, local energy generation and energy storage than single buildings and as such researchers and the energy industry are beginning to consider how blocks of buildings can operate collectively within energy networks to enhance the effectiveness of DR programs (Ala-Juusela et al 2016). This is because blocks of buildings offer more flexibility in the timing of energy use, local energy generation and energy storage than single buildings (Crosbie et al 2016).

The potential value of DR in blocks of buildings depends on the telemetry and control technologies embedded in the building management systems currently deployed at any given site and the potential revenue sources: both of which vary according to specific local and national conditions (Thomas et al 2009, Crosbie et al 2006). In this context, to encourage the growth of DR services' and reap the potential benefits of DR, it is necessary for current research to demonstrate the economic and environmental benefits of DR for the different key actors required to bring DR services in blocks of buildings to market. This is the aim of a current EU funded project called "Demand Response in Blocks of Buildings" (DR BOB) which is co-funded by the EU's Horizon 2020 framework programme for research and innovation. The research presented in this paper is based on the work conducted in the initial stages of the DR BOB project to identify the opportunities and technical, market and regulatory requirements for realising DR services in blocks of buildings in the European context.

Following this introduction, to set the context, section two of this paper outlines the drivers of demand response in blocks of buildings in Europe. In section three of the paper different types of DR programs are defined. Finally section four analyses the potential of each of the DR programs to be deployed in blocks of buildings pointing to the regulatory and market conditions required.

2. The Drivers of Demand Response in the EU

The three key binding targets for the year 2030 adopted by the EU in 2014 build on the 2020 climate and energy package which set targets of a 20% reduction of greenhouse gas emissions, raising the share of EU energy consumption produced from renewable resources to 20% and a 20% improvement in energy efficiency compared to 1990 levels (European Commission, 2015). As illustrated in Figure 1 energy consumption in the built environment (households and services sector) forms a major portion (40.3 %) of the total energy consumption in EU member states (European Commission, 2014). Thus, energy use in non-industrial buildings offers the potential to make a significant contribution to achieving Europe's targets for climate change and has a very significant impact of peak energy demand. As such it provides a huge largely untapped potential for demand response, offering an avenue for energy aggregators DSOs and TSOs to further manage energy demand.

In efficient energy markets during the hours of peak energy demand energy prices are at their maximum. In relation to electricity, this is because when national electricity demand is low, supply comes from relatively inexpensive base load generation and when demand is high and base load generation is exhausted, supply comes from relatively expensive peaking generators (Crosbie et al 2015). This creates rapidly fluctuating energy costs throughout the day in wholesale electricity markets that peak at times of peak load/ demand (see figure 2). This impacts on the ability of European Industries to compete globally (Capgemini, 2008). Large peaks in energy demand also creates problems with grid reliability, stability and efficiency (Crosbie et al 2015).

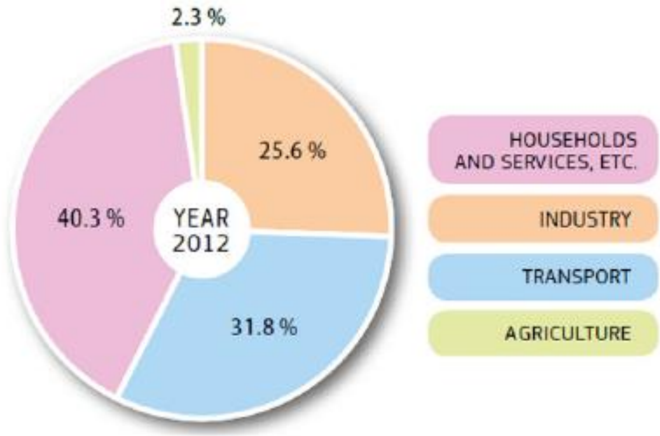

Fig. 1: Breakdown of energy consumption by sector in EU-28 in 2014 (Source European Commission, 2014)

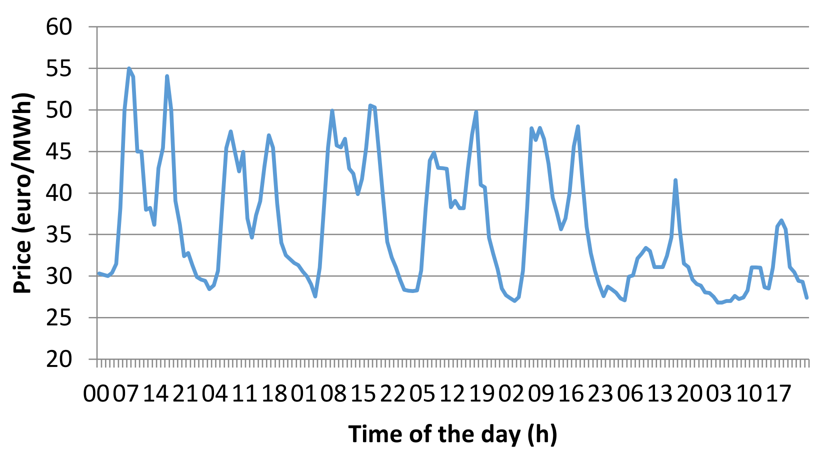

Fig 2.Example of the fluctuation in EU energy markets: Nord Pool Spot prices during an average week (Monday to Sunday) in Finland in February (Source Crosbie et al 2015)

The growing share of intermittent distributed renewable energy generation in Europe (see Fig 3) is exacerbating the problems created by peak demand in terms of gird security and stability and energy costs. The strong EU policies backing the introduction of renewable energy generation has encouraged this growth in distributed renewable energy which stood at 16 % in 2015. In 2015 25 EU countries were meeting their 2013/2014 interim renewable energy targets arising out of the 2020 climate and energy package. This means that the EU has three times more renewable power per capita in Europe than anywhere in the rest of the world. Renewable energy sources are also likely to continue to grow significantly in the near future with the 2030 climate and energy framework set to encourage an increase in the share of renewable to at least 27% by 2030.

To invest in more capacity is becoming an increasingly expensive option to the challenges created by growing peak energy demand and renewable energy sources, both for utilities and consumers, requiring heavy expenditure on power generation, transmission and distribution capabilities (Capgemini, 2008,Crosbie et all 2015). For example, it is estimated that European electricity networks (EDNs) will require six hundred billion Euros of investments by 2020, with two thirds of these investments required in Distribution networks (Eurelectric 2013). By 2035 the distribution share of the overall network investment is estimated to grow to almost 75 percent and to 80 percent by 2050 (Eurelectric 2013). When thinking about these figures it becomes clear that the prospect that DR solutions to reduce peaks in energy demand is significant. Thus, in recent times, the emphasis is on developing novel solutions which can align the energy demand to the energy supply in real-time (Patteeuwa et al, 2015; Bergaentzlé, 2014). With distributed renewable energy generation and real-time pricing and demand response, the end user can actively participate in energy markets.

Fig. 3: Share of energy from renewable sources in gross final consumption of energy, EU-28, 2004-2014 (source Eurostat).

Given that more than 40% of the energy demand from buildings is in the service and domestic sector it would seem that the potential of DR in blocks of buildings is significant and the increasing penetration of DER and climate change targets are significant drivers of demand response. However to fully realise the potential for DR in blocks of buildings, it will be necessary to identify which types of DR response programs are applicable to blocks of buildings in different technical market and regulatory contexts as discussed in the following sections.

3. Demand Response program architypes

Although DR programmes are to a certain extent unique - having to fit specific geographic and regulatory requirements - common elements and characteristics can be identified. Earlier research identified seven main DR program types (OpenADR Alliance 2016) and this work forms the basis of the types of DR programs discussed here. However those DR programs involving cost and pricing signals for typical DR programs involving variable tariffs - such as traditional Critical Peak Pricing (CPP), Real-Time Pricing (RTP), Time of Use Pricing (TOUP), Two-Tier Pricing (2TP) and various combinations thereof, can be combined. Therefore to simplify the analysis that follows, DR programs involving these pricing signals have been merged into a single 'Generic Variable Tariff' DR program.

Generic Variable Tariff (GVT) DR program: GVT DR programs provide variable pricing structures for electricity which are designed to reduce consumption during periods of high wholesale market price or during known periods of system contingency, and encourage consumption in times of low wholesale market price. In a GVT program, hourly or sub-hourly prices for electricity consumption (possibly having several tiered levels) will be advertised to DR participants by the program sponsor at least one hour in advance, typically one day in advance - and in some cases even months in advance. Although prices are variable and reflect market conditions, maximum prices may be negotiated in advance. Typically they are linked to day-ahead market conditions and seasonal market changes. Such DR programs are especially useful for planning and scheduling controllable resources such as smart appliances and the charging times of electric vehicles. There are no minimum load restrictions and the targeted participants may be residential, commercial or industrial.

Capacity Bidding DR Program (CPB): A DR program which allows a load resource and its owner to identify how much load it is willing to curtail for a specific price to the DR program sponsor requiring the demand reduction. Although CPB contracts may be negotiated by the resource owner and the sponsor well in advance, real-time negotiation may also be performed e.g. based upon balancing (real-time) market conditions to help cover unplanned contingencies such as loss of expected renewable availability due to inaccurate weather forecasts. Notice periods for activating negotiated CBP contracts are typically one hour minimum and are mostly one day-ahead. Such DR programs are especially useful for deferring planned operation of large/medium sized industrial loads, where enforced loss or change of production is recouped through pre-commitment contracts and subsequent activation payments. There are minimum load restrictions (typically 100 kW) and the targeted participants may be load aggregators, commercial or industrial.

Direct Load Control (DLC) DR Program: A DR activity in which the program sponsor remotely controls a participant's electrical equipment on short notice (normally several hours). Typically this would involve temporarily reducing temperature, humidity or air pressure set points in home and building HVAC equipment to achieve a short-term reduction in electricity demand. Once the DR event has passed, conditions are automatically returned to nominal levels. Financial incentives are paid for enrolling in the DR program and may also include bonuses when DR events occur. It is possible for a participant to opt-out of a given DR event for a financial penalty. There are no minimum load restrictions and the targeted participants may be residential or (small) commercial.

Fast Dispatch / Ancillary Services (FD/AS) DR Program: A DR program which provides incentive payments to participants for fast load reductions (or increases in some cases) during emergency conditions on the grid that require immediate action to prevent loss of transmission lines, distribution equipment and/or generator tripping which can negatively impact the reliability of the wider system. Contracts are negotiated in advance and often activated without prior warning, as load needs to be shed (or increased) at very short notice ($\approx$ 2 seconds for frequency regulation). Such DR programs are especially useful for large/medium sized industrial loads where enforced loss or change of production is recouped through pre-commitment contracts and subsequent activation payments. There are minimum load restrictions (typically 100 kW) and the targeted participants may be load aggregators, commercial or industry. This DR program is very similar to the CBP DR program, but timescales for real-time response and reliability of load change are much more stringent (and participation incentives much larger).

Distributed Energy Resources (DER) DR Program: These are DR activities which are utilised to smooth integration issues for Distributed Energy Resources (DER) into the wider electricity grid, e.g. to help curtail over or undersupply issues. For most implementations of this DR program, some form of storage and/or a dispatchable[4] DER are required. The DR participant responds to day-ahead pricing signal incentives from the sponsor to either increase or decrease its nominal load at requested times during the day, using batteries, flywheels or other forms of energy storage or by dispatching a DER for a particular time period when it would not normally do so. This allows the DR participant to modify its nominal load profile in accordance with the sponsors' incentives (which are often linked to intermittent availability of renewable energy elsewhere in the grid). There are no minimum load restrictions and the targeted participants may be residential, commercial or industrial.

4. Potential of DR Programs for Blocks of Buildings

The different types of DR programmes outlined in the previous section all have potential for DR in blocks of buildings. However some maybe expected to be deployed more easily in a wider variety of situations than others due to significant variations in their technical, market and regulatory requirements.

Table 1 below presents an assessment of the different types of DR programmes for deployment in blocks of buildings based upon an estimation of the level of effort required and technical and regulatory considerations related to the implementation of each DR program. Note that since all DR programs require an existing Advanced Metering Infrastructure (AMI) and DR ICT infrastructure, this is not stated as an explicit technical requirement.

Table 1. Technical, Market and Regulatory Requirements for DR Programs block of buildings potential

DR Program	DR Incentive and Impacts	Technical Requirements	Regulatory and market requirements	Block of Buildings Potential
General Variable Tariff (GVT)	Low to medium economic benefit to participant, continual peak-to-peak reduction	Schedulable / controllable devices or Electric vehicle (EV) charge points, Optimizer, Human–machine interface (HMI), Building management system (BMS) or Home area network (HAN).	Relevant variable tariffs	Very High
Capacity Bidding DR Program (CBP)	High economic benefit to participant, sporadic peak reduction	Sheddable load of 100 kW or more, HMI	Relevant CBP DR product and load aggregators	Low
Direct Load Control (DLC)	Medium economic benefit to participant, sporadic peak and energy usage reduction	HVAC with appropriate control system or other suitable load, HMI, BMS or HAN	Relevant DLC product and load aggregators	High
Fast Dispatch / Ancillary Services (FD/AS)	Potentially very high economic benefit to participant, sporadic peak reduction	Fast sheddable load of 100 kW or more, Plus high-speed and reliable telecontrol & telemetry interfaces OR frequency sensitive / frequency aware loads	Relevant FD/AS products and load aggregators	Very Low
Distributed Energy Resources (DER)	Medium to high economic benefit to participant, continual peak-to-peak reduction	Dispatchable DER, Storage, Optimizer, HMI, BMS or HAN	Relevant variable tariffs allowing renewable energy self-consumption and decentralised storage.	Medium

The most favourable DR programs according to this initial evaluation are GVT, DLC and DER. This is principally because in most (not all) blocks of buildings have some controllable appliances (e.g. washing machines and EV

[4] Dispatchable renewable energy refers to sources of renewable electricity that can be dispatched at the request of power grid operators or of the plant owner; that is, renewable generating plants that can be turned on or off, or can adjust their power output accordingly to an order.

chargers etc.) and HVAC systems for climate control (temperature and humidity). Since market conditions in most EU countries already support simple on-peak and off-peak tariff structures – and many are moving towards RTP pricing structures - the basics for implementing GVT and DLC DR Programs are present, even if manual implementations are required. In addition, in many modern buildings, distributed energy generation is also present (typically in the form of PV panels and/or a CHP plant). Therefore a DER DR program also seems favourable, albeit slightly less so due to the additional need for storage and day-ahead signal from the DR sponsor.

The main reason for less favourable conditions for the CPB and FD/AS DR programs is the need for a controllable resource which is large enough to be activated (at very short notice in the FD/AS case). This is less likely to be available in a block of buildings. However, in many cases it is most likely that hybrid combinations of the DR programs outlined in section 3 can be considered for a particular area. For example, recent works by Zhou et al. (2015) and Patteeuwa et al. (2015) have shown that by aggregation of multiple HVAC systems and the application of co-ordinated controls, it is possible to provide FD/AS-type DR programs to provide demand-side frequency regulation services to support intermittency of renewable generation, e.g. in the presence of fluctuating wind power. The work by Patteeuwa et al. (2015) also considers the use and role of thermal storage units in such applications. These DR approaches are, in essence, hybrid combinations of DLC, FD/AS and DER DR programs which are enabled and supported by appropriate ICT infrastructures and control/optimization systems.

Another possible approach to providing fast ancillary and dispatch services for leveraging demand-side contributions to frequency regulation could also be emerging (Molina-García et al. 2011; Villena et al. 2015). In this decentralised approach, instead of having demands under tele-control by a DR sponsor, loads are equipped with (low-cost) instrumentation which is able to measure frequency directly at the point of supply. They are also equipped with controls which can quickly react to frequency deviations by modulating demand accordingly, without the need for any external signals. If properly implemented, a form of fast-acting demand-side primary droop control can be achieved by participating loads. Follow-up secondary frequency stabilisation using tele-control signals from the DR sponsor can also be used within such a framework ('traditional' DR). With respect to blocks of buildings, then HVAC systems seem to be the most appropriate for this kind of droop control by manipulating temperature and air-flow set-points to obtain fast, short-term reductions in demand (which are not likely to impact occupant comfort if only present for short time periods). This approach avoids the need for fast and reliable tele-control and telemetry interfaces and infrastructures, but requires the development of an appropriate set of technical standards and legislation. However currently seems to be a minimal market with few financial incentives offered for providing such services within the EU. This is currently a barrier to an approach which appears to be emerging as one of the most technically feasible and potentially effective approaches for DR. Current exceptions are the Frequency Control by Demand Management (FCDM) and Enhanced Frequency Response (EFR) services introduced in 2016 as part of a range of demand-side management initiatives for the UK market (Proffitt 2016). FCDM is a tendered balancing service which requires that a load of 3 MW minimum is shed by participants within 2 seconds of the system frequency falling below a preset threshold, for minimum duration 30 minutes. EFR extends traditional primary frequency controls to the demand side in the manner described above, but the product is still in development and the technical and contractual requirements not yet fixed.

An example of how DR involving the control of local energy production are inhibited in some EU countries is the way in which the price paid to individuals and organisations that generate renewable energy is subsidised. Many EU countries have introduced Feed-in-Tariffs (FITs) that guarantee a price for the renewable electricity produced by distributed energy resources. Two types of tariff schemes are commonly applied: fixed-price FITs (FFITs) which guarantee a fixed price for every unit of produced electricity and premium based FITs (PFITs) which pay a premium on top of the variable market price (Crosbie 2016). *"FFITs do not provide any incentive to produce electricity when marginal production costs are high. Also, costs for balancing intermittent electricity production may be significantly lower with PFITs. Therefore, PFITs provide an incentive to match renewable power output better with* *marginal production costs in the system*" (Schmidt, 2013). So, for example, in France while recent changes to regulations make self-consumption possible the currently very generous FFITs make this financially unrewarding.

It would seem that within a block of buildings scenario featuring large enough quantities of schedulable devices and controllable loads - along with DER/storage units (e.g. CHP with batteries / hot water tank) - modern optimization and control techniques such as those described by Ogwumike et al. (2016), Short et al. (2016), Patteeuwa et al. (2015) and Zhou et al. (2015) – including others - allow for potentially large opportunities for DR in blocks of buildings. A key enabling factor, however, will be the selection and deployment of an appropriate AMI/DR ICT framework to assist with coordinated actions between buildings and blocks of buildings, and the selection and deployment of appropriate local controls and optimisers.

In the case of DER DR it must be highlighted that there are three key barriers to consider when thinking about the potential for the deployment of DER DR in blocks of buildings in some EU countries. Firstly renewable energy self-consumption and decentralised storage are not allowed in all EU countries (European Commission 2016b). Secondly complex and burdensome administrative and authorisation procedures still represent an important barrier for the competiveness of small-scale self-consumption projects in blocks of buildings where renewable energy self-consumption and decentralized storage are allowed (European Commission 2016b). Thirdly on-line information platforms and applications are so far used in only a few Member States (e.g. Portugal, Hungary, Italy and Sweden) (European Commission 2016b). Thus while several EU countries have introduced facilitated notification procedures for small renewable energy installations such as roof-top PV installations, additional national action is required (European Commission 2016a).

When considering the potential for DR in blocks of buildings the rise of the independent aggregator within European electricity markets is also crucial. As demand response in blocks of buildings will be difficult to capitalise on in those EU countries whose regulatory frameworks discourage or ban their growth. This is especially in the case of Explicit DR programs in which consumers receive direct payments to change their consumption (or generation) patterns upon request, such as what we have called CPD, DLC and FD/AS. This is because most blocks of buildings do not have the level of generation / demand reduction/ storage capacity to engage in many of the current DR products. Consumers, if they are to be engaged in DR need a clearly defined offer, which is clearly beneficial and simple to use. As such they "*require a party with expertise in selling and providing this offer through aggregation. Aggregation service providers (who may or may not be electricity suppliers) are therefore central players in creating vibrant demand-side participation and Explicit Demand Response*" (SEDEC 2015).

In 2015 an analysis[5] of sixteen of the EU's member states found six EU member states have commercially active explicit demand response markets; while a further four states had partial opening of demand response markets and two were found to have no current opening of the market for explicit demand response (SEDEC 2015). However, there are considerable barriers in many countries to be overcome before there is an EU market for a solution to enable explicit demand response in blocks of buildings. One of the key barriers being that in most EU countries consumers cannot choose a separate service provider for providing demand response. "*They are restricted to their supplier, or at least need their supplier's permission before working with a third party aggregator. Often the supplier is in direct competition with the aggregator, or may have other reasons to hamper the uptake of Demand Response, and thus has an incentive to block the aggregator from doing business with the consumer*" (SEDEC 2015).

[5] This analysis graded markets according to the four main criteria: 1) Enabling consumer participation and aggregation 2) Appropriate programme requirements 3) Fair and standardised measurement and verification requirements and 4) Equitable payment and risk structures.

The pilot sites in the DRBOB project are situated in France, Italy, the UK and Romania. Of these the markets in France and the UK have commercially active explicit demand response markets, while in the pilot site countries all except Romina have current variable energy tariffs. The findings presented suggest that in the first instance the demonstrations in the DRBOB project should seek to illustrate the potential of existing capacity bidding (across all sites), variable tariffs (UK, France, Italy) and direct load control programs (UK, France) to underpin demand response in blocks of buildings. However, it is also noted that energy tariffs which offer real incentives for demand response and DLC products are not available in all EU countries and these markets will need further development. For demonstration of decentralised fast ancillary and dispatch services, the UK market seems to be most appropriate with some early DR products currently available and others in latter planning stages.

In summary the UK market, at present, offers the largest scope for DR demonstrations at the block of buildings level due to its recent initiatives on the demand side in general. The outputs of the DR-BOB project will therefore include an assessment of potential socio-technical (Grünewald, et al. 2012) and techno-economic (Crosbie et al 2016) barriers to DR deployment in blocks of buildings, to guide less mature market development using the UK market (and its emerging operational and contractual specifications) as a reference point. Following energy studies informed by the social sciences (Crosbie 2006, Crosbie and Baker 2009, Stephenson et al 2010, Grünewald, et al. 2012) the approach adopted will involve in-depth interviews with stakeholders (including facilities managers, building owners and building occupants) to explore the various perspectives, motivations and vested interests which are at play when seeking to implement demand response in blocks of buildings.

Conclusion

The different types of DR programmes discussed all have potential for DR in blocks of buildings. However given the different technical market and regulatory contexts in different EU countries some will be deployed with greater ease in some countries than others. To address the uneven development of the technical, market and regulatory requirements for realising DR services in blocks of buildings the DR-BOB project will seek to identify how mechanisms for DR response from more mature markets could be implemented in EU countries with less mature markets for DR (Crosbie at al. 2016). The results will provide feedback to the market participants with recommendations on how that country could adopt new mechanisms and what value there is in doing so for the different actors involved in the value chain required to bring DR in blocks of buildings to market (Crosbie et al 2016).

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Authors

Dr Tracey CROSBIE is a Senior Research Lecturer in Energy Reduction at Teesside University. She has been researching issues associated with energy consumption in built environment and ways of informing its reduction for more than fifteen years. She is a trans-disciplinary academic with degrees in the social and technical sciences. Her main research interests involve the development of socio-technical approaches to applying ICTs to urban sustainability and the development of business models to exploit those ICTs. She has a wide experience of research within the Utilities industry and managing EU projects and work packages.
ORCID ID: 0000-0002-9355-4816

Dr Michael SHORT is a Reader in Electronics and Control at Teesside University. He is the technical coordinator of the DR_BOB H2020 Innovation project. He is a full member of the Institute of Engineering and Technology (MIET), a member of the Institute of Electrical and Electronic Engineers (IEEE), and sits on the Fault Tolerant and Dependable Systems (FTDS) sub-committee of the IEEE Industrial Electronics society.
ORCID ID 0000-0001-6290-4396

Dr Muneeb DAWOOD is a Research Assistant at Technology Futures Institute, TU. He has a PhD degree in Communication (Electrical) Engineering and an MSc degree in Telecommunications and Computer Networks Engineering. His experience and research interests include modelling and simulation of renewable energy resources, real-time communication protocols for wired and wireless networks, error-resilience techniques for real-time communication, monitoring protocols and communication infrastructure for smart grid and visualization of scientific data.
ORCID ID:0000-0002-1427-4331

Richard CHARLESWORTH is a Solution Architect for Siemens and has over 20 years of experience in IT in a variety of roles from developer to Lead Technical Architect. He has over 15 years proven track record in utilities and metering systems of all sizes. Richard was responsible for key stages technical bid, specification, design and delivery of the Manchester Triangulum project, and otherwise has consulted on Smart Metering, Demand Response and eCar across UK and Europe. He was Lead Author on the Low Carbon London "Report 10 - Opportunities for smart optimization of new heat and transport loads." He is also leads a technical work package in the DR_BOB H2020 project.
ORCID ID: 0000-0001-8182-4383

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INNOVATIVE TIME SERIES FORECASTING: AUTO REGRESSIVE MOVING AVERAGE VS DEEP NETWORKS[6]

Anthony Mouraud

CEA Tech PdlL, 5 rue de l'Halbrane, 44340 Bouguenais, France

E-mails:anthony.mouraud@cea.fr;

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Abstract. Growing interest in meaningful indicators extraction from the huge amounts of data generated by energy efficient buildings instrumentations has led to focusing on so called smart analysis algorithms. This work proposes to focus on statistical and machine learning approaches that make use only of available data to learn relationships, correlations and dependencies between signals. In particular, time series forecasting is a key indication to anticipate, prevent and detect anomalies or unexpected behaviors.
We propose to compare performances of a classical Auto Regressive Moving Average (ARMA) approach to a Deep Highway Network on time serie forecasting only making use of past values of the serie. In recent years, Deep Learning has been extensively used for many classification or detection tasks. The complexity of such models is often an argument to discard such approaches for time serie prediction with regard to more common approaches performances. Here we give a first attempt to evaluate benefits of one of the most up to date Deep Learning model in the literature for time serie prediction.

Keywords: Sustainability, Buildings, Time Series Forecasting, Auto Regressive Moving Average (ARMA), Deep Networks

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JEL Classifications: C45, C53

Additional disciplines: Mathematics, Data Science, Computer Science

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1. Introduction

The growing interest in building efficiency in terms of energy and comfort leads to critical needs in modelling tools to design them and efficient instrumentations to be aware of their real behaviour (Foucquier, Robert, Suard, Stephan, & Arnaud, 2013). Furthermore the huge amount of data generated during building lifetime hardens the extraction of useful information about real building behaviour, sensors health and to anticipate future needs.
The latter issue has seen lots of interesting work achieved in the last years. Several kinds of approaches are used to help in understanding data produced. Physical models (white boxes) are among the preferred methods due to their accuracy in describing the building studied. Another category builds analyses upon a mix between physical considerations and statistical methods (grey boxes).

In this work based on the PERFORMER project (FP7, N°609154), we focus on studies based on statistical and machine learning approaches (black boxes) that make use only of available data to learn relationships, correlations and dependencies between data. These studies often introduce exogenous information such as weather information to help models to converge to better predictions. The main drawbacks of such methods is to apply the suited pre-processing on data, find the best exogenous information to add to models inputs and make use of a sufficiently large and reliable dataset.

The present work proposes to use a well-known class of models in signal processing, namely: an ARMA model to generate predictions from the signal past values (Box, Jenkins, & Reinsel, 1994). In that way, signal is considered as a time series and the objective is to predict future values of this series without any other information as input, a so called 'data-driven' approach. An ARMA model makes no physical assumption about the underlying process but still has some assumption about the process itself. Aside from classical prediction models, recent years have seen Deep Learning (DL) models win lots of open contests on various application domains ranging from handwritten characters classification (LeCun, 2015) to breast cancer mitosis detection (Ciresan, Giusti, Gambardella, & Schmidhuber, 2013). Despite their performances on classification/selection, the use of DL models for time series prediction is mainly seen as an overshoot considering both performance of common models and complexity of DL models. In this work, our aim is to give an insight into the comparative performances of a recent model of Deep Neural Network (DNN) to the more common ARMA model for time series prediction.

This work both proposes to give useful forecasting information to time series data producers, further looking for anomalies comparing forecasting and actual values, and to give an insight of the ability of DNNs in time series prediction. This is part of a work that aims at generating online forecasting for each signal of instrumented building that upload their recordings to a database. This allow automatic forecasting production of several hundreds of signals without human interaction at each building. Each prediction model generates new forecasting at regular periods of time from the data uploaded by the building sensors. The provided forecasting for each individual signal is then used as a criterion for anomaly detection (not detailed here).
Furthermore, such massive forecasting can then be used as input to other indicators such as expert systems, for part of the control for local energy storage/consumption, or to allow anticipation with regard to cooling/heating materials inertia …

2. Data time series

As a part of the PERFORMER Eurpoean project this work benefits from the project's pilot sites buildings settings. The project is based on four pilot sites:

- *Baltic Plaza Hotel (PL)*

- *Las Letras Hotel (ES)*
- *Saint Teilo's High Scool (UK)*
- *Woopa office (FR)*

In the scope of the project are the instrumentations of each building. Buildings' sensors transmit their recordings to an online data warehouse that can be queried via a REST API. Datasets considered in this paper come from Woopa building (Lyon, France) and Saint Teilo's High Scool (Cardif, UK). This section presents some of the data used to achieve analyses presented in the following sections. Datasets are presented in two subsets each: a training set and a test set.

Saint Teilo High School

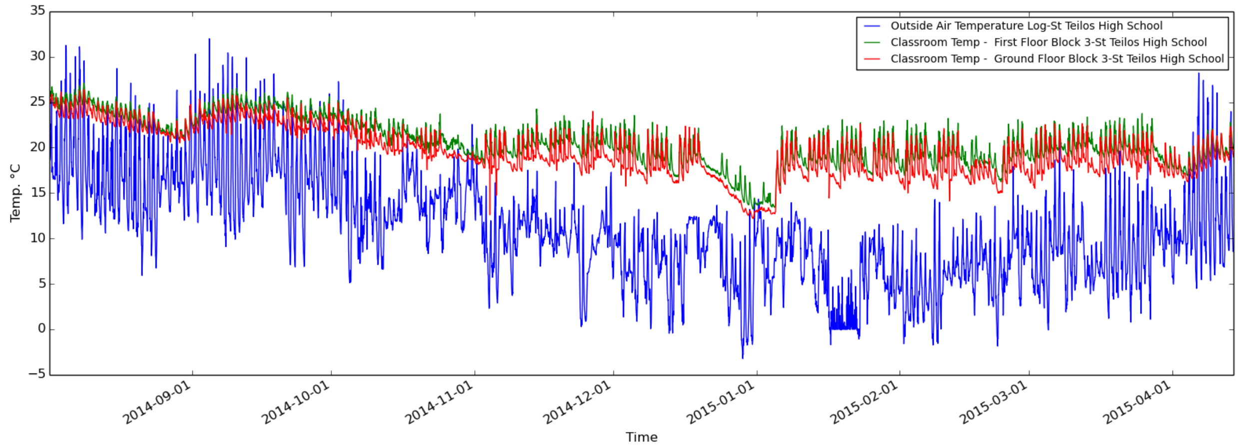

Fig. 11 Raw data hourly resampled

The Saint Teilo's high school data available for analysis are temperature values coming from a block of classrooms in the building. Figure 1 shows a resampled set of data. It consists in a first floor temperatures dataset and a ground floor temperatures dataset. The third set is the outside temperature recorded during the acquisition phase.
These data have been used in preliminary analyses (not shown) and have allowed to explore the periodicities and cluster properties of such building data and helped to set the parameters of the models detailed in the following sections.

These data have not been used thereafter for the forecasting because not enough different types of data were available at Saint Teilo for a common period of time. Thus, models presented in section 3 focus on data from the Woopa building introduced below.

Woopa

The first set of data in Woopa's building is the global gas consumption of the building (Figure 2).

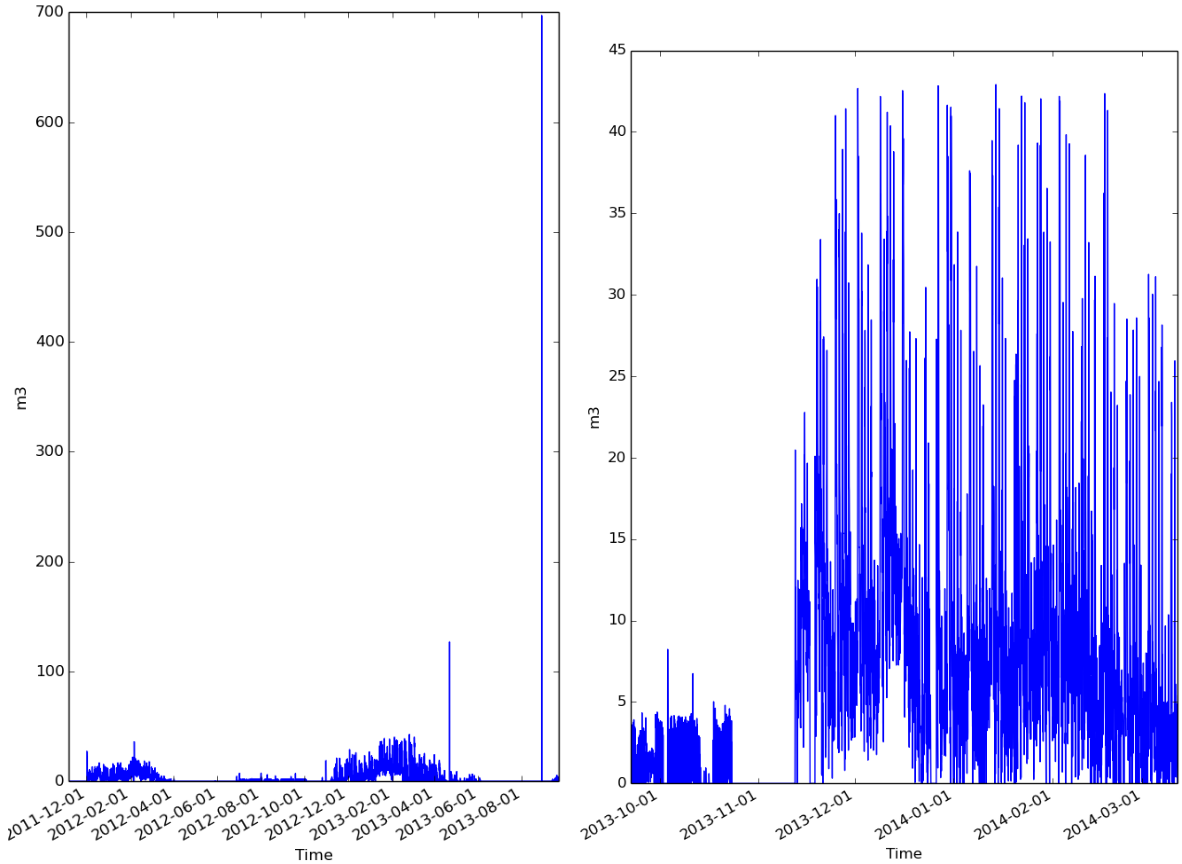

Fig. 12 Woopa Total Gas Consumption (m3). Training set (left), test set (right).

Data is acquired at a sample rate of 15 minutes and ranges from 2011 November 6th to 2014 March 12th. Data is first resampled hourly keeping track of the summed consumption in that interval. Data contain some erroneous values, baseline data should be validated by pilot sites specialists before considering that no abnormal values are present. The dataset is given as is to the models.

A second set of data is the Cold Sanitary water consumption in the Woopa building. Acquisition period and sample rate remain identical to previous set. Again some suspicious spikes are easily detected in the training set, the highest spike has been removed from dataset and remaining is given as is to the models.

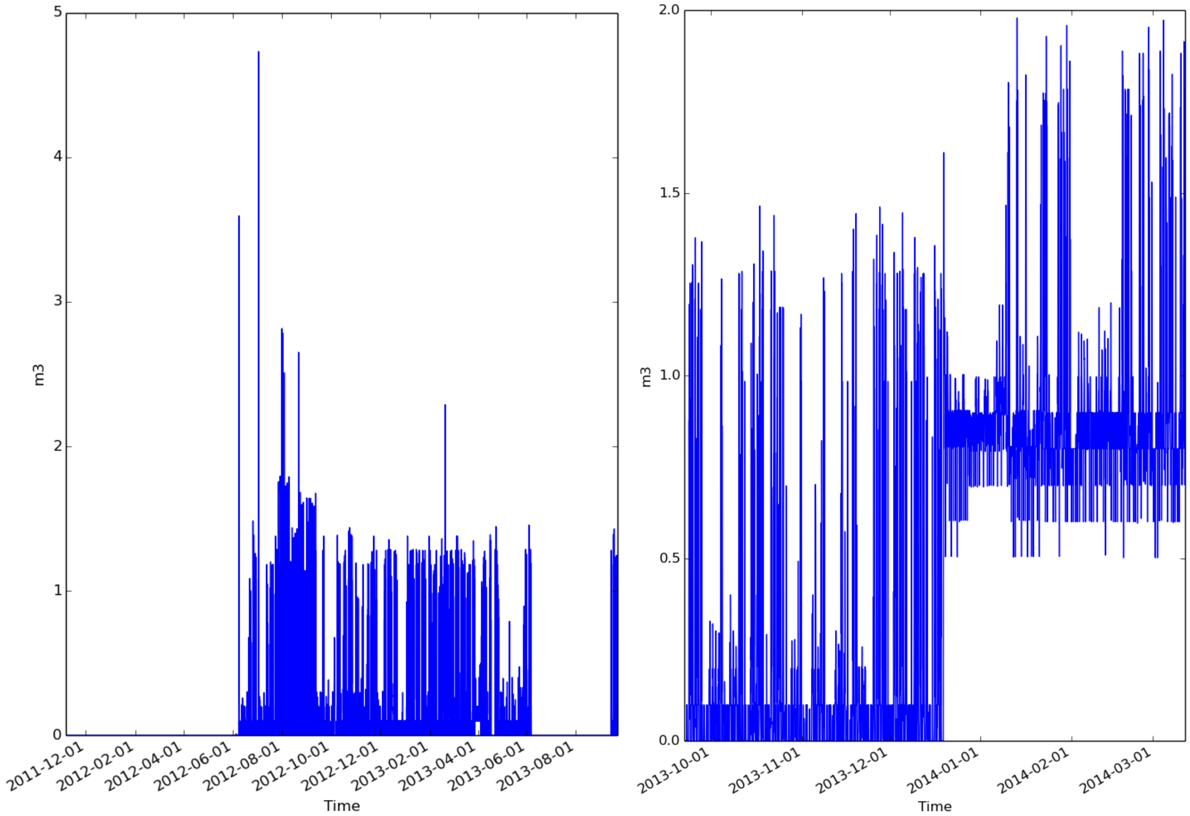

Fig. 13 Woopa Total Water Consumption (m3). Training set (left), test set (right). (m3)

However, in this dataset, some slippage offset is also clearly visible in test set. Test set starts in October 2013 until the end of the period (see Figure 3). This may/will have an impact on models performances as it is not included in models training set. A huge part of the training set is also composed of zero values. It seems that consumption has either not been correctly recorded during the acquisition period or greatly changed over time.

The third dataset used in this work is an electrical consumption one (Figure 4). We chose to use the global lighting consumption of a subzone in the first level of the Woopa building. This third dataset allows us to test the models on an occupancy signal of the building which constitutes a third category of data.

The training set contains some abnormal spikes, especially one raising up to about 750kWh that has been removed from training set (0 instead). There remain suspicious ones that are fed as is to the models. Normal data range is more visible in the test set (< 1kWh per hour). For Deep Networks models, total value range of the data has great influence as being normalized before feeding network. A quick test showed that there is a factor 10 between test mse with the 750kwh spike and without.

3. Algorithms

ARMA model

Auto-Regressive and Moving Average (ARMA) (Box, Jenkins, & Reinsel, 1994) is a common class of models for time series prediction composed of two parameterized parts for describing a stationary process. If raw data do not reflect a stationary process, an Integrated model (ARIMA) can be used to get rid of non-stationarity behaviour by using a given order of process differentiation.

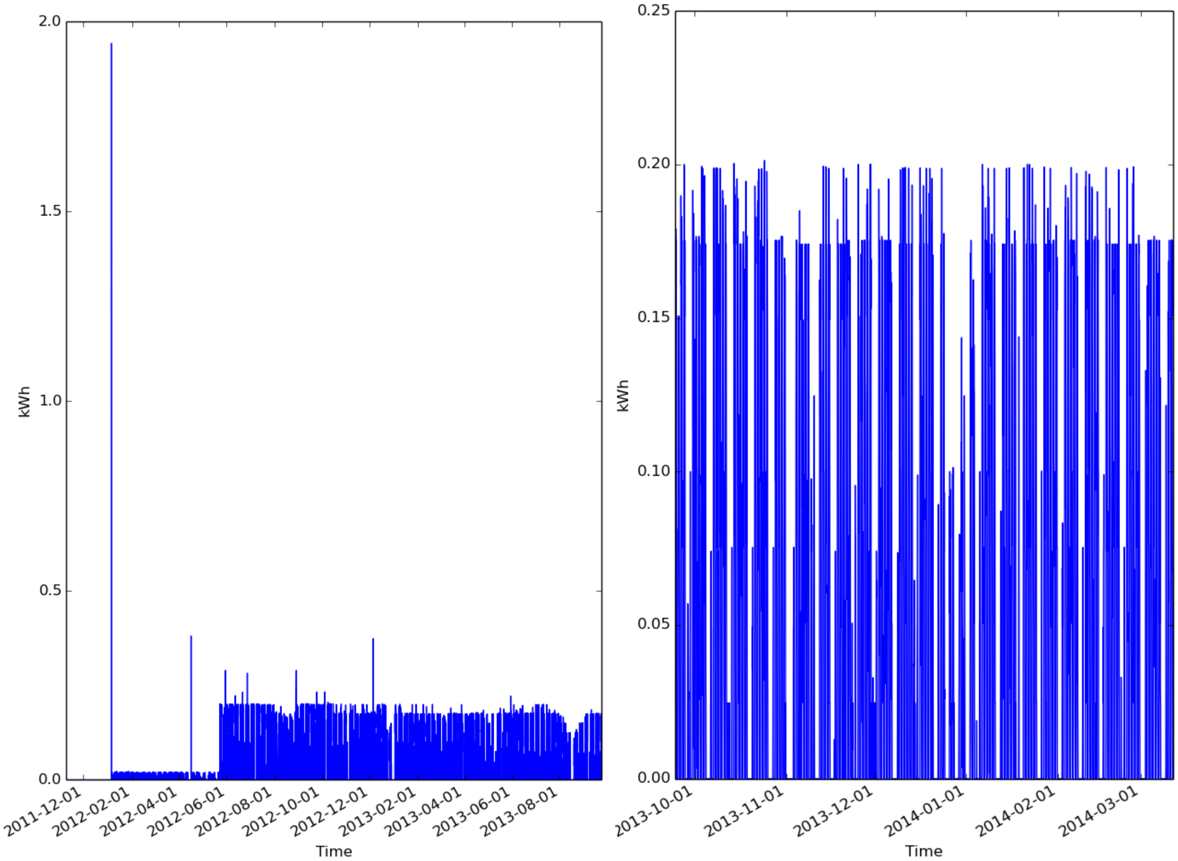

Fig. 4 Woopa lighting consumption of a subzone of a storey (kWh). Training set (left), test set (right)

An ARMA model is a combination of an auto-regressive AR and moving average model.
An AR model can be expressed as follows:

$$X_t = C + \sum_{i=1}^{n} \propto_i X_{t-i} + \varepsilon_t$$

where C is a constant, ε is a residual (random noise), n is the model's order, and $\propto$ is the coefficients used for the weighted sum of the past values used in the model. X_t is the time serie value at time t. The order of the model can be a consecutive past values set, where n will then reflect the number of past values used. The order can also be a list enumerating indices of past values to be used in the combination.

An MA moving average model is expressed as follows:

$$X_t = \mu + \sum_{i=1}^{p} \beta_i \varepsilon_{t-i} + \varepsilon_t$$

Where μ is mean of the series modelled and ε is random noise.
From these definitions, an ARMA model is the combination leading to the following expression;

$$X_t = C + \mu + \sum_{i=1}^{n} \propto_i X_{t-i} + \sum_{i=1}^{p} \beta_i \varepsilon_{t-i} + \varepsilon_t$$

The model implementation used in the present work comes from (Perktold, Seabold, & Taylor, 2016). The model is encapsulated in a python library for online data acquisition and predictions updates.

Deep Highway Networks

DNN has gained popularity in recent years (LeCun, 2015). They have been extensively used in different applications for classification purposes (He, Zhang, Ren, & Sun, 2015) (Ilya Sutskever, 2014) but their application for sequence/times series prediction is quite new (Busseti, Osband, & Wong, 2012) (Dalto, 2015) (Li, Bai, & Zeng, 2016) (Wang & al. 2016). A recent review (Schmidhuber, 2014) retraces progress and advances in DL which encompasses a wide scope of applications and contests. The learning phase of these models can be a challenging task. In particular, learning algorithms hardly perform when increasing the networks depth. A recent work (Srivastava, Greff, & Schmidhuber, 2015) proposes a Deep so-called Highway Network (DHN) model that shows to be more stable in learning when increasing the number of hidden layers. A Highway Network can be defined in a simplified form as follows;

$$y = H(x, W_H).T(x, W_T) + x.C(x, W_C)$$

Where y is the output of the network, H is the non-linear transformation applied to the input x weighted by a parameters matrix W_H. This corresponds to a classical feedforward neural network architecture. In the H is generally composed of several layers of non-linear transformations (and their corresponding weights matrices), where each layer receives its inputs from the preceding layer's outputs and outputs to the next layer.
The Highway property of this model compared to a more classical DNN lies in the two classes of linear transformations added; the *transform gate* $T(x, W_T)$ and *carry gate* (x, W_C) . The first gate transforms the input and the second allows to carry input in a possibly unchanged form through the different layers of the network, depending on the weights applied. In this work, a simplified model is used as proposed in the original work where $C = 1 - T$.

The regular hidden layers are populated with Rectifier Linear Units (ReLu) (Glorot, Bordes, & Bengio, 2011) and gate layers use a sigmoidal activation function. The model used in the present work is adapted from (Dieleman, 2015) and encapsulated in a python library to allow online data acquisition and predictions updates.

4. Results

Preliminary analyses have shown that daily, weekly and yearly periods were among the most powerful periodicities contained in time series. It also showed that clear discrimination between week days and week end/vacations existed in data.
From these preliminary analyses, the models parameters have been chosen. ARMA models orders were also slightly optimized minimizing the Bayesian Information Criterion (BIC). A best moving average order was found at 20 (with a paremeter space between 0 and 50). The first derivative order, making the ARMA an ARIMA model, of time series was used to make the data stationary. For the auto-regressive order, two models were kept for comparison. The first one uses values of the same hour the day before and the same hour on same day the week before to predict a value. The second model uses every values of the past 24 hours and every values of the same day the week before (24 hours starting 168 hours in the past). ARMA models parameters are tuned through maximum likelihood.
This produces two ARMA models to compare.

Table 1. Root mean squared error obtained on Woopa Total Gas consumption. Forecast 1hour

Woopa Total Gas consumption (m3)	
Model	**RMSE**
Best ARMA	5.49
Best DHN	**5.04**
Naïve	7.86

Highway networks parameters have been selected after preliminary tests on subparts of data. The selected set of parameters showed the best prediction behaviour compromise between parameters space size and performance. Networks are fed with the same inputs as the second ARMA model: every hour of last 24 hours and the 24 hours of the last week's same day. A 48 input vector is thus built from signals to feed the network. Thus both kinds of models received comparable inputs.

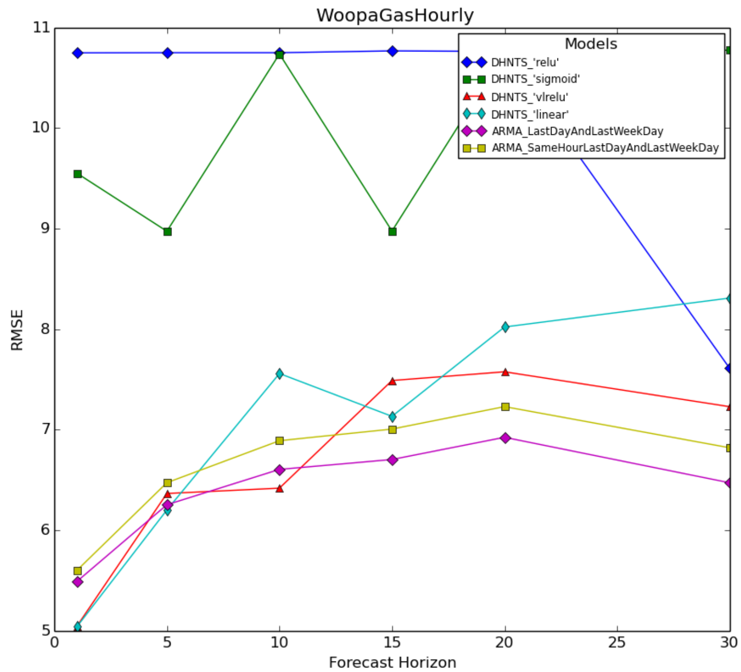

Fig. 5. Performances of models w.r.t the forecast horizon, Gas consumption.

The networks are chosen with 150 hidden units in each of the 20 hidden layers. An output layer is composed of only one cell, to reproduce a one dimensional time serie. The network is thus trained to achieve a regression on the input time series. Four types of activation function of the output layer are used for sake of comparison: ReLu, VeryLeaky Relu (with 0.3 as slope of the rectified part), Sigmoid and Linear. 150 training epochs with a learning rate set to 0.3 (momentum at 0.95) and a bias initialized to -4.0 ends the set of training parameters. Networks are trained through SGD (Stochastic Gradient Descent) with batches of 64 samples and some optimization as described in (Srivastava, Greff, & Schmidhuber, 2015).

Each model is trained with the same part of data and tested with another same part to make results comparable. Models are trained and tested with a forecast horizon of 1, 5, 10, 15, 20 and 30 steps ahead to compare their ability to produce accurate predictions on different horizons.

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Networks outputs consist in only 1 value predicted for the next step. To achieve several steps ahead forecasting predictions are reused as input for next step prediction. Thus the same model is used, as for ARMA models, to generate forecasted values whatever the the forecast horizon is.

Table 2. Root mean squared error obtained on Woopa sanitary cold water consumption. Forecast 1hour

Woopa Total Sanitary cold water consumption (m3)	
Model	**RMSE**
Best ARMA	**0.22**
Best DHN	0.53
Naïve	0.3

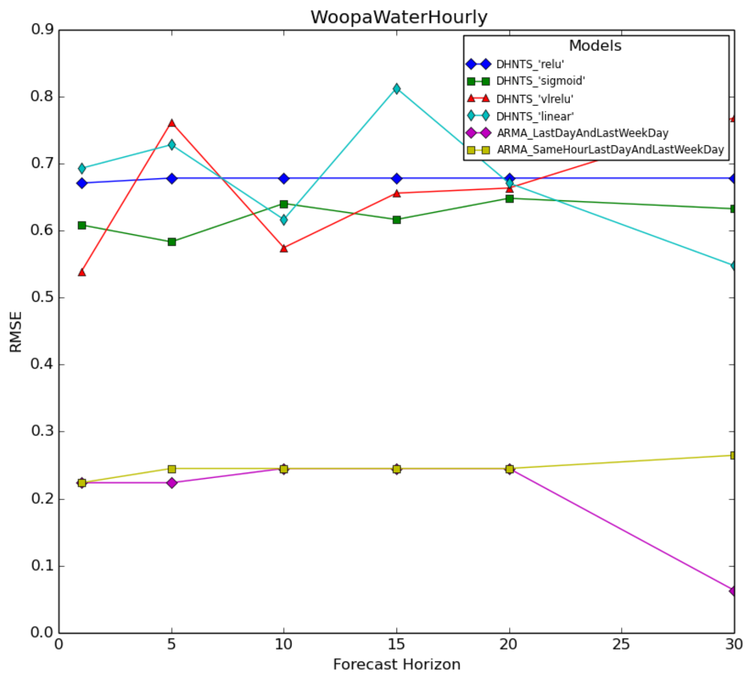

Fig. 6. Performances of models w.r.t the forecast horizon, Water consumption

Tables 1, 2 and 3 shows the performances of the best models for a forecast horizon of 1 sample for each data type. Models performances are compared to a so-called "naïve" model which only reproduces last sample's value as the predicted future value.

Figure 5, 6 and 7 shows performances of all models w.r.t. the forecast horizon duration from 1 to 30 steps ahead. Performance is expressed in terms of root mean squared error.

Table 3. Root mean squared error obtained on Woopa First floor zone RH5 Global Lighting consumption. Forecast 1hour

Woopa Light consumption zone RH5 – R+1 (kWh)	
Model	**RMSE**
Best ARMA	0.03
Best DHN	**0.02**
Naïve	0.22

Labels in Figure 5, 6 and 7 legends indicate the corresponding model: four different output activation functions for DHN models and the two different Auto Regressive orders for ARMA models. From this plot and the tables presented above, we can observe several indications of comparative performances of each model.

The first observation concerns one of the three datasets; namely the water consumption one. In the Figure 5 presented in previous sections a clear offset arises during the test set. This offset shifts the average consumption values until the end of the dataset. Such an offset is not observable in the training set. When we focus on models performances on this dataset, the weak performance of DHN models (worse than naïve, see Table 2) can be explained by this difference of behaviour in training and test sets. The ARMA models on the contrary handles this difficulty with an interesting performance (0.22 as RMSE for an average dataset value between 0.0 and 2.0 m^3, see Table 2 and Figure 5).

This difference in performances is explainable by the fact that DHN focuses on training set to build a model of the data when ARMA considers a moving average and an auto-regressive part, thus whatever the changes in dataset, ARMA will adapt its predictions in this way.

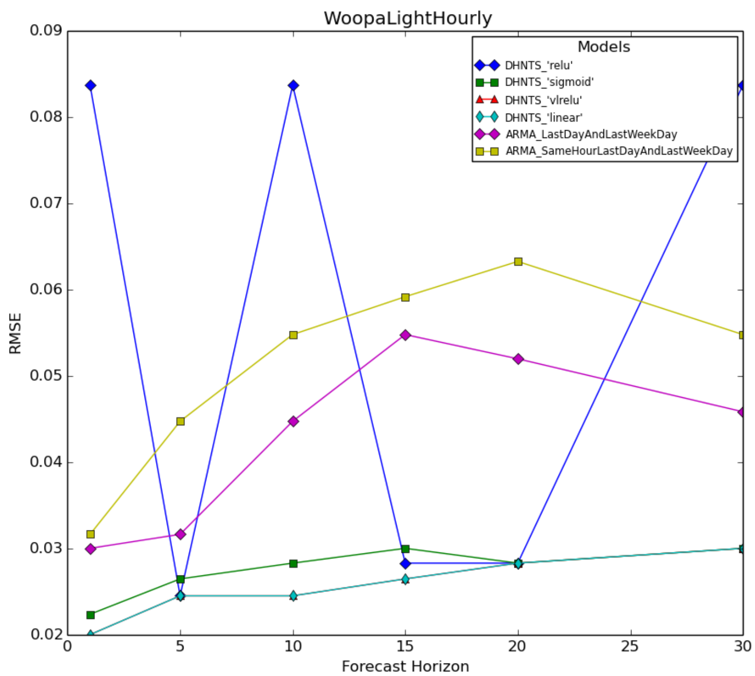

Fig. 7. Performances of models w.r.t the forecast horizon, Light consumption

A second observation is that, if we exclude the water dataset for the reasons explained above, DHN models perform better than ARMA models. This is particularly true on short term prediction as shown in table 1 and 3. Figure 7 also shows that it remains true in the light consumption dataset even for longer forecast horizons.
However, the gas consumption dataset shows that long horizons benefits to ARMA models (Figure 7). The fact that, in this study, DHN models are built with only one output value for next step can be a limitating property in this case (Models with *n* output values could have been created for each of the forecast horizons studied, with *n* the considered horizon). Output function of DHN models shows great influence on model performance depending on dataset. Across datasets and forecast horizons, linear and very leaky rectified linear units (vlReLu) show better performance than sigmoid and rectified linear units (ReLu).

The complexity of the models often being used as a criterion against the use of deep networks models, it is interesting to have an idea of the computational time needed for each model type. In the present work, the the models implementations used lead to a faster execution time for DHN models training and test w.r.t. ARMA models.

Conclusions

This work as part of the Performer European project has focused on comparing performances of ARMA and Deep Highway Networks models for the forecasting of monodimensional signals solely based on past values. Data used have been produced by the project pilot sites, mainly Woopa building, and represent different types of real data acquired over a long period of time. Models parameters have been chosen based on preliminary anylses conducted on project's buildings data. Models performances have been compared across data types and different forecast horizons.

Performance results show that both model types achieve accurate predictions with regard to a naïve prediction, even for uncleaned datasets. Results also show that Deep Networks can improve forecast accuracy. As a counter part they are less adaptative to changes in data behaviors. As is known, networks need to be trained on highly representative datasets to improve accuracy.
It has also been shown that computation load is heavier for the ARMA models than for the DHNs when considering the implmentations used in this work.
Thus, even in a regression scheme with unclean datasets, Deep Networks seem to be able to perform beyond ARMA models, for the present data tested, with less computational load. The main drawback lie in the need for a representative training set and an adapted output dimension.

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Author

Anthony MOURAUD is a Research Engineer and Project Manager at CEA Tech PdlL, Bouguenais, FR. He has been working on computational neuroscience as a Doctoral and Post-Doctoral fellow at Louis Lumière University, Lyon, FR, Antilles-Guyane University, Pointe-à-Pitre, FR, Luminy University, Marseille, FR, Computer Science Research Laboratory (LRI), Orsay, FR and CEA, Saclay, FR. He also has been a Software Engineer at INCKA, Arcueil, FR. Research interests: Machine Learning; Computational Neuroscience; Signal Processing.
ORCID ID: 0000-0003-3692-7310

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TOWARDS INNOVATIVE DISTRICT ENERGY MANAGEMENT: A CASE STUDY WITH STOCHASTIC RENEWABLE GENERATORS

Stefano Barberis[1], **Francesco Roncallo**[2], **Alberto Traverso**[3]

Department of Mechanical Engineering, TPG, University of Genoa, Via Montallegro 1, 16145 Genoa, Italy

E-mails: [1]*Stefano.barberis@edu.unige.it,* [2]*Francesco.roncallo@edu.unige.it,* [3]*alberto.traverso@unige.it*

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Abstract. The conversion of ocean wave power into sustainable electrical power represents a major opportunity to Nations endowed with such a kind of resource. At the present time the most of the technological innovations aiming at converting such resources are at early stage of development, with only a handful of devices close to be at the commercial demonstration stage. The Seaspoon device, thought as a large energy harvester, catches the kinetic energy of ocean waves with promising conversion efficiency, and robust technology, according to specific "wave-motion climate". University of Genoa developed and patented a prototype to be deployed in medium average energy content seas (i.e. Mediterranean or Eastern Asia seas). This paper presents the installation phases of the first real scale prototype installed in the gulf of Genova and the monitoring of its performances. A brief description of the Seaspoon WEC is presented together with the monitoring equipment and procedures.In this research a thermoeconomic analysis of its integration in a real polygenerative district is also investigated. The impact of such this kind of stochastic renewable generator in the Savona Campus Smart Polygeneration Microgrid (SPM) is evaluated. The SPM plant is made up by (i) two auxiliary boilers (500kWth each), (ii) four micro gas turbines (30kWe, 2x65kWe and 100kWe), (iii) an internal combustion engine fed by natural gas (20kWe), (iv) an absorption chiller (100 kWf) and (v) PV panels for a total power installed of 100 kWe. Generators are "distributed" around the campus and they are coupled to electrical and thermal storages. Since the system is constituted by co-generative prime movers it can supply both electrical and thermal energy of the campus and the integration of storage is really important in order to follow both the requests, pursuing the best management strategy.

The analysis of this smart-grid is performed exploiting a software developed by the Author's research group, which allows for the thermo-economic optimization of poly-generative energy systems. A model of the real plant was built and it was implemented in the software. The off-design curves of the real devices installed in the campus were used in order to increase the reliability of the simulation results. The grid was simulated considering the time dependent nature of the demands throughout the whole year. The model was used to simulate the smart grid behavior during the whole year, and find the best operational strategy. A time-dependent thermo-economic hierarchical approach has been used, considering the time-dependent electrical, thermal and cooling load demands during the year as problem constraints. The results are presented and discussed in depth and show the strong interaction between fossil and renewable resources, particularly the impact of unpredictable and randomized generators like the WECs ones. A dedicated model of the Seaspoon was implemented and exploited in the code.

Keywords: wave energy converter, smart grid, energy storage, thermoeconomics, polygeneration

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JEL Classifications: Q20, Q42
Additional disciplines: energetics and thermoenergetics, environmental engineering

1. Introduction

The integration of renewable and other efficient distributed power generation sources into existing and future unified electricity systems represents an enormous technological challenge which can be overcome particularly thanks to energy storage and the management of power demand and production by the exploitation of Information and Communications Technology. All these technologies are the fundamentals of Smart Grids and they are the crucial research topic in Europe for a new Energetic revolution (Barstow et al. 2003).

Distributed generation (DG) will play a key role in this novel scenario (Falnes et al. 2007) enabling new roles of citizens as prosumers instead of simple consumer of energy (Olkkonen et al. 2016) also requiring specific social (Tvaronavičienė et al. 2012) and business models (Izvercianu et al. 2014). It covers a broad range of technologies, including many renewable technologies supplying small scale power at sites close to users. Highly efficient combined heat and power (CHP) plants, back-up and peak load systems are providing increasing capacity. Together with renewable energy, these technologies offer new market opportunities and enhanced industrial competitiveness.

The ocean waves are an important renewable energy resource that, if extensively exploited, may contribute significantly to the electrical energy supply of countries with coasts facing the ocean (Barstow et al. 2003). A wide variety of technologies has been proposed, studied, and in some cases tested at full size in real ocean conditions (Izvercianu et al. 2014; Drew et al. 2009; FalcãoA.F.de O et al. 2010; Lopez et al. 2013). The mechanical process of energy absorption from the waves requires a moving interface, involving (i) a partly or totally submerged moving body and/or (ii) a moving air–water interface subject to a time-varying pressure. This kind of generators can be exploited in distributed generation facilities particularly for smart grids and district energy located nearby the shores where the sea has a considerable wave energy potential. The production of WECs is strongly aleatory, even if it is a little bit more predictable than wind power. Due to strongly randomized production, it is important to evaluate the interaction of this kind of generators with the other equipment (generators and storage) installed in the local energy district in order to maximize the exploitation of WECs' production.

The management of distributed generation facilities, the demand-side management, the design of the energy district is a complex multiobjective optimization process that could be analysed through a thermoeconomic approach. Thermo-economic analysis (Verda et al. 2001) is a well-known method to approach energy systems, in order to develop efficient and profitable real time controllers and to identify the best size for the different installed devices. Energy storage systems can help in successfully meeting the district energy demand, such as building heating and cooling applications, and they are able to solve the problems of not dispatchable renewable energy sources in the electrical market.

The purpose of this paper is to evaluate the impact of an original patented WEC named SeaSpoon, developed by the researchers of the Thermochemical Power Group, in the management of a real polygenerative energy district installed at the University of Genoa campus located in Savona (Bracco et al. 2013). A one-year analysis is carried out with one hour time intervals, taking into proper account the time-dependent nature of energy demands, RES generation and investigating the best operational strategy for the devices. A thermoeconomic model of the SeaSpoon was developed in the original software W-ECoMP (Web-based Economic Cogeneration Modular Program) (Barberis et al. 2016) thanks to the optimization process was performed, which aims to investigate the best management strategy of the devices installed in polygenerative energy districts in order to satisfy the load energy demands and make eventual new equipment installations profitable.

2. Savona Campus Smart Polygeneration Microgrid

In the previously introduced scenario, one of the most innovative European demonstrator is the Smart Polygeneration Microgrid (SPM) (Fig.1), installed in the University of Genoa campus, located in Savona (Italy), and built with both the contribution of the Italian Ministry of Education, University and Research MIUR and the European Project FP7 RESILIENT. The SPM installed in Savona includes several commercial CHP units, traditional prime movers and renewable generators, as it follows:

- A cogenerative micro gas turbine (mGT) Turbec T100, 100 kWe, 165 kWth and a cogenerative internal combustion engine (ICE) TANDEM T20, 20 kWe, 44 kWth; (these two CHP units are included in the Innovative Energy System laboratory managed by TPG)
- A cogenerative micro gas turbine (mGT) Capstone C30, 30 kWe, 49 kWth;
- Two cogenerative micro gas turbines (mGT) Capstone C65, each rated 65 kWe, 112 kWth;
- A photovoltaic roof of 400 m2, corresponding to a peak power of about 77 kWe;
- Three CSP dish Stirling units, each rated 1 kWe, 3 kWth;
- Two conventional gas natural boilers, each rated 500 kWth;
- Two absorption chillers, LWM-W003, each rated 100 kWth;
- Two storage tanks for hot water, for a total volume of 10,000 l;
- A storage tank for cold water, volume of 3,000 l;
- A FIAMM SoNick electrical energy storage, capacity of 470 Ah and nominal voltage of 300 V.

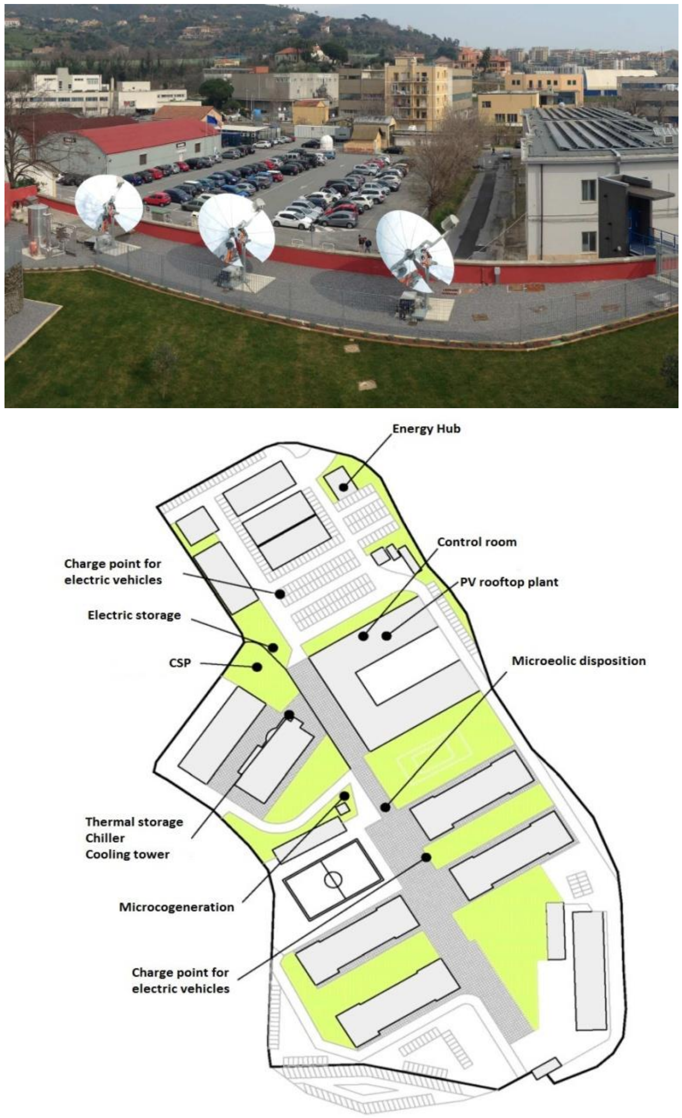

Fig.1. University of Genoa campus located in Savona (above) - SPM overview (below*).*

The SPM is connected to the National electrical grid in a single point. The CSP dish Stirling units (Fig.1 above) contribution to the grid will not be ever considered in the present analysis, as the thermal and electrical production of these units is negligible.

3. The SeaSpoon Wave Energy Converter

The development of an innovative wave energy converter designed to exploit the Mediterranean Sea wave energy potential started in 2010 at the Thermochemical Power Group. A first design and layout was patented in 2011 and the concept originates from merging the best technologies of existing Wave Energy Converter (WEC) devices with up to date wind energy turbines.

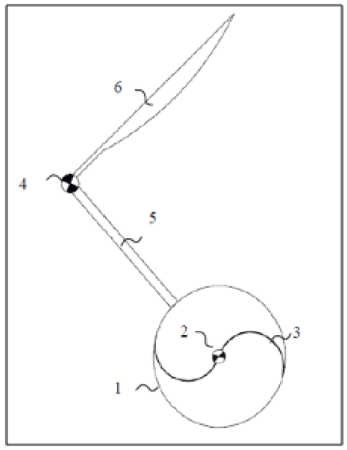

Fig.2. SeaSpoon First Layout

The first simplest layout of the Seaspoon (Fig. 2) consists of a rotor (1) whose spinning axis (2) is submerged at an appropriate depth, considering the sea conditions (wave period, wave height and wavelength), perpendicular to the wave propagation direction. The wave particles, while in motion, hit the rotor blades (3), which start spinning in one direction independently on the wave direction. A connecting rod (5) ties stiffly the rotor axis to a main spinning axis (4). The main spinning axis is placed as well parallel to the rotor axis. It is submerged at an appropriate depth likewise the rotor axis. The main axis is hinged to a flat plate (6), which acts as a rudder for the overall rotation. In turns, the entire device is free to spin around the main axis (4) in the same direction of the propagating waves. At the same time, the blades are set to motion and spins around (2) and (4) at once.

The results of numerical simulations (DiFresco et al. 2015) showed that the Seaspoon (Savonius-type rotor coupled to spoon plate) performs better than a simple Savonius-type rotor, exploiting the peculiarity of the circular velocity field of the flowstream associated to the waves motion. This proves the basic idea on which the Seaspoon is based on. The spoon plate eventually coupled to a rotor with even higher efficiency of the Savonius (e.g. Darrieus-type rotor) can improve its conversion efficiency (DiFresco et al. 2014).

After a first test campaign in a wave flume facility, it was decided to move towards a simple spoon plate and a full-scale prototype (Fig.3) was realized and installed in the gulf of Genova thanks to a elastic beacon installed in open-sea where a complete monitoring campaign is currently in progress. The technical details of the prototype are reported in Tab.1, the most important innovative aspects proposed by the SeaSpoon are its ability of self-orienteering hortogonal to the wave direction, the possibility to move the converter on a vertical direction (5 m) in order to follow the waves and the fact that the WEC has no visual impact, thanks to the submerged installation.

Technical Sheet	
Nominal Power	1-3 kW
Blades Size	2 blades – 1x1 m
Nominal Optimized Designed Wave Height	2 m
Vertical Displacement	5 m

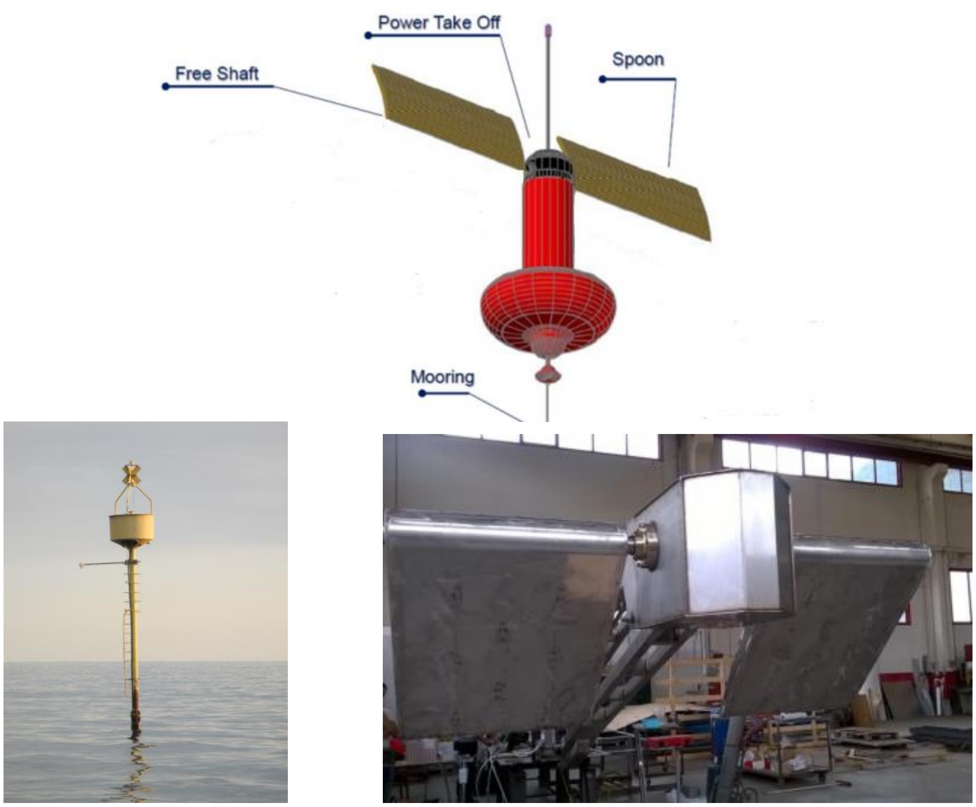

Fig.3. SeaSpoon Full Scale Prototype: Render and Prototype

The monitoring campaign is based on a remote control of the most important parameters where all the data are collected through a MATLAB model (Fig.4):

- Generated power
- Efficency
- Wave height
- Wave period
- Wave-power correlation
- Wave potential
- Daily performance

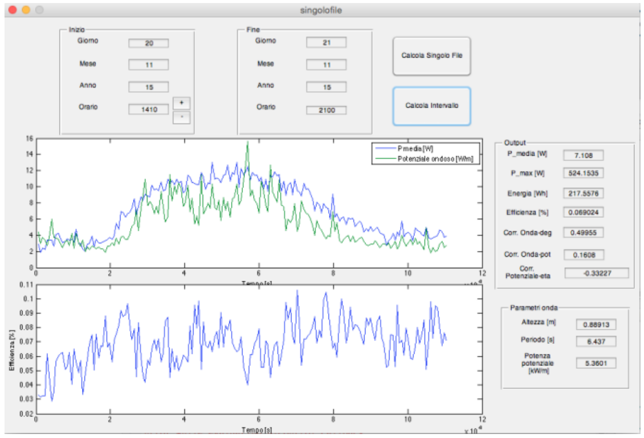

Fig.4. SeaSpoon Monitoring Campaign MATLAB Model

4. Thermoeconomic Approach and W-ECoMP software

Thermo-economics aims to find a correlation between the thermodynamics, particularly energy and exergy flows, and the economics of an energy system. The peculiarity of this thermo-economic analysis consists in the use of the concepts of specific consumption of components or processes and the energy costs of the flows; these two items of cost constitute the so-called internal economy of the energy conversion system.

Thermo-economic analysis can be insightful in polygenerative districts, where the energy manager has to decide whether i.e. follow the thermal or electrical demands, and optimise the electricity exchanged with the grid.
The objective of thermo-economics is to indicate where and how energy and money savings are possible and to quantify the results obtained in terms of fuel or money saved.

W-ECoMP (Web-based Economic Cogeneration Modular Program) is an original software tool developed by the Thermochemical Power Group, at the University of Genoa. W-ECoMP aims at the thermo-economic, time-dependent analysis and optimization of energy districts: it is characterized by a modular structure that allows the user to easily build complex cycle configurations without significant modifies at the core of the program. This approach maintains the possibility of extending the libraries containing the components (48 modules are available). Each component is described by three subroutines, that define mass and energy flows, off-design performance curves (Ferrari et al. 2014), variable and capital costs. W-ECoMP allows the optimization of energy systems at two different hierarchical levels (Yokohama et al.; Gamou et al.):

- Determination of the best operational strategy for existing energy systems (low level)
- Determination of the optimal size of plant components or whole plant design (high level)

Capital and variable costs are considered for the system size optimization, while only variable costs are considered to optimize the operating strategy of existing energy systems. In the design optimization, the size of each component is evaluated together with its capital cost, through cost functions updated periodically (once a year). The main inputs of the model are: (i) electricity, heating, cooling load curves; (ii) economic scenario where the plant is installed, including trade prices (fuel and energy costs); (iii) component capital costs vs. size; (iv) operating and maintenance costs vs. time; (v) generator off-design performance curves. In particular, off-design performance curves for the devices installed in the energy district were implemented by the authors in a previous work (Barberis et al. 2016) starting from their real performance measured in experimental tests at different load conditions.

The constraints of the problem are the balance equations between supply and demand of components. For example, as far as the electrical energy balance is concerned, the energy produced by installed prime movers (ICE, gas turbines, etc.), the energy sold to the user and the energy consumed by plant components (i.e. compressors, heat pumps) are included in the balance, as follows:

$$E_{req} = \sum_{i=1}^{N} E_{i,prod} + E_{acq} + E_{virt} - \sum_{i=1}^{N} E_{i,cons} \qquad (1)$$

Eq. 1 includes a virtual term as well, representing energy exchanges between the plant and the external environment, necessary to satisfy the optimization constraints (i.e. load demands). The same approach can be applied for thermal and cooling energy balances. W-ECoMP considers only energy and power flows between units: fuel mass flows and consumptions are evaluated from the energy flows and the generators efficiencies. The thermal storage is modelled starting from a volume capacity and evaluating the storable thermal energy by hot water with that volume and a fixed temperature.

At low level, the components size is considered fixed (therefore capital costs are fixed) and a genetic algorithm is used in order to determine the best operational strategy (Barberis et al. 2016). In this case, the software aims to minimize an objective function (Eq. 2) that represents annual variable costs:

$$C_{\text{var}} = F_i \cdot \sum_{i=1}^{N} c_{fuel,i} + c_{el} \cdot E_{acq} + c_{virt} \cdot \left(F_{virt} + E_{virt} + Q_{virt}^{*} \right) \qquad (2)$$

Variable costs are made up of the following terms: (i) a term related to fuel consumption costs, (ii) a term related to electrical energy costs and (iii) a term that represents “virtual costs”. It is important to underline that “virtual flows” represent energy exchanges between the plant and the external environment, necessary to satisfy the optimization constraints (i.e. load demands), as reported in Eq.1. Since these amounts of energy cannot be produced by the plant, penalty costs are associated to virtual flows. Since the term “cvirt” is high (usually, two orders of magnitude higher than the other specific cost terms), the optimization process is forced to find an operational strategy which minimizes virtual flows.

At high level, W-ECoMP is able to perform the size optimization of one or more components at the same time, minimizing the objective function, which includes both variable and fixed annual costs. More details on the high-level optimization are reported in (Barberis et al. 2016). The optimization process is performed by dividing the operational time (usually one year) into a proper number of representative periods, one hour or less depending on the application. At both optimization levels, the constraints of the problems, represented by energy load demands, must be satisfied; if these conditions are not verified, strong penalties are applied and virtual costs associated with virtual flows increase the objective function (Yokohama et al.). Thanks to the presence of the storage, the energy load demands can be managed with more flexibility, allowing for fuel and energy savings as well. For any further detail about the model of the storage implemented in the software, please refer to (Verda et al. 2001).

4.1 Thermoeconomic Model of the SeaSpoon WEC

The SeaSpoon Wave Energy Conveerter was modelled in the WECoMP software to be integrated in an already existing model of the Savona Campus SPM, modifying the “Renewable Random Generator” module (Fig.5). This module is able, starting from a *txt file with an hourly profile of the renewable associated potential (solar irradiation, wind speed, wav height and frequency), to calculate the producibility of the Renewable Generator.

In this case the Seaspoon WECoMP was built after a deep statistical analysis of the wave potential of the sea in front of the city of Savona, where it would be installed the Wave Energy Converter. This analysis started from monitored data (weather and meteo open sea floating stations) and from wave forecast models from the Ligurian Sea.

In the analysed scenario, the average wave height is usually between 0 and 3 metres, with rare peaks of 4 or 5 metres. Although the stochastic distribution of these data, some values are often maintained for hours or days around equilibrium values then moving suddenly to set around a new average value of balance. This trend allowed to prepare three average profile of the daily wave potential per each month, related to calm, moderate and wavy situations. These data could be used as input for the "Renewable Random Generator" module.
Starting from the wave potential equation (Eq.3), it is worthy to consider an average period of the wave to evaluate the producibility of the Wave Energy Converter.

$$P = \frac{\rho g^2 H^2 T}{32\pi} \qquad \left[\frac{W}{m}\right] \quad (3)$$

The values of the periods were identified with a different approach previously described for the wave heigth values and an average value for the three sea conditions were identified that ais equal for all months. These values were directly inserted in the code, and not in the *txt file that the user has to provide to the module for the simulation, so the user, choosing the sea condition (calm, moderate, wavy) impose the period.
According to period and heigth values the three different daily profile were divided as follows:

- Calm, period equal to 5 s and heigth inferior to 1 m;
- Moderate, heigth between 1 m and 2,5 m and period equal to 6,5 s;
- Wavy, heigth higher than 2,5 m and period equal to 7,5 secondi.

For a complete evaluation of the production of the WEC, the WECoMP software consider a different number of days of the three profile per each month.

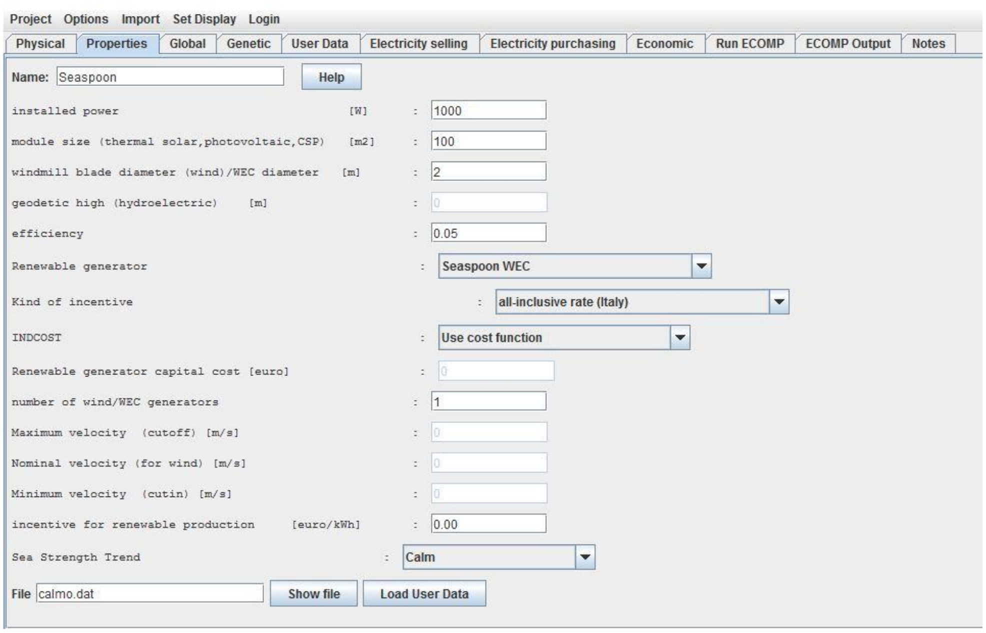

Fig.5. SeaSpoon WECoMP model input data

The input data that has to be inserted by the user together with the *txt file of the wave potential are those one related to the design of the WEC: the size of the blades (strictly related to the portion of the wave front that the generator is able to exploit), the number of WECs present in the farm, the nominal efficiency.
An off-design curve was implemented in the code mostly referred to the ratio between the wave height and the diameter of the blade. This curve was built starting from the producibility data obtained from the open sea

monitoring that show how the nominal efficiency is performed by the WEC for a H/D ratio equal to 2. (Fig. 6) This curve has been approximated by two parabolic tendency curve and equations (Eq.4-5):

- Considering H/D inferior to 2:
  $y= 0.2981 (H/D)^2 - 0.1404 H/D + 0.0939$ (4)

- Considering H/D superior to 2:
  $y= 0.1514 (H/D)^2 – 1.2066 H/D + 2.8171$ (5)

while in order to perform a complete thermoeconomic analysis, a very simplified cost was introduced in the code with a linear cost of 15000 €/Kw that conside all the generation installation, cabling and manufacturing cost.

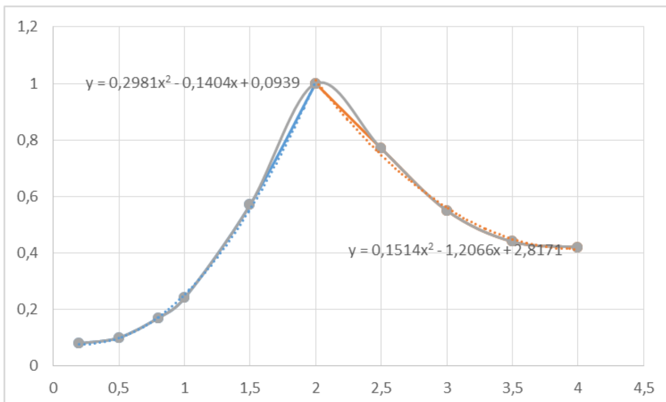

Fig.6. SeaSpoon off-design curve

4.2 Economic scenario and plant assumptions

The calculation is performed by dividing the year in 12 representative days (one for each month), for a total of 288 representative periods (hours). Since the campus is closed during the weekend (demands are zero), only weekdays are considered as representative. W-ECoMP software needs several input data, most of them related to the economic scenario where the plant is installed, as follows:

a) **Energy load demands:** they are one of the optimization problem constraints, they have to be satisfied in all the periods by the traditional and renewable generators installed or purchasing electrical energy from the National grid. The excess of power production of the generators can be also sold to the National grid. A typical electrical and thermal demand load profile is generated for each month from real consumption data received by the SPM controller. Fig. 7 shows the demands for typical winter (continuous lines) and summer (dashed lines) working days.

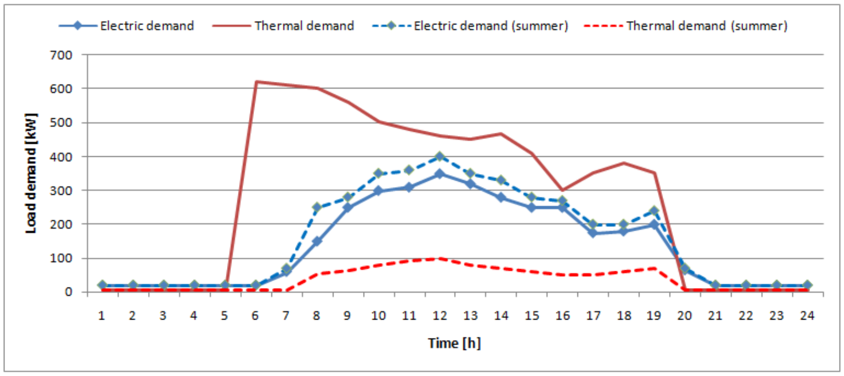

Fig. 8. Electrical / thermal demand profiles in winter (continuous lines) or summer (dashed lines) days

b) Solar irradiation curves: the irradiation curves considered are related to the city of Savona, located in North Italy. Irradiation hourly average values are calculated hour per hour for each month, as reported in (Barberis et al. 2016).

c) Economic scenario data are presented in Tab.1 according to typical electrical energy and natural gas Italian market prices for energy producers at this power size. The prices of electrical and thermal energy sold to users are referred to the local contract while cooling energy production is considered as an electrical energy saving from the present cooling system (compressor chillers, COP=2), therefore cooling power selling price is assumed 0.085 €/kWht.

Table 1. Economic Scenario

Price of natural gas	0,88 €/kg
Purchasing price of electricity from the National grid	0,20 €/kWh
Selling price of electricity to the National grid	0,08 €/kWh
Selling price of electricity to the users	0,17 €/kWh
Selling price of thermal energy to the users	0,08 €/kWh
Selling price of cooling to the users	0,085 €/kWh

Plant life is assumed equal to 20 years, depreciation time equal to 10 years and inflation rate equal to 3% [Bejan et al. 1996]. Basing on thermal and electric demand curves, W-ECoMP calculates the best operating strategy.

d) Local Wave Potential Data: as previously introduced the data related to the wave progile in the Savona Gulf were evaluated through a cross-statistical analysis from different monitored and previsions data.

5. WECoMP Simulation

In this research the installation of a 10 SeaSpoon farm in the sea shores in front of the city of Savona was considered in order to evaluate how this kind of strong tochastic generators can interact with the Savona Campus SPM. It is worthy to underline that, due to low energy potential of Ligurian Sea, the SeaSpoon contribution in the SPM is significant only during wavy days that are more frequent in winter months like December and February (Fig. 8 – Table 2)

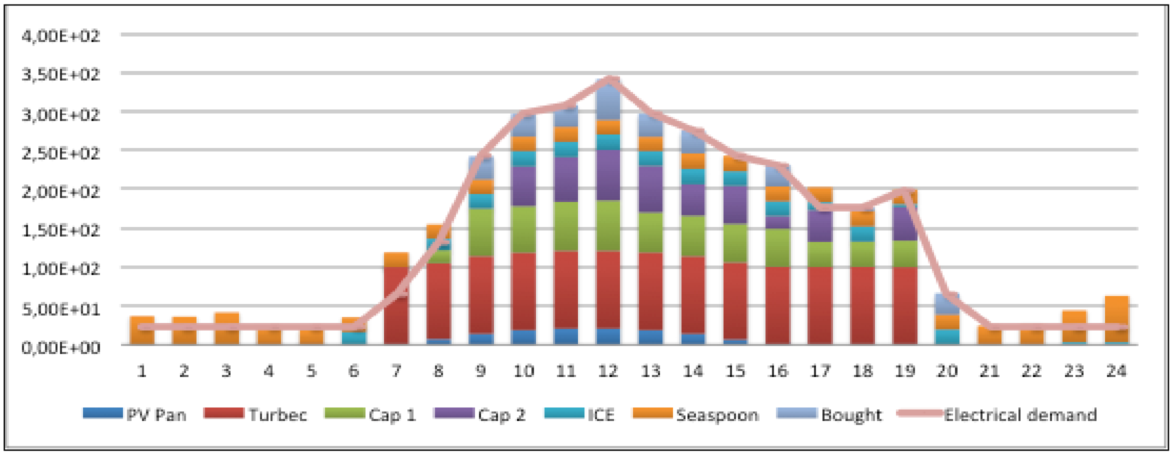

Fig. 8. SPM connected to the SeaSpoon farm - Electrical Management in the month of December

In wavy days a significant contribution of the Seaspoon farm can be observed, with an average power production comparable to that one normally produced by the CHP internal combustion engine TANDEM T20, often even higher. As can be seen from the graphs, the Seaspoon facility is able to statisfy the energy demand of the campus during the night. The exploitation of SeaSpoon energy production at night seems to be plausible as wave presence and profile are fairly predictable. The Seaspoon night overproduction could be sold to the Electrical National grid, or it could be stored in the battery (not the subject of these simulations) for the operations of the peak-shaving during mid-day peaks demand.

Table 2. Yearly Electrical Energy Producibility of a Ten SeaSpoon Farm in Savona Sea [kWh]

	Monthly Energy Production [kWh]			
	Calm	**Moderate**	**Wavy**	**Total**
January	74,42	684,36	0,00	758,78
February	64,83	510,17	427,96	1002,95
March	78,32	946,28	0,00	1024,59
April	33,02	508,94	0,00	541,96
May	48,03	1121,54	0,00	1169,57
June	42,31	118,56	0,00	160,86
July	13,99	101,15	0,00	115,14
August	27,44	29,44	0,00	56,88
September	29,95	786,42	0,00	816,37
October	44,98	431,21	471,63	947,81
November	36,32	848,06	859,84	1744,21
December	22,46	409,12	1190,89	1622,47
			TOTAL [kWh]	9961,59

For what it concerns the WECs' contribution during the day, the SeaSpoon production helps to reduce the energey bought from the National grid without any particular negative effect on the management of the thermal demand, entirely satisfied by CHP units particularly at the peak of the electric demand.

As it can be seen in Table 2, even if the day with a calm sea wave profile are more frequent, the energy production is more or less not remarkable while the wavy days are very few in a year considering the Ligurian Sea in Savona, so despite the good quantity of power produced, SeaSpoon farm doesn't play a significant role in the management of the SPM electric demand.

Conclusions

In this paper an innovative Wave Energy Converter designed to exploit the wave energy potential of the Mediterranean Sea is presented. The SeaSpoon was briefly introduced, together with the monitoring campaign that is started in Spetember 2015 thanks to the installation of a full scall prototype in the Gulf of Genova. Starting from the first data coming from the experimental campaign, a thermoeconomic model of the SeaSpoon was realized in order to evaluate its connection with an already existing smart polygenerative microgrid and how its stochastic production can influence the management of the energy district.

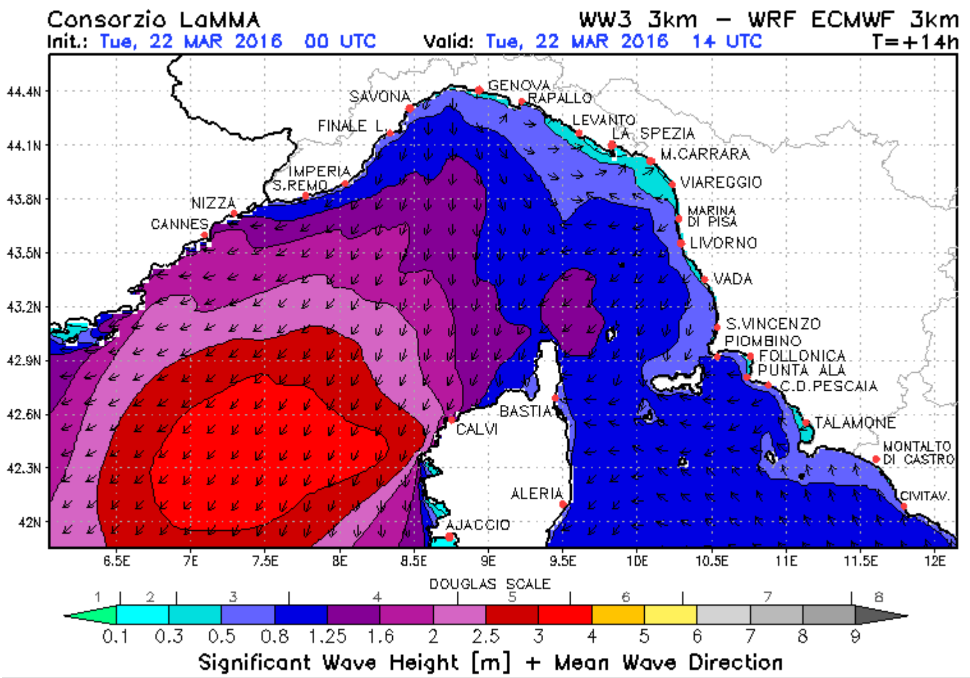

Fig. 9. Example of the wave significant height distribution in the Ligurian Sea

At the end of this analysis performed with the software WECoMP it is possible to say that the interaction of a WEC with a Smart Grid in this kind of scenario (the city of Savona) is almost negligible as the most of the days of the year the energy produced by SeaSpoon is not remarkable due to the calm condition of the sea (Fig.9). Nevertheless it is worthy to underline that, during the rare days of wavy and mderate sea, the contribution of the WEC farm reduce the amount of energy purchased from the electrical National grid.

The energy production is not remarkable because the area considered for the installation, in front of the city of Savona, is characterized by very low waves, less than one meter of significant height for the most of the year. Moreover the off-design performance of the machine strongly reduce the producibility of the machine particularly considering smaller waves.

In the end, the integration of such this generation in the Savona Campus Smart Polygeneration Microgrid would be possible, as in the 83 days per year with a significant wave potential, it is possible to produces a small share of easily integrable and manageable energy. This integration can not, however, appear very affordable and remunerative due to the reduced production in the designed area. Particularly in summer, when the electrical demand increases and the CHP units production is not remunerative anymore because of the reduced thermal demand and the RES generators production could be acceptable, the Wave Energy converters don't produce a significant amount of energy.

This paper presented the modelling and analysis of the WEC as well as its contribution to the campus SPM. Nevertheless, given the negligible size of the WEC compared to the total size of the SPM it should be expected that one SWEC wouldn't offer an attractive business model regardless of the total production of the WEC. The contribution of WECs for energy district can be interesting for isolated contexts like islands with significant wave potential where this kind of renewable generators can increment the energy independency of the island and the reduction of their use of fossils. In order to develop an attractive exploitation of these generators, it is important to take into account the cost of electrical connection of these open sea units with the shores, reducing as much as possible.
Other possible uses of such this WEC can be searched in renewable stand-alone power generation systems, useful in isolated communities or to recharge AUV vehicles (Autonomous Underwater Vehicle) [Di Fresco et al. 2015] particularly thanks to the submerged installation of the generators.

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Stefano Barberis is Associate Researcher at Unversity of Genova. He joined TPG (Thermochemical Power Group – www.tpg.unige.it) in 2013 as a PhD student and he is now active in the field of Distributed Generation focusing his interests on energy harvesting , energetic storage (thermal and electric) and Concentrating Solar Power Plants. His main topics are innovative energy cycle thermoeconomics and analysis and optimization of renewable plants and smart grids.
ORCID ID: 0000-0002-6597-8793

Francesco Roncallo is PhD Student at University of Genova. He obtained his Master Degree in Mechanical Engineering at University of Genoa in 2014 with the Thesis "Sustainable energy solutions in developing countries". He joined TPG as PhD student in 2015. His research is mostly focused on renewable energy and about an innovative renewable energy system based on wave energy conversion, the "Seaspoon". He is also active on cooperative engineering for the sustainable development of emerging countries.
ORCID ID: 0000-0003-4463-6425

Alberto Traverso is Associate Professor of Energy Systems for Mechanical Engineering. He obtained the Ph.D. in 2004 with the thesis "TRANSEO: A New Simulation Tool for the Transient Analysis of Innovative Energy Systems". His main field of expertise is the time-dependent analysis of energy systems, including fuel cell hybrid cycles. He is also responsible of WTEMP software development for thermoeconomic analysis of innovative energy systems. He is part of the steering committee at TPG for the Rolls-Royce Fuel Cell Systems Ltd UTC.
ORCID ID: 0000-0001-5934-3452

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ENERGY EFFICIENCY FACETS: INNOVATIVE DISTRICT COOLING SYSTEMS[7]

Francesco Passerini[1], Raymond Sterling[2], Markus Keane[2], Krzysztof Klobut[3], Andrea Costa[1]

[1]R2M solution s.r.l., Via Fratelli Cuzio 42
27100 Pavia, Italy

[2]National University OF Ireland Galway, University road
Galway, Ireland

[3]Technical Research Centre of Finland, Vuorimiehentie 3
02150 Espoo, Finland

E-mail: [1] francesco.passerini@r2msolution.com

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Abstract. Cooling demand in buildings is globally increasing, therefore developing more efficient cooling systems is important for the sustainability of European cities. Directive 2012/27/EU of the European Parliament and of the council on energy efficiency states: "Member States should carry out a comprehensive assessment of the potential for high-efficiency cogeneration and district heating and cooling". The EU project INDIGO is investigating this issue considering also the economic efficiency and the use of renewable energy sources.

In a district cooling system different kinds of cooling production can be combined. E.g., the use of absorption chillers with waste heat or through the solar cooling or the use of free cooling (generally the heat is rejected to seas, lakes, rivers or waterways) offer the possibility of a more sustainable way of cooling. Controlling those systems in an efficient way is a complex problem (consider that the cooling demand is much more difficult to predict than the heat demand, particularly the peaks, and sources such as the solar energy and the waste heat are not predetermined by the designers).

The main results of INDIGO will be the development of:

- predictive controllers (responsible for obtaining the HVAC systems set-points and based on component dynamic thermos-fluid models, some of them also including embedded self-learning algorithms);
- system management algorithms (focused on energy efficiency maximization or energy cost minimization);
- an open-source planning tool (based on design and performance parameters as well as simulation and optimisation results; LCA framework will be used as a method for both economic feasibility and climate impact assessment).

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To validate the results, the consortium is analysing case studies, both through energy modelling and through on-site observations and measurements. The present paper focuses mainly on the development of dynamic energy models and on their use in the context of the project.

Keywords: energy efficiency, predictive controllers, new system management algorithms, new planning tool, more efficient district cooling systems, energy models

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JEL Classifications: C63, C88
Additional Disciplines Mechanical Engineering

1. Introduction

Energy efficiency issues are widely discussed in scientific literature (e.g. Vosylius et al. 2013; Lapinskienė et al. 2014; Tvaronavičienė et al. 2015; Tvaronavičienė 2016; Strielkowski et al. 2016). Directive 2012/27/EU of the European Parliament and of the council on energy efficiency states: "Member States should carry out a comprehensive assessment of the potential for high-efficiency cogeneration and district heating and cooling". INDIGO is a project that is funded by the European Union's Horizon 2020 research and innovation program and is investigating the improvement of the district cooling systems. It started in March 2016 and is going to last 42 months. The importance of the development of efficient cooling systems is clear if we consider that:

- according to different prognosis the cooling demand in the EU27 countries will increase significantly in the next decades (RESCUE Project. 2013);
- due to the cooling demand, often in city centres and in commercial areas the electricity peak loads appear during the summer season (Frederiksen, S.; Werner, S. 2013).

The management of cooling systems shall consider that providing cooling efficiently is more difficult than providing heating.
The cooling demand is more difficult to predict than the heat demand (Frederiksen, S.; Werner, S. 2013) because it depends on different factors that can change quickly, e.g. on solar radiation, on internal heat gains, and on the "urban heat island" effect. Since the cooled spaces are generally more commercial than residential and the solar radiation has a large influence on the cooling loads, the daily load variation is rather large for district cooling systems. Moreover, temperature differences between the supply water temperature and the return water temperature for district cooling (DC) networks are generally around 8°C, while in district heating (DH) networks the difference is usually greater than 40°C. For district cooling systems this causes an increase in the cost of the piping system and of the energy requirements for pumping.

In a district cooling system different kinds of cooling production can be combined. E.g., the use of free cooling (generally the heat is rejected to seas, lakes, rivers or waterways) or the use of absorption chillers with waste heat or solar heat offer the possibility of a more sustainable way of cooling. Controlling those systems in an efficient way is a complex problem (sources such as actual solar energy are not predetermined).

The goal of INDIGO is to provide tools that can help the designers and the energy managers that deal with district cooling. The project deals with all the parts of the system: generation, distribution, storage, and demand. In order to facilitate the proper control of complex systems, one of the main results of the project will be the development of predictive controllers. They will be responsible for obtaining the HVAC system set-points and will be based on component dynamic thermal-fluid models, some of them also including embedded self-learning algorithms.

The control system will consider an innovative system management strategy which will take in account both the energy savings and the costs.

To assist the designers' work, INDIGO is going to develop an open-source planning tool. It will be based on design and performance parameters as well as simulation and optimisation results. The LCA framework will be used as a method for both economic feasibility and climate impact assessment. A library with thermo-fluid dynamic models of DC System components will provide the designers detailed information about the systems.
Next sections of this paper focus on the project demonstration site (section 2), energy modelling approach (section 3) and conclusions.

2. Project implementation in a real pilot district

The results of INDIGO are going to be validated in a real District Heating and Cooling (DHC) installation, i.e. in the Basurto Hospital, in Bilbao. The hospital is divided in about 20 buildings and belongs to Osakidetza, the public health service of the Basque Country. Heating and cooling demand of the hospital is satisfied thanks to a DHC installation connected to a trigeneration plant (electricity, heat and cold). The DHC system was installed in the hospital site in 2003 by GIROA, and extended in 2011. GIROA-Veolia currently owns and operates the system and also the HVAC systems in the buildings. Nowadays the trigeneration plant consists of 2 natural gas internal combustion engines of 2MWe (each), some natural gas backup boilers, and 2 absorption chillers plus 4 conventional chillers for cooling purposes.

The cooling demand is very stochastic since it depends on the number of programmed surgeries (operating room usage), rooms occupancy level, as well as on the weather data.

Fig.1. A case study: the Basurto hospital in Bilbao

Source: www.irekia.euskadi.eus

In the Basurto hospital the actual impact of the predictive controllers and of the innovative management strategy is going to be tested. As a first phase, the test will be through simulations. As a second phase, the results of INDIGO will be implemented and measured onsite.

3. Energy modelling approach

Different partners of the consortium are developing different parts of a model that regards the buildings and all the components of the DC system. The different parts are:

1. generation systems;
2. distribution and storage systems;
3. HVAC systems inside the buildings;
4. thermal behaviour of the buildings, internal loads, and building use.

The first three parts are being developed in Modelica, the fourth one in EnergyPlus. They are going to be integrated through the Functional Mock-up Unit (FMU) for co-simulation (Nouidi, T.S. 2014). The coordination among the energy modellers of the different parts is anyway fundamental in order to avoid problems at the interfaces between the different parts. E.g. the thermal zones are created by the energy modeller who is responsible for the building but they will affect also the model of the HVAC system inside the building. Other interfaces are between the different parts of the HVAC system (generation, distribution, storage, heat exchange, AHUs…).

The integration of different tools can permit the exploitation of their different capabilities. EnergyPlus is a whole building energy simulation program. It is a free, open-source, and cross-platform. Its purpose is the evaluation of the energy consumption and comfort conditions relative to the building. In EnergyPlus many models relative to the building envelope and to the HVAC systems are available and already tested. Modelica is a free modelling language. It is component-oriented and it is more flexible than EnergyPlus. It can exchange data also with Building Management Systems (BMSs).

The energy modellers are collecting the data that are needed for their work. The first buildings of the hospital were erected during the first decade of the 20th century while the newest buildings were built about ten years ago. Since the situation is very variegated (from the point of view of the construction techniques and of the available data), the data collection is based on many sources: datasheets, design information (for the newest buildings), drawings, monitored data, equipment tags, on-site measurements, contacts with the facility manager and with the occupants. Since a BMS is present, some monitored data are stored and available through that system.

A monitoring plan for the envelope properties was developed and is going on. Since the project regards the cooling systems, a monitoring campaign is carried out during the summer season. Another campaign is going to be carried out in winter, which is the most appropriate season for some tests (e.g. for the detection of thermal bridges with the thermographic camera and for the measurement of the thermal transmittance of the envelope an important temperature difference -at least 10°C- between the internal environment and the external environment is necessary).

The thermal transmittance and the thermal conductance of the walls and of the roofs is going to be evaluated according to the technical standard ISO 9869-1:2014. The thermal flow, the outdoor and the indoor air temperatures and the surface temperatures are measured and the data, which are stored by a data logger, are going to be elaborated according to the standard. For the summer season the measured data can help understand the dynamic behaviour of the envelope. The external surface temperature and the heat flow rates that are obtained as result from EnergyPlus are going to be compared with measured data. Both the hourly trend and the total heat flow in a defined time slice (in some days) are going to be considered in the comparison. Since in the model of EnergyPlus parameters such as the solar absorbance of the external surface, its thermal emittance, the thermal properties of the layers that compose the wall (thermal conductivity, density, specific heat) influence the wall temperature and the heat flow rates, the monitored data will help in the definition of those parameters in the model.
Since the thermographic camera is used for detecting thermal irregularities in the building envelope, the best positions of the heat flow meter have been evaluated on the basis of the observations made with the thermographic

camera. The windows have generally a higher transmittance than opaque parts, they have much lower thermal inertia, and they are the main entrance for the solar energy. Because of these reasons, the properties of the windows are very important for the thermal behaviour of the buildings, particularly during the summer season. A pyranometer measures the solar radiation flux density (W/m^2) and is used for measuring the solar irradiance on a planar surface. If the solar irradiance is measured on the outside surface of a window and then on the internal surface the solar transmission factor can be estimated.

The buildings that are part of the Basurto Hospital have pitched roofs. The most external layer is made by shingles, under which there is an air cavity. If the air cavity is ventilated with outdoor air, the ventilation can remove part of the entering heat, which is mainly due to solar radiation. In order to evaluate the air velocity, a hot wire anemometer is going to be used. In order to evaluate the air tightness of the building, an innovative test method is going to be applied in collaboration with the University of Nottingham, which is among the developers of the system. The system is called "Pulse" and is considered an alternative to the blower door test (Cooper, E. et al. 2015). The air leakages, particularly those ones at the perimeter of the windows, are going to be examined also through the use of the thermographic camera and of the hot wire anemometer.

As for the HVAC systems inside the buildings, component models for the air handlers (heating coils, cooling coils, humidifiers, etc.) in Basurto site will be developed in Modelica based on previously existing models such as those of the Modelica Buildings Library (Wetter, M et al. 2014). The air handlers will be built as a combination of component models matching the actual configuration of each AHU following the real physical interconnection in the plant. Given that the main focus of INDIGO is on cooling systems, the components directly linked to the district cooling systems (cooling coils and radiant cooling) will be modelled in higher details while any other component (e.g. heating coil, humidifiers, heat recovery) will be simplified in order to lower model complexity and decrease simulation times.

A common set of the physical parameters has been established for every component model: specific heat capacities of water and air, atmospheric pressure and the saturation efficiency. The element-specific parameters are commonly provided by the manufactures. Table 2 shows the manufacturer data used for each component (Table 1).

Table 2. *Parameters provided by the manufacturer*

COMPONENT	PARAMETER
Mixing Box	No data required
Heating Coil	Nominal air input temperature Nominal air output temperature Nominal air mass flow rate Nominal water input temperature Nominal water output temperature Nominal water mass flow rate
Cooling Coil/ Chilled Beams	Nominal air input temperature Nominal air input relative humidity Nominal air output temperature Nominal air output relative humidity Nominal air mass flow rate Nominal water input temperature Nominal water output temperature Nominal water mass flow rate
Humidifier	Maximum steam mass flow rate Steam temperature
Fans	Nominal air flow rate Nominal power Fan curves

In order to obtain data required to validate the models in the environment of the Basurto site, a monitoring plan has been developed also for the HVAC systems. That monitoring plan requires the measurement of air temperature and relative humidity before and after the cooling element and also the air flow rate in order to determine the amount of energy delivered to the air. Ideally such data is readily available from the BMS. Also, in order to understand the relationship between control signal produced by the BMS and the actual actuator (e.g. valve) steady state data at various operation points (e.g. various valve openings) needs to be recorded.

All models developed will be independently validated using data acquired at test-site: models will be simulated and the results compared to acquired data. The validation will be carried out utilising acceptance testing criteria required by international standards such as ASHRAE Guideline 14-2002 and the international performance measurement and verification protocol (IPMVP).

After the models will be validated with measured data, they can be considered a reference point for the development of the innovative controllers and of the management strategy and the new models that are being developed in Modelica will be part of a *District cooling open-source library* (DCOL).

Conclusions

The research project INDIGO, which is funded by the EU's Horizon 2020 research and innovation program, is developing solutions for the improvement of the district cooling systems.
In the context of that project energy modelling is an important activity. The detailed energy models that are being developed consider all the relevant parts of the district cooling system and of the demand side (the building, which needs the control of the indoor air temperature and, in some cases, of the indoor humidity ratio). The development of the model is a complex process that involves different phases: identification of the required data, research of the required data, monitoring, validation of the model.

In the development of the project the energy models are going to help in the development and in the evaluation of a predictive control system, of innovative management strategies, and of a new planning tool. The results of the research project could improve the design and the management of district cooling systems, in terms of efficiency, economic convenience, and environmental impact.

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Authors

Francesco PASSERINI holds a Doctoral degree from the University of Trento in Environmental Engineering with specialization in sustainable buildings. His research work focused on passive solar systems, the calculation of the building energy performance and the refurbishment of blocks of flats. He has dealt with sustainable buildings and energy modeling, both at the academic level and in the private sector. He is member of AICARR (Italian Association for HVAC systems) and of IBPSA-Italy (the Italian regional affiliate of the International Building Performance Simulation Association).
ORCID ID: 0000-0001-5147-1425

Raymond STERLING has a double degree in Electrical Engineering (2009) and Systems Engineering (2008) from the Central University of Venezuela and University of Rome "La Sapienza" respectively. In 2010, he successfully completed a postgraduate Masters of Science in Intelligent Systems in the University of Salamanca, with a dissertation on Neural Network Control of HVAC Systems. Between October 2010 and February 2011 he participated in the traineeship program of the European Commission, providing technical and logistic support to the "New Forms of Production" unit of the Industrial Technologies Directorate within the Research and Innovation Directorate General. He was awarded with a PhD in Civil Engineering for his work under the title: Self-Aware Buildings: An evaluation framework and implementation technologies for improving building operations, supervised by Dr. Marcus M. Keane. Raymond is currently a postdoctoral researcher in the College of Engineering and Informatics at NUI Galway.
ORCID ID: 0000-0001-9545-7908

Markus KEANE graduated from National University of Ireland Galway (NUIG) in 1988 with a first class honours degree in mechanical engineering. He completed his PhD at NUIG in 1994 focusing on the development of Computer Aided Learning Environments to support building energy simulation under the EU sponsored SAFE programme and the University of California Scholarship. He was awarded the John Murphy postdoctoral Research fellowship by UCC in 1992 with the remit of developing an undergraduate Environmental Building Services stream within the department of Civil & Environmental Engineering and the development of a research programme in informatics in building services. He was appointed college lecturer in the department of Civil & Environmental engineering in 1993 and promoted to Senior Lecturer in 2006. Dr. Keane established the Informatics Research Unit in Sustainable Engineering (IRUSE) in 2000 at the commencement of the HEA-PRTL2 funded Environmental Research Institute (ERI) programme. Dr. Keane has published over 25 peer reviewed papers relating to the "Green Building" project in the last seven years and obtained over 1.5Million in research funding in that same period. Dr. Keane has established strong research links with renowned universities in his field that include the University of California at Berkeley and Georgia Institute of Technology. Dr. Keane has research projects supported by funding agencies that include HEA PRTL programme, Sustainable Energy Ireland (SEI), Embark Initiative and Enterprise Ireland and Science Foundation Ireland (SFI).
ORCID ID: 0000-0002-6785-3484

Krzysztof KLOBUT, senior scientist, has 30 years of scientific experience in the field of heating systems, energy consumption in buildings, RES, district heating and residential applications of fuel cells. He was involved in a number of projects co-funded by EC FP5&6 (JOULE-PSI, EDIFICIO, SSHORT, BOILERNOISE), SAVE-programme (Boilsim, Indirect, Savelec) and IEA coordinated (ECBCS, Annexes 37 and 42). Recently he was involved in the following recently completed EC-funded projects: IDEAL EPBD (IEE), IntUBE (FP7) and AmI_MoSES (FP7). Currently he contributes to the following ongoing EU-projects: Ambassador, Design4Energy and Indigo. Mr. Klobut has authored or co-authored over 80 scientific publications.
ORCID ID: 0000-0002-5892-7066

Andrea COSTA is originally a graduate from the Politecnico di Milano. He pursued and was awarded a PhD in Civil Engineering from the National University of Ireland Galway (NUIG) with a PhD topic of providing support to the energy manager in improving the building operation strategy with considerations on building energy use and occupant comfort throughout the building lifecycle.
He is expert in building simulation with experience on an array of building energy simulation software and ISO 50001 certification tools.
After his PhD, he was awarded an industrially supported Postdoctoral Fellow co-funded by IRCSET (Irish Research Council for Science Engineering and Technology) as part of the Enterprise Ireland Partnership Scheme and D'Appolonia Spa in Italy. Andrea Costa brings with him a balance of field and research experience including FP7 projects for energy efficiency with targeted focus for office buildings, airports, sport facilities, and schools.
ORCID ID: 0000-0001-7849-0052

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TOWARDS SUSTAINABLE HISTORIC CITIES: ADAPTATION TO CLIMATE CHANGE RISKS[8]

Alessandra Gandini[1], Leire Garmendia[2], Rosa San Mateos[1]

[1]TECNALIA, Sustainable Construction Division, Parque Tecnológico de Bizkaia, c/ Geldo, 48160 Derio, Spain

[2]UPV/EHU, Department of Mechanical Engineering. c/Rafael Moreno Pitxitxi nº2, 48013 Bilbao, Spain

E-mails: alessandra.gandini@tecnalia.com; leire.garmendia@ehu.eus; rosa.sanmateos@tecnalia.com

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Abstract. During last decades, the international community has become aware of the need to adapt to the effects of climate change, as the sensitivity of natural and human systems gained relevance. Europe is one of the most urbanized regions, accounting for a 73% of people living in urban areas. This share, together with the increase of urban land take, has concentrated the fight against climate change in cities, which are considered as one of the most vulnerable areas.
European cities are characterised by a wide range of cultural heritage, which is commonly located in what is defined as the historic city. In order to protect urban heritage from a changing environment, emphasis should be given to the integration of conservation management and urban planning strategies, within wider goals of local sustainable development.
Historic cities have a great potential in contributing to local economy and enhancing investment climate. Modern conservation strategies need to address a balance between urban growth and quality of life in a sustainable way. They should match the interrelationships of existing building stock, spatial organization, natural characteristics and social, cultural and economic values. Furthermore, the need to address a new generation of strategies, adapted to new climatic scenarios, should be considered as a priority for an effective management of the whole city.
The proposed paper presents research results of the ADVICE project, based on a multiscale approach for the management of climate change impacts on cultural heritage located in the urban context. Vulnerability is addressed for different types of heritage, both at urban or building scale, considering their singularities as well as the context in which they are included. This will permit addressing the overall urban scale, together with data at structure level. Adaptive measures in general can be of a preventive character and improve resilience yet they can also offer preparative support when dealing with the anticipated effects of climate change and extreme events. In order to be effective, they need to be addressed according to the typology of object to be protected and to the scale of the impact or disaster they are facing.
Vulnerability mapping is one of the first steps in clarifying the challenges which climate change pose for a city and its stakeholders. Assessment of climate change impacts and vulnerability vary widely, depending on the subject, time frame, geographic coverage and purpose of the assessment. KPIs are therefore needed to address the overall as well as the specific vulnerability and exposure for risk scoring, in order to propose effective adaptive measures.
Information is supported by a data model for the creation of an evidence-based decision making platform, which will contribute to a more educated and data-driven decision making process. This will permit eliminating one of the barriers to the effective implementation of climate change adaptation strategies by cultural heritage managers and public authorities.

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Keywords: climate change, historic cities, cultural heritage, sustainable cities

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1. Introduction

During last decades, vulnerability of cities towards climate change has become evident and the need to adapt to new challenges gained relevance. In order to limit negative effects of climate change, mitigation - focused on the reduction of greenhouse gas emissions - has been addressed worldwide. Nevertheless, mitigation strategies have resulted as insufficient and major efforts are required. According to the IPCC, adaptation is a necessary strategy at all scales to complete climate change mitigation efforts.

Climate change has become an increasing urban problem, as the growth in population and urban land take contribute to cities' vulnerability (. Beyond physical risks, caused by increased incidence and intensity of extreme weather events, cities will have to face challenges related to specific socio-economic and cultural conditions. The impact on historic cities, which are already facing major functional, environmental and socio-economic problems (e.g. ageing, physical and functional obsolescence and lack of economic development), may lead to accelerated degradation or loss of cultural heritage. Cultural heritage, comprising its tangible and intangible components, constitutes a key resource for local communities and accounts for complex interactions which need be addressed in urban planning practices. Historic cities are required to respond to new needs by transforming themselves into resilient systems. Besides, conservation, which is based on the management of change, should consider the impacts of climate change as one of the most significant global challenges today.

In its communication "*An EU strategy on adaptation to climate change*" [1], the Commission recognizes the urgency for implementing adaptation measures to deal with climate impacts on vulnerable sectors, reaffirming the commitment to promote urban adaptation strategies. Cultural heritage, as a sensitive element in the urban context, needs specific tools and methodologies for its inclusion, as a fundamental feature, in the whole city climate adaptation strategy.

Climate change adaptation has broadened its concept, shifting from the management of the direct manifestation of climate change hazards, to risk-based approaches. These incorporate an assessment of vulnerability and capacity to adapt to hazards. Vulnerability assessment is often based on a large scale and buildings are not considered as part of the urban environment. Besides, conservation is often developed on the operational scale of a monument or site. Management of cultural heritage requires an urban approach which considers all the elements and buildings as part of the urban environment. This paper presents the results of a research integrating the operational as well as the urban scale, through the development of an iterative risk assessment method. Multilevel indicators (urban, building, element) have been developed, according to the procedure established by the IPCC, which considers hazard, vulnerability and exposure. The analysis, complemented by stakeholders' involvement, allows mapping the vulnerability to climate change hazards and developing complex adaptation strategies.

2. Climate change risks evaluation and impacts on cultural heritage

Risks on heritage sites are dependent on nature, specific characteristics, inherent vulnerability and geographical location.

In cultural heritage it is possible to differentiate two main typologies of risks: on the one hand, the ones considered as chronic, which produce a cumulative degradation. On the other hand, the ones usually known as catastrophic, which occur accidentally and generating severe damages which may lead to the loss of cultural heritage. As a consequence of climate change, both chronic and catastrophic events are increasing in frequency and intensity, leading to new or accelerated degradation mechanisms and increase in cultural heritage losses respectively.

Damages to cultural heritage have gone from being an extraordinary event to become a continuous threat. For this reason, heritage managers are forced to develop new mechanisms to provide an appropriate response to these challenges. The concept of cultural heritage has broadened considerably since the definition provided by the Venice Charter of 1964 [2]. Nowadays, it includes environmental and social factors and, its preservation, stands away from the past conservation practice as an end. In 1975, the Charter of Amsterdam [3] introduced the concept of "*integrated conservation*", stating that the conservation cannot simply be limited to the built context, but must include protective measures, modification or implementation of uses and activities that take place within the built physical environment. Furthermore, the UNESCO Declaration of Hangzhou of 2013 [4] states that "*culture, in its manifold expressions ranging from cultural heritage to cultural and creative industries and cultural tourism, is both an enabler and a driver of the economic, social and environmental dimensions of sustainable development*". Conservation has traditionally been dealing with deterioration mechanisms related to materials and works of art, but has rarely been applied to the establishment of preventive interventions related to climate change. Nevertheless, the increasing number of extreme events is already affecting cultural heritage.

Integrated urban development has become increasingly important in many Member States, principally as a consequence of the adoption of the Leipzig Charter on Sustainable European Cities in 2007. The charter declares that "*all dimensions of sustainable development should be taken into account at the same time and with the same weight. These include economic prosperity, social balance and a healthy environment. A holistic approach is essential in order to reveal the potential of European cities in terms of cultural and architectural qualities, social integration and economic development*". Given that cultural urban heritage is associated with physical systems and human communities, the priority for an effective management of the whole city is to develop a new generation of strategies that provide mechanisms for balancing conservation and sustainability in the context of a changing environment.

The following table shows how climate change and related hazards may impact on cultural heritage assets, structures and artefacts:

Table 1. Climate change and related hazards impacts on cultural heritage

Climate change effects	Risks	Impact related to cultural heritage	
• Increase in global temperature	• Heat waves and extreme temperatures • Coastal flooding (sea rise level) • Drought	• Social	• Progressive abandonment of urban areas and historic buildings due to temperature increase; evacuation of coastal urban areas due to soil erosion
		• Economic and/or environmental	• Decrease in tourism and related activities; energy demand increase; economic losses for heritage managers and/or insurance companies

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Climate change effects	Risks	Impact related to cultural heritage	
	• Temperature and humidity fluctuations and hygrothermal cycles increase	• Physical	• Material and structural decay (cracking, detachment, fungal growth, degradation of material and biogenic patinas…) and possible loss of cultural heritage
• Increase in intense precipitation events	• River or inland flooding • Landslide • Extreme precipitation (rain and snow) and cold waves • Increase in humidity atmospheric level	• Social	• Evacuation; loss of identity and common values; progressive abandonment historic buildings due to poor comfort parameters
		• Economic and/or environmental	• Economic losses for heritage managers and/or insurance companies; energy demand increase
		• Physical	• Material decay (fungal growth, degradation of material, biogenic patinas and deterioration of movable heritage). Partial damage or destruction of cultural heritage structures and artefacts; structural damages due to increase in loads (snow...)
• Increase in the number of extreme storm events	• Intense gust of wind	• Social	• Evacuation. Loss of identity and common values
		• Economic	• Economic losses for heritage managers and/or insurance companies
		• Cultural	• Partial damage or destruction of cultural heritage structures and artefacts

Source: Tecnalia (2014)

In order to build a common analytical framework and link different disciplines, research has applied the adaptation planning concept (Effects-Vulnerability-Adaptation-Implementation (EVAI) model). It started from exploring the expected impacts of climate change on cultural heritage, including chronic degradation mechanisms but also the increased risk of extreme events and hazards. It continued with an assessment of the vulnerability of heritage within the urban context and followed with the consideration of relevant and applicable adaptation solutions and the conditions for their implementation. The use of common frameworks is needed to understand the nature and scope of these challenges, to identify problem drivers and their interconnections.

Many approaches related to the conservation of cultural heritage are still linked to geographically limited sites or to a group of properties. Cultural heritage sites are seen as belonging to the past, disconnected from the present and from each other. Nevertheless, urban heritage is a living and dynamic part of the city, an element of the overall urban setting. Modern conservation strategies need to find a balance between urban growth and quality of life in a sustainable way, matching the interrelationships of building stock, spatial organization, natural characteristics and social, cultural and economic values. In order to support the protection of urban heritage in a constantly changing environment, emphasis should be given to the integration of conservation management within wider goals of overall local sustainable development.

In order to provide integrated urban governance dynamics and identify key values in urban areas, a multidisciplinary approach involving different cross-section stakeholders and decision makers is needed. Furthermore, the uncertainty about the severity and timing of climate change impacts requires an iterative risk management process, involving different skills and knowledge, in a complex decision making scenario.

The assessment of climate change impacts, vulnerability and adaptation has been addressed according the risk management process, which involves exploring, making and acting on decisions under conditions of uncertainty. Decisions in relation to climate change cannot be static, but should be based on an iterative process, learning from and taking advantage of new information, for the inclusion of corrections. The ADVICE project considers, as part of the methodological framework for climate change assessment, the iterative risk management process proposed by the IPCC [5]:

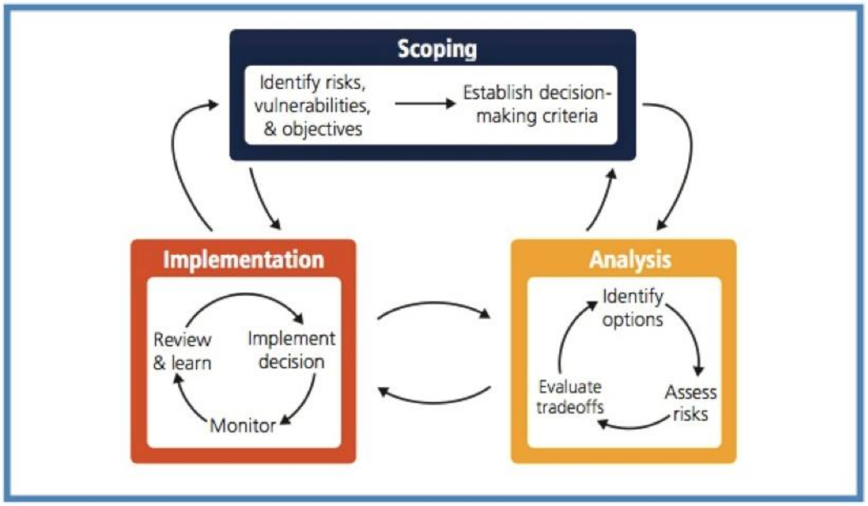

Fig.1. Climate-change adaptation as an iterative risk management process

Source: IPCC (2014) AR5, WG-II

3. Methodology for risk assessment in historic cities

The IPCC highlights several representative key risks for each region, assessed according to three timeframes scenarios. It identifies, in each region, the current existence of adaptation deficits as well as the future potential for adaptation and limits to adaptation. Research activities described in this paper, focus on hazards and impacts identified as critical for Europe:

- Temperature variations: in Europe, there will be a marked increase in extreme temperatures. Projections confirm an increase in the frequency of warm days and night, duration of heat waves and the decrease in the frequency of cold days and night. Daily and seasonal variations of temperature directly affect cultural heritage as freezing-thawing cycles induce thermal stress, accelerate degradation and mechanical damage to materials, reducing their lifetime. This effect will also have consequences on relative humidity variations, which can lead to an increase of several degradation mechanisms, such as efflorescences or biodeterioration. Heat and cold waves will also intensify the use of air-conditioning and heating consumption, increasing the energetic demand.

- Precipitation and sea rise level: changes in extreme precipitation in Europe depend on the region. It is demonstrated that Northern and Continental Europe will register an increase, while in Southern Europe it will depend on regions and seasons. Extreme sea level events will increase, due to the global mean sea level increase, while storm surges will vary along coasts. Climate change is projected to affect the hydrology of river basins. According to these data, extreme precipitation and sea rise level can be directly related to hazards, such as coastal, river and pluvial flooding. Damages related to cultural heritage depend on the intensity of the hazard, as well as on the exposure and vulnerability, varying from moisture and humidity contents variations to flooding.

- Windstorms: Several studies project an overall increase in storm hazards, but variations in frequencies are large. Currently, there is lack of information on these types of events; nevertheless, structural damages in cultural heritage have to be addressed, as they can lead to significant losses.

In order to assess the vulnerability of cultural heritage towards these impacts, a set of indicators has been established. These were designed according to different typologies: quantitative and qualitative indicators, simple or compound indicators and indirect or "proxy" indicators. One of the determinant criteria was to build indicators on existing and available information, using open data at local level. The methodological framework was developed with the main premise of integrating cultural heritage within other existing approaches of adaptation planning, in order to strengthen the overall adaptive capacity of cities.
Indicators have been divided in different categories and respond to a specific hazard:

- **Exposure**: indicators evaluating if a system or element will face an impact or stress factor. They are designed to determine if a certain type of heritage, due to its location, can be threatened by climate change impacts or hazards.

- **Sensitivity or susceptibility to harm:** is the grade in which a system, sector or element is affected by the climatic changeability or extreme event, both in a positive and negative way.

- **Adaptive capacity**: capacity to cope and overtake the effects. Is the ability of systems to assume the potential effects of climate change, taking advantage of the opportunities or overtaking the consequences.

Risk assessment has been developed using the integrated value model for sustainable assessment (MIVES) [6,7], which is based on the establishment of a requirement tree, value functions and analytic hierarchy process (AHP) [8]. The tool can be used to compare variables with different units and taking into account the relative importance of the considered aspects.

With the objective of identifying the most vulnerable buildings to climate change impacts, the following requirement tree was developed:

Table 2. Requirement tree for historic buildings vulnerability

<table>
<tr><th>Requirement</th><th>Criteria</th><th>Sub-criteria</th><th>Indicator</th></tr>
<tr><td rowspan="10">• Sensitivity</td><td rowspan="10">• Built environment</td><td rowspan="5">• Building</td><td>• State of conservation</td></tr>
<tr><td>• Year of construction</td></tr>
<tr><td>• Basement, type of ground floor, expansion joints</td></tr>
<tr><td>• Use</td></tr>
<tr><td>• Cultural value</td></tr>
<tr><td rowspan="4">• Envelope</td><td>• Type of roof</td></tr>
<tr><td>• Material</td></tr>
<tr><td>• Colour</td></tr>
<tr><td>• Orientation</td></tr>
<tr><td>• Equipment</td><td>• Drainage system, shading systems</td></tr>
</table>

			• HVAC
		• Structure	• Foundations
			• Material
• Adaptive capacity	• Built environment		• Previous interventions
			• Emergency plans
			• Ordinary maintenance
	• Socioeconomic		• Number of dwellings
			• Older people
			• Economic situation
			• Vacancies
• Exposure	• Built environment		• Urbanisation
			• Risk tendency
			• Waterproof surface
			• Street width
			• Green areas
			• Proximity to river/coastal areas

Source: Tecnalia (2015)

Weights have been assigned starting from indicators [9], through the establishment of value functions based on mathematical elements, in order to identify the most or less vulnerable parameters. The value function has the objective of transforming an attribute to a comparable variable comprised between 0 and 1. Each indicator has its own value function assigned. Weights can be determined through AHP or through a direct scoring, by the use of a pairwise comparison, which establishes how much an element is important compared to another element. Subsequently, based on this assessment, weights are determined through the development of a matrix calculation. Criteria and requirements were also weighted through AHP, relating indicators under the same criteria and criteria under the same requirement. Indicators will be included in an urban data model to facilitate the visualization of most vulnerable areas. The risk assessment methodology is used to prioritise interventions and to define the most suitable adaptive solution for the historic building urban stock. At this moment, the research project is focused on the validation of the risk assessment methodology by means of statistical methods, which will allow verifying the adequate selection of indicators and the robustness of the methodology.

Conclusions

This paper focuses on the research project ADVICE (Infrastructure and buildings adaptation to climate change), funded by the Basque Government. As part of an integrated risk assessment methodology, specific indicators to evaluate the vulnerability of historic buildings have been addressed. The MIVES model has been identified as the most appropriate for this kind of decision-making process, which involves different backgrounds and skills of stakeholders. Fine-tuning of the methodology still need to be addresses by the use of statistical analysis. Data in historic cities are complex and involve a large amount of variables. For this reason, the methodology is accompanied by a 3D data model, based on CityGML, for a proper and friendly data management. Risk assessment should consider also the integration of simulation tools which might enrich the information used, especially in the selection of adaptive solutions. The use of a holistic model, capable of integrating all this information will be addressed in further research, in order to guarantee its success in several historic cities.

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Authors

Alessandra GANDINI Architect by the Polytechnic of Milan (2006) with a master degree in Project Management (2011) at the University of the Basque Country (UPV/EHU). PhD candidate on risks management in historic cities (UPV/EHU). Since 2008 she works as Project Manager in the Rehabilitation and Urban Regeneration area within the Sustainable Construction Division of Tecnalia, focusing on the sustainable conservation of historic buildings and districts, dealing with management and planning, risks assessment, materials decay and energy efficiency. She has participated and managed several European and International cooperation projects. Previously, she has worked for Prof. Marco Dezzi Bardeschi and the 3rd International Exhibition on Monuments Restoration, promoted by ICOMOS.
ORCID ID: 0000-0001-5872-5774

Leire GARMENDIA PhD (2010), MSc on Advanced Materials (2009), BSc (2006) in Engineering at the University of the Basque Country. She works as a Senior Researcher in Integral Rehabilitation and Urban Regeneration area, within the Sustainable Construction Division of Tecnalia since 2006. She has been involved in several projects in the field of structural pathology, assessment and rehabilitation of structures. She is Assistant Professor at the University of the Basque Country and author of several papers. She is an active member of RILEM TC 250 Composites for sustainable strengthening of masonry, Spanish Normalization Technical Committee 140 for Concrete Structures and CEN TC 319 Structures Maintenance WG12.
ORCID ID: 0000-0002-3363-1015

Rosa SAN MATEOS BSc (2000) in Engineering at the University of the Basque Country. . She works as a Senior Researcher in Integral Rehabilitation and Urban Regeneration area, within the Sustainable Construction Division of Tecnalia since 2001. She has been involved as researcher and manager of several research projects in the field of building and structural pathologies and vulnerability analysis. She has experience in structural monitoring and diagnosis in cultural heritage, including the development of finite elements models for masonry structures.
ORCID ID: 0000-0002-6354-4465

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TOWARDS SMARTER AND MORE SUSTAINABLE CITIES: THE REMOURBAN MODEL[9]

Miguel Á. García-Fuentes[1], Cristina de Torre[2]

[1,2] Fundación CARTIF, Parque Tecnológico de Boecillo 205, Valladolid, Spain

E-mails: [1] miggar@cartif.es; [2]critor@cartif.es

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Abstract. REMOURBAN is an European project whose main objective is the development and validation in three lighthouse cities (Valladolid-Spain, Nottingham-UK and Tepebasi/Eskisehir-Turkey) of a sustainable urban regeneration model that leverages the convergence area of the energy, mobility and ICT sectors in order to accelerate the deployment of innovative technologies, organizational and economic solutions to significantly increase resource and energy efficiency, improve the sustainability of urban transport and drastically reduce greenhouse gas emissions in urban areas.
For developing this model, REMOURBAN is implementing several strategies at city level based on: the creation of a holistic catalogue of innovative technologies and solutions on energy, mobility and ICTs favouring the replicability, the identification and overcome of non-technical barriers, the development of new integrated business models oriented at the creation of a European market for innovation and the definition of a complete evaluation procedure using sustainability and smartness indicators.
This urban renovation strategy is focused on the citizens, where they become the cornerstones to making a smart city a reality For this reason, citizens are being actively engaged in REMOURBAN and the population awareness about energy and environmental impact of their daily activities are increased.
In order to ensure the usefulness and high replication of the REMOURBAN project at European level, the sustainable urban regeneration model is aimed at the decision makers, investors, public administrations and the industrial sector. Furthermore, in order to ensure this replicability, two follower cities, Seraing (Belgium) and Miskolc (Hungary) are involved in the project so they can apply the developed model once it is validated. The project will allow demonstrating that, by means of improving the current conditions of a city, it is possible to achieve low energy districts and more sustainable urban transport, as well as to perceive a greater quality of life. REMOURBAN, thus, will focus on improving the energy efficiency, reduction of GHG emissions, refurbishment of districts, transport sustainability, access to urban information and citizen engagement.

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A big impact across Europe is intended to be achieved by the REMOURBAN project results at European level, showing the model for sustainable urban regeneration can be easily applied and replicated. With the aim at maximizing the impact of the project results, REMOURBAN is deploying a powerful communication and dissemination plan that integrates a citizen engagement strategy and has started to disseminate the benefits of the project to a wide variety of audiences.

Keywords: Smart city, regeneration, replicability, energy efficiency, mobility

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JEL Classifications R11, R41, R51
Additional disciplines: urban planning, architecture, environmental engineering.

1. Introduction

REMOURBAN is a large-scale demonstration project, whose purpose is to accelerate the urban transformation towards the smart city concept taking into account all aspects of sustainability. Energy, transport and ICT sectors are essential for the day-to-day of the city. These sectors are widely considered as potentially appropriate to achieve economic and societal benefits, becoming a key towards improving the quality of life of the citizens, and representing most of the interrelations between people and technology. A big challenge to offer new interdisciplinary opportunities to strengthen the potential to become smarter and more sustainable cities is still open in the common area where energy production, distribution and use; mobility and transport; and information and communication technologies work together.

To deal with these challenges, Sustainable Urban Regeneration Models are needed, defining an integrated and holistic process to transform the city ecosystem with a jointly focus in the fields of sustainable buildings and districts, sustainable urban mobility, and integrated infrastructures and processes. This is where REMOURBAN is working to provide a replicable model which delivers solutions in both technical and non-technical related fields addressing the temporal goals, the main Smart City enablers within the transformation process –towards a more sustainable and smarter environment–, and innovations in the priority actions of energy, mobility and ICTs.

This urban regeneration model will be developed and validated in three lighthouse cities (Valladolid-Spain, Nottingham-UK and Tepebasi/Eskisehir-Turkey) accelerating the deployment of innovative technologies, organisational and economic solutions to significantly increase resource and energy efficiency, improve the sustainability of urban transport and drastically reduce greenhouse gas emissions.

Besides the lighthouse cities, two cities are involved in the project with the role of follower, Serajng in Belgium and Miskolc in Hungary. These cities allow increasing the European dimension of the project and its replication potential. In order to achieve this objective, a methodology for the replication of this urban regeneration model is being developed from the three main lighthouses to the follower cities and from there, to any other city in Europe, as a holistic strategy for city transformation and planning, integrating all the existing strategies for energy, mobility, ICTs and citizen engagement.

2. An Integrated Urban Regeneration Model

The main goal in REMOURBAN is to provide a Sustainable Urban Regeneration Model that defines a holistic process for urban transformation with a jointly approach in the fields of Sustainable Buildings and Districts, Sustainable Urban Mobility, and Integrated Infrastructures and Process. This model provides solutions in both technical and non-technical fields addressing the temporal goals, the main Smart City enablers within the transformation process –towards a more sustainable and smarter environment– and innovations in the priority actions of energy, mobility and ICTs. The Urban Regeneration model covers the four main phases of the city transformation process, which are linked to the specific actions and the Smart City enablers, being:

- **City audit** is the first phase of this model, aiming at implementing a set of integrated existing methods and tools that can support the evaluation of the current conditions of the cities in which the Sustainable Urban Regeneration Model will be implemented.

- **Actions design**. The objective of this second phase is the definition of the specific interventions or actions that will be undertaken in the city. After the analysis of the information collected in the first phase, it will be proposed a solution according with the expectations about energy savings and costs. This is a decision-making process.

- **Implementation.** The actions designed in the second phase will be implemented and commissioned, covering all fields involved in this urban transformation. In this phase, the deployment of the monitoring program will be key to allow gather the necessary information for assessing the impact of the intervention in the following phase.

- **Assessment.** This last phase is in charge of assessing the impact of the interventions following evaluation protocols and using the information gathered during the implementation phase. For this evaluation, the most appropriate KPIs will be selected in order to assess the sustainability and the smartness and some specific parameters as the energy consumption, CO_2 emissions reduction, reduction of the journey delays, even the social acceptance of the final users and citizens.

The toolkit of solutions and methods needed to transform cities into smarter and more sustainable ecosystems, and integrated through a Sustainable Urban Regeneration Model, is designed with the capability to be adapted and implemented in a wide range of European Cities, focusing on their specific goals and targets, and the boundary conditions that characterize their environment.

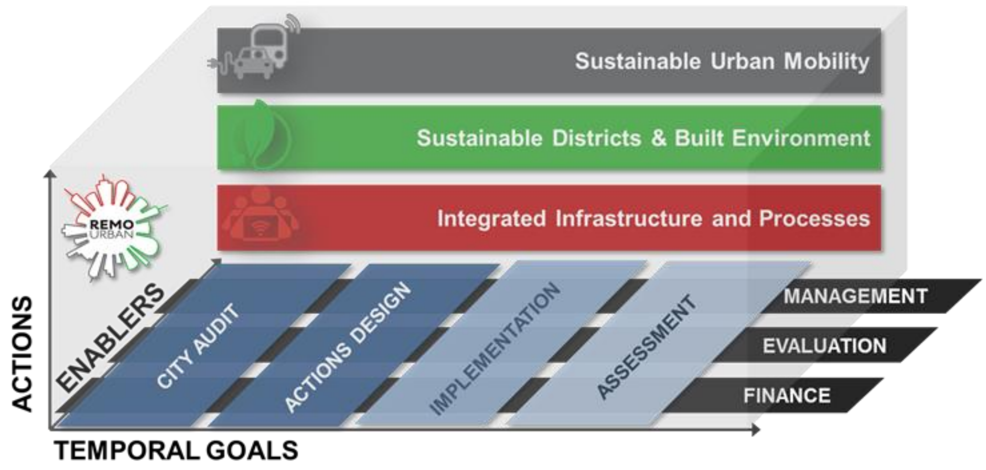

Fig.1. Sustainable Urban Regeneration Model

Source: prepared by the authors

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Urban Transformation actions: addressing energy, mobility and infrastructures challenges

To ensure city transformation is holistic, it is necessary designing multi-sectorial actions that allows achieve more ambitious goals. Most opportunities for city transformation are in energy, mobility and ICT sectors. In fact, it is in the common zone in which these three sectors could act jointly where is possible to find relevant impact.

- **Urban districts and built environment.** Energy sector, considering the energy supply, distribution and use (mainly in buildings) is a sector with a big impact in city sustainability. A set of actions focused on increasing the overall energy efficiency of a residential district will be developed encompassing the retrofitting of a residential area towards a low energy district, the installation and connection of the heating and cooling systems to a centralized one with a high ratio of generation with renewable energy and the use of advances building energy management systems to automatically monitor and control the main facilities, devices and services at district level.

- **Urban transport.** Taking into account the mobility sector has a very important impact on quality of life, some sustainability mobility actions will be carried out in order to create a new culture of urban transport. In this field, the use of cleaner vehicles will be promoted and clean power for transport will be improved using electric or hybrid vehicles and charging infrastructure. The logistics supply chain inside cities (last mile delivery) will be enhanced and alliances that use open data will be supported to ease the deployment of demand-responsive and integrated mobility services which help minimize energy consumption.

- **Integrated infrastructures and processes**. By taking advantage from the ICT sector that is fully integrated in cities, a platform to integrate information and deploying added value services for the grid management and traffic systems will be deployed. ICT sector will enable the deployment of integration strategies of the urban infrastructures with a variety of targets, for instance empowering people to interact with infrastructures, enabling people to become a sensor within overall city infrastructure systems through mobile devices as ubiquitous means, enabling business cases based on the integration of a city's network infrastructures.
  In the project, each city will use its own Local ICT platform with the main goal of monitoring all the devices exiting in the city for the project and a Global ICT platform will be used to consolidate the data from these local ICT platforms. Due to the key goal of the REMOURBAN project being its replicability to other cities, a platform with a common model is needed which defines and manages a set of parameters and indicators for assessing the success of the project. This platform is the city integrated infrastructure and this city integrated infrastructure will be created and deployed in the Global ICT platform.

Urban transformation enablers: managing, evaluating and financing the Smart City

- **Management framework for the urban regeneration.** It is necessary to optimise the current regulatory framework developing new forms of smart city policies and regulation or optimizing of the existing documents. Moreover, a strategy will be developed for innovative public procurement procedures.
  Aspects such as human and social capital, equity, diversity, accessibility, safety, health or quality of housing and the built environment will be taken into account. These will be considered when defining city transformation strategies and designing specific actions, as well as when assessing the achievement of goals at the end of the process. Development of new strategies for favouring the transition to Smart Cities, integrating existing urban plans and redefine them in a common and unique sustainable urban plan (mobility, energy, ICT,..), that would implement a holistic strategy with the objective to transform the city and to make it smarter.

- **Evaluating the urban regeneration**. An evaluation framework is defined in order to assess the sustainability and smartness of demonstration cities involved in the project. This framework allows estimating the effect of the urban regeneration model and the intervention plans for the demonstration cities. Monitoring and evaluation procedures allow quantifying the actual impact of the renovations in order to reduce investment risks, improve the benefits perception and favor the replicability.

- **Financing the urban regeneration.** Understanding the current status of the city economic ecosystem is essential to define find out suitable economic models for the city transformation, in which a combination of innovative schemes of Public Private Partnerships can be drivers for the implementation of the model. Smart Cities require large amounts of investment to be realised and capital invested in this sector will likely grow every year for decades. Several financial instruments are necessary in order to support these investments. Some financial schemes are already available to stimulate investments in smart cities and, more generally, energy efficiency projects. In this field, innovative financial schemes and business plans for each of the pillars of the project will be developed in order to get that most of the possible interventions can be feasible.

3. Validation of the urban regeneration model

The Urban Regeneration Model is being validated in two phases, consisting the first one consists in a large scale demonstration strategy of the potential that the proposed model offers for urban regeneration to deploy integral actions in the areas where energy, mobility and ICT sectors are intimately linked. In particular, the retrofitting of an existing district for reducing energy demand to very low values, improving the generation facilities and the supply of energy for a better use of the local resources (use of renewables) and higher efficiency (use of district scale systems), in order to achieve low energy districts (renewable district heating and cooling, PV, CHP, …), substitute a high number of conventional vehicles by clean vehicles, improving in parallel the associated infrastructures and the management (for instance electrical vehicles and charging infrastructure) and finally improving through ICT solutions the management of some of the city infrastructures, as the smart grids or the traffic management systems. Moreover, a financial and feasibility plan has been developed in order to guarantee the investments and the return of them. The lighthouse cities also commit the deployment of a powerful monitoring system, in order to gather the necessary variables for the evaluation procedure that is being designed. Further that the technical actions, these interventions will include a relevant citizen engagement activity for maximizing the impact and achieve a wider validation.

The second phase consists in ensuring the model replicability. REMOURBAN has involved from the very beginning other two cities as followers, Seraing and Miskolc, whose mission is twofold: they will ensure that a greater number of use cases are represented in the designing phase, and that the model is properly developed and it is usable even to address some very specific aspects of the cities.

4. Large scale demonstration in three lighthouse cities

The deployment and validation of the sustainable urban regeneration model is being carried out through three large scale demonstrations in the aforementioned three lighthouse cities, which are committed to deploy very ambitious holistic interventions, well balanced in terms of actions on energy, mobility and ICTs, that will be fully monitored and properly assessed.

The first demonstration is being carried out in Valladolid (309,000 inhabitants), a medium-size city located in Spain. The demonstration aims at the reduction of 50% of the energy consumed and 80% of the CO_2 emissions, and involves actively more than 5,700 citizens. The demonstration consists on the renovation of 398 dwellings (total 24,600 m^2), the implementation of renewable energy in the district heating system, the deployment of 45 electrical

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vehicles, 5 electrical buses and improvement of the charging infrastructure, as well as the development of a city information platform for energy demand management.

The second intervention is taking place at Nottingham (306,000 inhabitants), located in central UK. The target of energy consumption reduction is estimated to be 50%, achieving 26% of reduction in terms of CO_2 emissions. More than 8,100 citizens will be involved actively. The demonstration consists on a deep renovation of 624 dwelling (total 26,823 m^2), the deployment of 13 new electrical buses and the deployment of an e-Bus charging site, deploying a city information platform for traffic management.

The third intervention is located at Tepebasi (314,599 inhabitants), a municipality of the Eskisehir city, located in Turkey. The demonstration aims at the reduction of 85% in the energy consumption, and a 79% of the CO_2 emissions. At least 600 citizens will be directly involved in the demonstration, in which 57 dwellings (40,570 m^2) will be retrofitted, a district heating/cooling facility based on biomass will be installed, and 11 hybrid vehicles will be used, in addition to a 50 e-bike rental system. An ICT city management platform will be developed in order to put together all energy and mobility data.



		Lighthouse city	Valladolid (ES)	Nottingham (UK)	Tepebasi (TK)
		Energy savings	**50%**	**50%**	**59%**
		Emissions avoided	**80%**	**26%**	**63%**
		Citizens involved	**5,700**	**8,100**	**6,000**
LOW ENERGY DISTRICTS		**District scale retrofitting**	**24.700** m^2 district retrofitting **398** dwellings **1000** residents. **50%** energy savings	**28.318** m2 district retrofitting **411** dwellings **1600** residents **35%** energy savings	**9.110** m^2 district retrofitting **57** dwellings **60%** energy savings
LOW ENERGY DISTRICTS		**Renewable heating and cooling**	Biomass district heating	Connection with city scale district heating (**90%** renewables and waste heat)	WSHP for H&C and Biomass heating plant Solar thermal for DHW
LOW ENERGY DISTRICTS		**Electricity distributed generation**	PV panels on façade (**64 kWp**)	CHP PV panels on roof (**75 kWp)**	PV panel on roofs (**100 kWp**) Energy monitoring and control system
LOW ENERGY DISTRICTS		**Advanced BEMS at district level**	Advanced controlling of district heating and building comfort controllers	Advanced controlling of district heating and building comfort controllers	Energy monitoring and control system (automatic control, occupancy control, CO_2 sensors, comfort controllers)
LOW ENERGY DISTRICTS		**Monitoring tools for energy**	ICT platform for energy performance monitoring	Advanced monitoring including user behavior	Advanced monitoring and energy performance viewing ICT platform
SUSTAINABLE		**Improve clean power for transport: vehicles**	20 FEV taxis 3 e-Buses 2 FEV fleet 20 FEV private	NET* Tram 50 e-Buses existing 2 tourist link e-Buses	50 e-bikes 4 e-Buses & minibuses 7 EHV

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		Improve clean power for transport: infrastructure	Deployment of a new public charging infrastructure (up to 60 charging points)	Recharging burning city's waste 2 FC PV panels	15 e-bike charging stations 2 EV charging stations
		Foster seamless door-to-door multi-modality in urban transport	Ticketing system shared among users from buses, bicycles & car-sharing fleet	City-card tourist smartcard	Ticketing, Smartcard, Smart Debit Card
		Further clean logistics	5 FEV Last Mile of Delivery in CYLOG	Last mile delivery network 3 electrical vehicles	
		Open up intelligence in urban transport systems	Smart Phone App as an Aid to Mobility		Smart Phone App Mobility: Info. interface to bike system
		Promote use of cleaner vehicles	Free parking EV Taxes reduction Special lanes		Integrated bike rental system Free parking EV Kiosks for travel information
INTEGRATED INFRASTRUCTURES		**City Information Platform**	City Information Platform	Integrated Infrastructures City Model	Smart City Monitoring Portal
		Shared infrastructure planning	Access to district smart metering infrastructure	Access to district smart metering infrastructure	Energy data monitoring infrastructure access via SCMP
		Transforming the energy chain		Energy control at home (app)	Micro grid: renewables, storage, demand side management
		Road systems	Smart phone apps	Crowd-sourcing data connection (smart meter, traffic model)	
		Intelligent multi-modal transport solutions			Smart phone apps. (Info interface bike rental system, availability, location, social media promotion)
		P2P transport information	Car Sharing municipality fleet (Sustainable mobility priority area)		
		Adverse events			Link Smart Grid with Earthquake sensor for emergency scenarios
SMART CITY ENABLERS		**Tools for community insight and engagement**	REMOURBAN common citizen engagement strategy	REMOURBAN common citizen engagement strategy	REMOURBAN common citizen engagement strategy
		Social network regulation	Common commun. and exploit. strategy	Common commun. and exploit. strategy	Common commun. and exploit. strategy
		Stakeholder platform			Stakeholder platforms & protocols with municipalities, NGO's & associations.
		City visualisation		Real Time Integrated Infrastructure City Model	
		Smart city strategy and implementation plan	REMOURBAN common strategy for development of integrated urban plan	REMOURBAN common strategy for development of integrated urban plan	REMOURBAN common strategy for development of integrated urban plan

		**Innovative funding models**	Retrofitting of buildings adopts an innovative strategy for multi-owner property districts	Help private owners of retrofitted properties	
		**Smart energy map**		Create a real time energy map in the demo area.	
		**EU smart city indicator framework**	REMOURBAN common sustainable and smartness evaluation procedure	REMOURBAN common sustainable and smartness evaluation procedure	REMOURBAN common sustainable and smartness evaluation procedure

Fig.2. Technical and non-technical actions under implementation in the lighthouse cities

Source: prepared by the authors

5. Replicability plan

REMOURBAN aims at not only implementing this model in the three lighthouse cities where the main benefits and suitability of the model will be tested and demonstrate its replication potential and ability to be adapted to these different conditions. A first replication stage will be tested in the follower cities of Seraing (Belgium) and Miskolc (Hungary); but also a wider replicability plan to European Cities is being defined and will be validated.

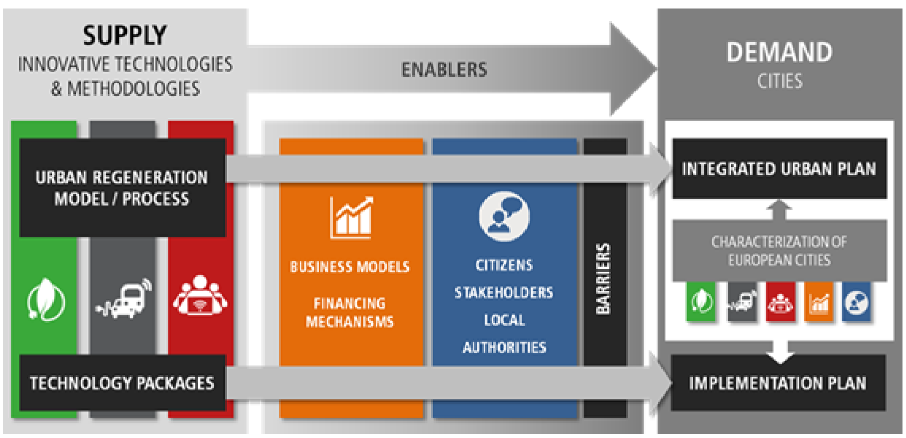

Fig.3. Overall replication strategy approach

Source: prepared by the authors

This replicability plan is based on the characterisation of the European Cities, and grouping of them into specific target areas according to a set of indicators in the main fields of work of this model. The analysis performed in the characterisation of European Cities represents the demand side for urban transformation strategies, it can be connected with the supply side which is able to provide the proper methods and processes, and technology packages to transform the city into a more sustainable and smarter ecosystem. For this, it has to be linked through the proper enablers that make possible its implementation, mainly focused on the finance and governance aspects which are able to lead the transformation approach. This necessarily needs to be accompanied by an in-deep analysis of the existing barriers that block the implementation of both the methods and technologies.

This replicability framework is dealing with this connection through integrating all the pieces of the Sustainable Urban Regeneration Model in a single approach, establishing two ways of linkage that lead to the definition of Integrated Urban Plans for the cities and the related Implementation Plans. Thus, the replication of methods and processes can lead to these strategic plans at city level which should establish the long-term approaches needed in the city to ensure the effectiveness of the transformation strategy, while the implementation of the technical solutions can catalyse the integrated city plan into real interventions leading to achieve the macro-level objectives.

6. Expected impact

The main challenge is to reduce the impact of the city daily activities of the citizens in the major indicators. These achievements can be summarized as follow:

- Reduction of the human activities impact in the cities at least 5%, in terms of CO_2/person·yr emissions and kWh/person·yr of energy consumption, by means of the achievement of the following partial objectives:
    - Reducing the building energy demand at least a 40%, with respect to the current consumption to implement zero emission facilities for thermal energy production and increase to a 30% the distributed electricity generation ratio. Increase the thermal and electrical energy distribution and use efficiency at least a 10%, through public and private investment with a return of the investment less than 15 years in the building retrofitting case and 5 years in case of energy supply interventions.
    - Increasing the low carbon mobility solutions a 5%, 25% at medium term (5 years). That means a reduction of CO_2 emissions of at least a 50%. Reduction, by means of improvements in the transport management (intermodality…) the average journey delay and door to door journey time a 10%.
- Increase the citizen awareness about the impact of their activities in the city, through an innovative strategy of citizen engagement, which will achieve a reduction of a 10% of the emissions and energy consumption per capita.

Conclusions

REMOURBAN project will allow demonstrating that, by means of improving the current conditions of a city, it is possible to achieve low energy districts and more sustainable urban transport, as well as to perceive a greater quality of life. REMOURBAN, thus, will focus on improving the energy efficiency, reduction of GHG emissions, refurbishment of districts, transport sustainability, access to urban information and citizen engagement.

A big impact across Europe will be achieved by the REMOURBAN project results at European level, showing the model for sustainable urban regeneration can be easily applied and replicated. With the aim at maximizing the impact of the project results, REMOURBAN is deploying a powerful communication and dissemination plan that integrates a citizen engagement strategy and disseminates the benefits of the project to a wide variety of audiences. In addition, several exploitation and market deployment strategies will support the commercial exploitation of the sustainable urban regeneration model and other project outcomes.

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Authors:

Miguel Á. GARCÍA-FUENTES. B.Arch. (2010) and MSc Arch. (2012), from the Valladolid University (Spain). Working as European Projects' Coordinator at the Energy Division of CARTIF Technology Centre in European RTD Projects in the framework of Smart Cities and Nearly Zero Energy Cities, he currently coordinates REMOURBAN and OptEEmAL EU-H2020 funded projects. He has contributed to various national and international relevant congresses related to sustainability and energy efficiency in building. Recently, he has been appointed as member of the Special Interest Group (Advisory Council) of the FP7 funded project OPTIMUS and as member of the Technical Committee for the 3rd Spanish Congress on NZEB.
ORCID ID: orcid.org/0000-0001-6739-599X

Cristina DE TORRE. Industrial Engineer (2006) and MSc. Eng. in Energy Engineering (2010), both from the University of Valladolid (Spain). Working as researcher and Head of Projects at CARTIF's Energy Division. Along her work career at CARTIF, she has been involved on many National and European Projects linked mainly on integration of renewable energies in buildings, energy performance simulation, buildings energy refurbishment, energy audit, monitoring and control of solar thermal heating and cooling installations and low energy buildings. She has contributed to different congresses of national and international relevance related to renewable energies and energy efficiency.
ORCID ID: orcid.org/0000-0002-7609-5099

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TOWARDS SUSTAINABLE WATER NETWORKS: AUTOMATED FAULT DETECTION AND DIAGNOSIS[10]

Domenico Perfido[1], Massimiliano Raciti[1], Chiara Zanotti[2], Niall Chambers[3-4], Louise Hannon[3-4], Marcus Keane[3-4], Eoghan Clifford[3-4] , Andrea Costa[1]

[1] *R2M Solution s.r.l., Via F.lli Cuzio 42, 27100 Pavia, Italy*

[2] *Università degli Studi Milano Bicocca – DISAT - Milano, Italy*

[3] *IRUSE, Informatics Research Unit for Sustainable Engineering (NUI) Galway, Ireland*

[4] *Civil Engineering, College of Engineering & Informatics, NUI Galway, Ireland*

E-mail: domenico.perfido@r2msolution.com

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Abstract. The paper will present an overview of one of the Fault Detection and Diagnosis (FDD) systems developed within the Waternomics project. The FDD system has been developed basing on the hydraulic modeling of the water network, the real time values of flow and pressure obtained from installation of innovative ICT and commercial smart meters and the application of the Anomaly Detection with fast Incremental ClustEring (ADWICE) algorithm adapted for the drinking water network. The FDD system developed is useful when we have to consider more than one parameter at the same time to determine if an anomaly or fault is in place in a complex water network and the system is designed on purpose to cope with a larger features set. The new FDD system will be implemented in an Italian demo site, the Linate Airport Water network in Milan, where a large water distribution network is in place and where, due the many variables coming into play, it could be very difficult to detect anomalies with a low false alarm rate.

Keywords: FDD, Water network, Anomalies detection, Leakages, ADWICE

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JEL Classification: O32
Additional disciplines: environmental engineering, ecology

1. Introduction

In many water distribution systems, a significant amount of water is lost due to leakage from distribution pipes. The problem of leaks in water distribution systems has generated significant interest due to the financial cost borne by utilities, potential risks to public health and environmental burden associated with wasted energy. In recent years, such concerns have led to the introduction of stricter penalties against water authorities for ignoring leakage and have provided the necessary incentives for the investment in better leak detection technology and enhanced leak reduction strategies.

Leak detection methods are broadly classified in terms of internal and external monitoring methods: internal methods involving intrusive measurements to monitor fluid state, and externa1 methods applied to the environmental condition of a pipe. Pipelines are designed and engineered for full load operations assuming steady state flow conditions. Operational parameters will range from maximum allowable operating pressure in exceptional circumstances to a depressurized state corresponding to a no-flow situation. Normal pipeline operations may involve day-to-day transients such as pump start/stop operations, the operation of control valuing and changes in delivery rates. Internal leak detection system must therefore operate over wide range of process conditions, some of which may appear to have the characteristic of leak patterns.

The basic problem of leak detection is to distinguish between the normal operational transients and the occurrence of non-typical process conditions that would indicate a leak. Whereas steady state can be achieved for many pipeline operations, in general it is assumed that most pipelines undergo continual transient changes. In addition, hydraulic noise and instrument noise are characteristic of normal operation, forming a background base threshold to discrimination of any unusual event. The characteristic of a leak is that the pressure profile in the pipeline becomes distorted, flow rate curve plotted against distance exhibits a step discontinuity whereas the pressure profile exhibits cusp. These pressure and flow variations can be sensed to indicate that a significant event has occurred. The efficiency of a leak detection system in recognizing a leak, locating it and estimating the size of a leak depends on factors such as: (i) location of sensors, (ii) accuracy of sensors, (iii) size of leak.

A fault is a malfunction of a system component, which ultimately leads to a decline in the system’s intended performance and/or efficiency. The Fault Detection Diagnosis (FDD) systems aim to recognize, locate and quantify faults: the Detection is the recognition of when and where there is a fault present in the system. Diagnosis is the act of isolating the location and nature of the fault to the extent that it can be rectified, so as to restore the effected system’s performance to its intended level. To implement FDD to a system, at the very minimum, the full extent of a system’s operational capacities must be understood and information from a system must be received so that its state/operation can be characterised at any one time. The desired attributes of an FDD system include the following:

- Early Detection and Diagnosis: the longer that a fault persists, the greater the cumulative effect of the associated inefficiency’s. More importantly, the more time that a systems fault goes undetected and undiagnosed, the more likely it is to develop into a component failure which could lead to economic loss and potential human injury/fatality. Timely identification and rectification is key.
- Fault Segregation: this is the ability of an FDD system identify the offending component and to distinguish the faulty part from others. Ambiguous fault reports lead to chaotic maintenance procedures.
- Fault Characterisation: this is to estimate the severity, type or nature of a fault. To fix a fault, the exact issue with the component must be known.
- Robustness: expected variability of the system leads to uncertainty in the fault detection. A fault detection algorithm able to handle uncertainty is called robust and its robustness is the degree of sensitivity to faults compared to the degree of sensitivity to uncertainty.

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- Adaptability: a useful FDD system can be applied to multiple machines and systems of the same genre, without the need for a completely new set up and reprogramming.

Various FDD methods are applied to different systems, based on the nature of the system and requirements of the FDD. The different groups of approaches may be defined in many ways, as has been done in (Bruton et al. 2013; Katipamula, and Brambley 2005; Venkatasubramanian et al. 2003). A synthesis of the different classification schemes is presented herein (Figure 1). On the limits of the fundamental FDD classification continuum, there is:

- Empirical (a priori) reasoning, which will draws conclusions about how a system should operate under different conditions based entirely on models formulated from first principal theory (laws of conservation, Newtonian mechanics, thermodynamics, etc.)
- Analytical (posteriori) reasoning, which will draw conclusions about how a system should operate under different conditions based entirely on models formulated from historical measurement data. (Katipamula, and Brambley 2005)

Katipamula and Brambley, defined the following classification scheme for FDD methods:

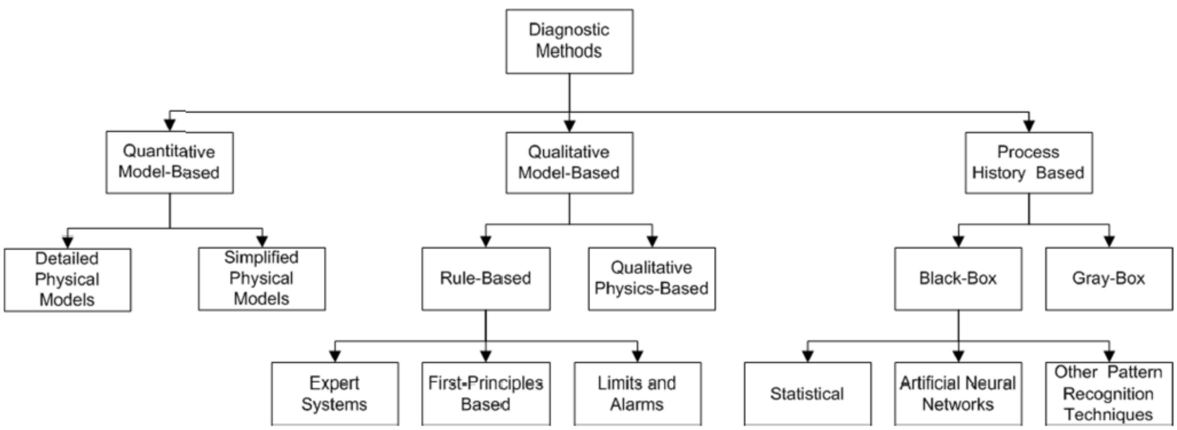

Fig. 1. FDD Classification (Katipamula and Brambley, 2005)

In accordance with this structure, a Quantitative Model-Based system in the form of a Detailed Physical Model detailed in Section 3.3 and Qualitative Model-Based system in the form of a rule-based, limits and alarms approach are developed as case studies for the Waternomics Project. Some of the fundamental logic underlying FDD common approaches are (i) Rule Based FDD, (ii) Data Driven FDD and (iii) Law Driven FDD. These are further explained in Table 1.

Table 1. Different FDD methods

Rule Based FDD	This method utilises elementary logic applied to a system to decide whether it is operating as designed or not. Basic, binary on-off principles provide a simple example of an FDD rule. If a whole system (a water boiler) is turned on, but an integral component (the water pump) is turned off, then a fault is present and the system's operation is impaired. It is the most basic form of FDD and will be utilized first in most systems due to the high resource savings ratio/investment.
Data Driven FDD	Sensors are applied to the various components of a system to measure various operating properties e.g. temperature, air flow rate, humidity etc. Statistical models will be developed over time, while the system is running fault free, to develop a baseline for how the system should operate in various conditions. This model is then compared to the actual (real time) operation of the system and checked for abnormalities. Variances from its modelled optimal operation then indicate a fault. An example would be emissions from a car. From observing how the emissions change with different variables (car speed, acceleration, and load), the FDD platform can compare expected emissions with actual emissions and suggest a fault if the expected and actual emissions differ. Data driven FDD is also known as *backward modelling* as it uses historical data from the system to recall the intended operation.
Law Driven FDD	This applies physical laws to the system to forecast its operation under a given set of conditions. A model of the system will be developed through computer programming. Limited operational data of the system is required, but extensive knowledge of the system and its laws is essential. In the example of an air-conditioning system, laws of thermodynamics and Newtonian equations are used to predict the optimal running of the system. Similarly to the Data Driven models, if the characteristics of the day to day running vary from its predicted operation then a malfunction is likely. Law driven FDD is also known as forward modelling as it uses laws to project the intended operation.

The various groups of FDD which can be applied have inherent strengths and weaknesses in comparison to each other, and thus make them more suitable to certain systems than others. With regard to Rule Based FDD, its strengths reside in the fact that it is the simplest to develop and deploy and that its reasoning is fundamental and transparent, so that can be understood easily. Its weaknesses include that the rules created for a system will be very specific and so they will not be transferrable as well as that it is difficult to ensure that all rules are always applicable and to find a complete set of rules. Rule based FDD is best suited to simple, non-critical processes that require a cheaper FDD solution. Model based methods are attractive when the system does not have well developed theory for observed performance and when training data is plentiful and inexpensive to collect. Its deficiencies stem from the fact that large amounts of data are required and that sometimes this training data can contain hidden faulty states which compromise the validity of the models created. Model based FDD is most applicable to systems which are not suited to rules and that have recognisable patterns in their operation. Law based approaches main proficiency is that the models developed are based on sound physical and engineering principals. As a result of this, they can provide the most accurate estimators for output when they are well formulated. However, they can be very complex to develop and computationally expensive. The time investment to create them is also significant. They are most applicable for complex systems which have critical failure consequences. This paper presents the model based FDD approach adepted in the Waternomics project and the initial results obtained with it.

2. The model based FDD methodology introduced by the Waternomics project

The need for an efficient Water Management System is strongly highlighted by Water utilities, Municipalities and in general by Corporates that have to face every day with problems dealing with water usage and supply. So it is essential to develop an automated system to implement the fault detection in the water network at an early stage in order achieve a more sustainable water management by avoiding the waste of natural resources and the consequent economical losses.Whichever water network we consider "the leakages exist; and they have to be localized and measured" and solved (B. Brunone, 2008). This problem is more relevant when large water networks are considered. In this case many variables come into play and it is very difficult to detect anomalies or faults in the system especially when faults are not major issues concentrated in one place and not not necessarily affect the service level of the network (e.g main pipes breakdown). The Linate airport water network represent one of the above mentioned cases (large network comparable to a small city), and the innovative approach proposed here is based on the combined use of an hydraulic model simulation with an FDD algorithm (ADWICE - Anomaly Detection With fast Incremental ClustEring) to detect anomalies in the operational phase of the water network. The objective of the novel FDD proposed in the Waternomics project is to create and automated FDD suitable for large water network. In doing so the Linate pilot water network has been chosen to test the method. The methodology here proposed is based on the construction of an hydraulic model by using the EPANET software, distributed as open source by EPA – US Environmental Protection Agency, which describe the behaviour of the water network in a normal scenario (without leakages). Outputs (pressure and flow) of this hydraulic model are compared with the data gathered in real time from the pressure and flow meters installed in place by an algorithm (ADWICE) able to point out the faults in the WDS by arising an alert that will be shown in the Waternomics information platform. The methodology proposed is made up of 5 phases described in the figure below (Figure 2).

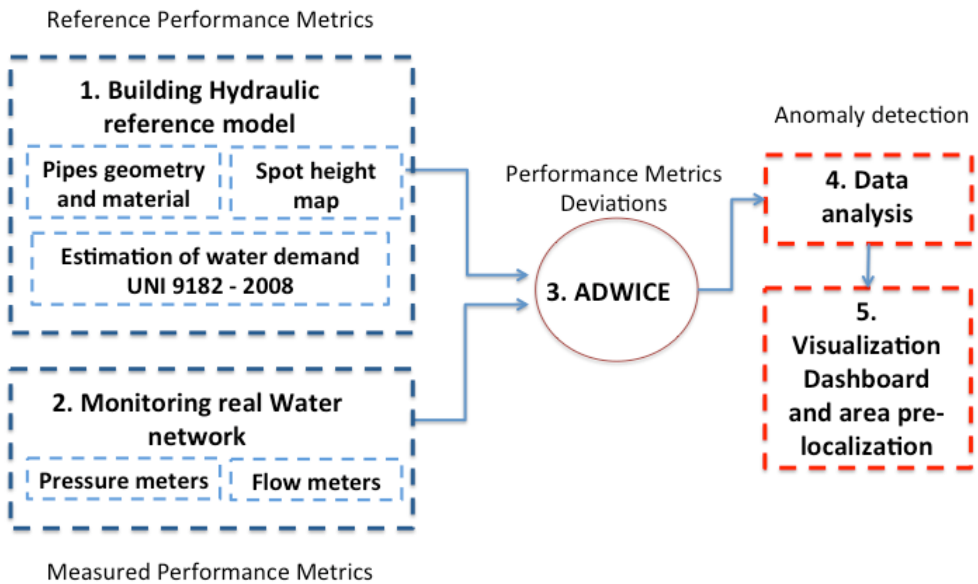

Fig. 2. FDD methodology developed whithin the WATERNOMICS project

In the following a detailed description of each phase is proposed.

<u>Phase 1 – Building Hydraulic reference model</u>

Water network information, as pipes geometry material and age, is necessary in this phase. This kind of information can be gathered both through design documents study and on site surveys. In Linate pilot 12 technical meetings have been held in order to get an accurate knowledge of the WDS and its characteristics as the pumping stations system, the materials of the pipes, the spot height map of the pilot area, the depth of installation of pipelines. For estimating the water demand also an accurate survey of all the building within the pilot area was conducted in order to deveop for each building an inventory of the water equipment installed on each floor. The UNI 9182/2008 law was utilized in order to get for each building a corresponding water demand. The UNI 9182 is an Italian law for design, testing and management criteria for hot and cold water supply and distribution installation and it is generally used in the design and hydraulic consultancy field for sizing of water pipes through the calculation of the estimated flow rate flowing out. The water demand is estimated by conducted a loading units methodology. Loading Unit value is assumed conventionally according to the flow of a delivery point, its characteristics and its frequency of use, used for the calculation of the contemporaneous maximum flow in a water distribution network. The method basically consist in assigning to each water equipment a number of load units in accordance with the UNI 9182. These load units already take into consideration the contemporaneity of utilization of different water equipment. The table used to assign the load units is the following. By knowing the loads units for each building is possible to obtain the estimated water demand (UNI9182). The geometry of the pipes in the WDS, the materials, the depth of installation the water demand calculated in accordance to th UNI EN 9182/08 are all input data for the Epanet software and for the development of the hydraulics model of the WDS. EPANET is a computer program that performs extended period simulation of hydraulic within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank during a simulation period comprised of multiple time steps. EPANET can be used for many different kinds of applications in distribution systems analysis, sampling program design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment are some examples. EPANET can help assess alternative management strategies for improving water quality or distribution throughout a system. Running under Windows, EPANET provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded network maps, data tables, time series graphs, and contour plots. Full-featured and accurate hydraulic modeling is a prerequisite for doing effective water network modeling. EPANET contains a state-of-the-art hydraulic analysis engine that includes the following capabilities:

1. Places no limit on the size of the network that can be analyzed
2. Computes friction headloss using the Hazen-Williams, Darcy- Weisbach, or Chezy-Manning formulas
3. Includes minor head losses for bends, fittings, etc.
4. Models constant or variable speed pumps
5. Models various types of valves including shutoff, check, pressure regulating, and flow
6. Considers multiple demand categories at nodes, each with its own pattern of time variation
7. Models pressure-dependent flow issuing from emitters (sprinkler heads)
8. Can base system operation on both simple tank level or timer controls and on complex rule-based controls.

Typically the following steps should be carried out when using EPANET to model water distribution system:

1. Draw a network representation of the distribution system
2. Edit the properties of the objects that make up the system
3. Describe how the system is operated
4. Select a set of analysis options
5. Run a hydraulic analysis
6. View the results of the analysis.

The output of the Epanet model helpful to implement the reference performance metrics are:

- Pressure in the juncions (nodes)
- Flow in the pipes

In the following the hydraulic model developed with the Epanet model of the Linate Pilot WSD (Figure 3).

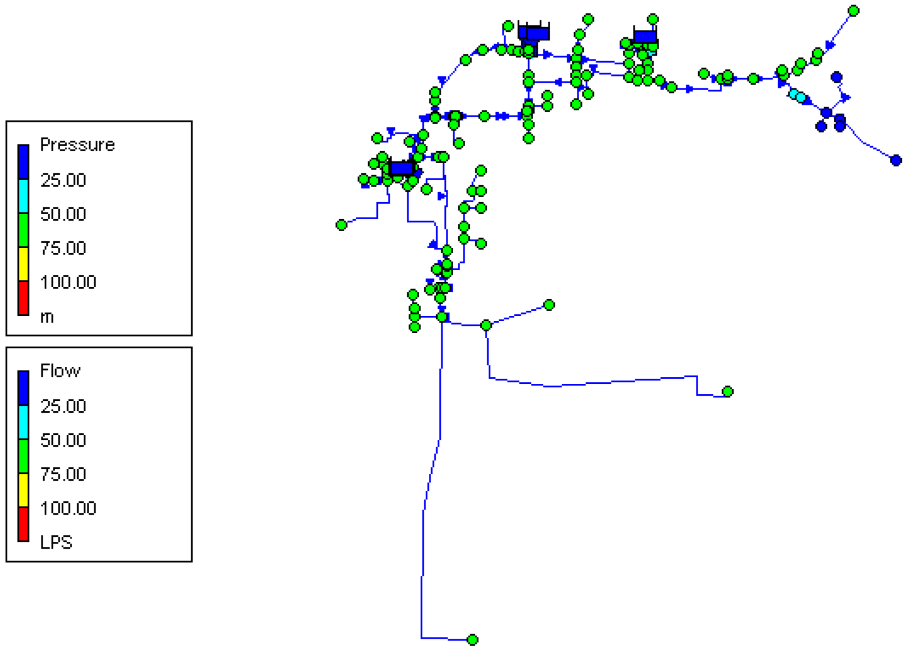

Fig. 3. EPANET model of the demo site – Linate Airport – Milan (Italy)

Phase 2 – Monitoring real water network

As part of the Waternomics metering plan developed for Linate pilot, some points have been chosen to implement the installation of flow meters and pressure meters in the overall WDS.

The objective is to realize a real time monitoring of the water network and make data available for the Waternomics Information Platform and for the end-users.

These meters will allow the researcher to have a real time status of the water network by metring for every pipes the flow and for each node the pressure. These data helps to understand the network behaviour and to gat data helpful to be compared with the output of the Epanet mode

Phase 3 – ADWICE algorithm

A large water distribution network is in place in the case study of Linate Water network that leads to a large amount of variables influencing the effectiveness of the fault detection this resulted in choosing anomaly detection techniquesas depicted in Figure 4. This class of algorithms is based on modelling the system selecting the best set of parameters that characterize the operational conditions (in our case they can be the flow rate, pressure, energy consumption for pumps system, ground water level for the wells, etc.) assuming normal operation, i.e. absence of problems (leaks, faults, etc.). This model will be used as a comparison baseline with the operational values observed by the water sensors installed in the network in real time. Whenever the system under observation is not found to be operating in the modelled normal region and the deviation between the normality and the current situation exceeds a certain threshold, an alarm is raised (Figure 4).

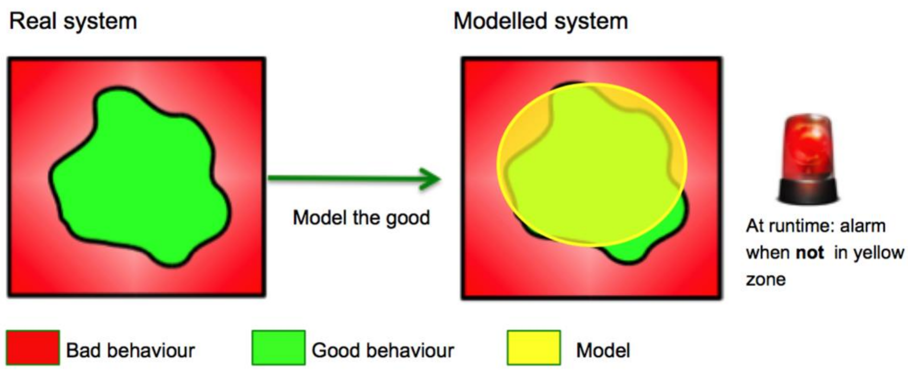

Fig. 4. Anomaly Detection model [22]

The anomaly detection module will be based on an existing algorithm, called ADWICE.
ADWICE (Anomaly Detection With fast Incremental ClustEring) is a clustering-based anomaly detector that has been developed in an earlier project targeting critical infrastructures protection. Originally designed to detect anomalies on network traffic sessions using features derived from TCP or UDP packets, ADWICE represents the features of the observed system as multidimensional numeric vectors, in which each dimension represents a single feature. The vectors are therefore treated as data points in the multidimensional space. Similar observations (i.e. data points that, using a certain distance metric, are relatively close to each other) can be grouped together to form clusters. The basic idea of the algorithm is then to model normality as a set of clusters that summarize the normal behaviour of the system observed during the algorithm's learning process. ADWICE assumes semi-supervised learning, where the data instances provided in the learning phase to create the normality clusters are given labelled and known to be good examples of the system's normality.
Once ADWICE is trained, it can be used for online detection of anomalies or faults. During the detection phase, when a new observation of the parameters of the system is made, a feature vector is produced. When the resulting multidimensional datapoint is close enough (using a threshold) to any normality clusters, ADWICE classifies it as an instance of a normal behaviour, otherwise it considered the data point as an outlier and an alert is generated (Figure 5).

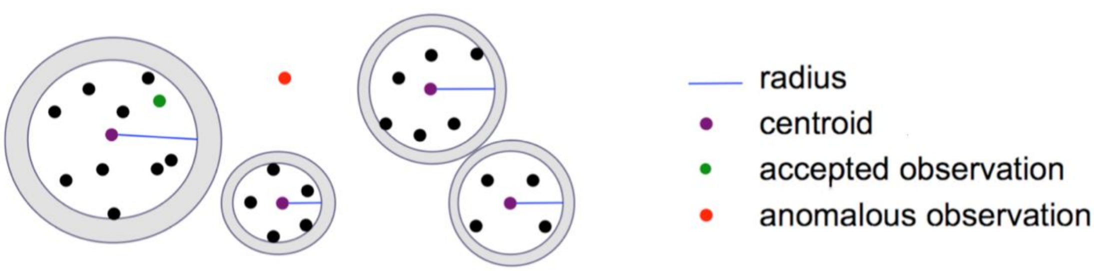

Fig. 5. ADWICE clustering schema

In ADWICE, each cluster is represented through a summary denoted Cluster Feature (CF). CF is a data structure that has three fields

$$CF_i = (n, S, SS)$$

where n is the number of points in the cluster, S is the sum of the points and SS is the square sum of the points in the cluster. The first two elements are used to compute the average for the points in the cluster used to represent its centroid

$$v_0 = \sum_{i=1}^{n} \frac{v_i}{n}$$

The third element, the sum of points, is used to check how large a circle is that would cover all the points in the cluster, which is the radius

$$R(CF_j) = \sqrt{\frac{\sum_{i=1}^{n} (v_i - v_0)^2}{n}}$$

With all this information one can measure how far is a new datapoint from the centre of the cluster (as Euclidean distance between the cluster centroid and the new point) and whether the new point falls within or nearby the radius of the cluster. This is used for both building up the normality model (is the new point close enough to any existing clusters so it can become part of it or should it form a new cluster?), and during detection (is the new point close enough to any normality clusters or is it an outlier?). Using this structure, during the training phase, a new point can be easily included into a cluster and two clusters

$$CF_i = (n_i, S_i, SS_i)$$

and

$$CF_j = (n_j, S_j, SS_j)$$

can be merged to form a new cluster just by computing the sums of the individual components of the cluster features

$$(n_i + n_j, S_i + S_j, SS_i + SS_j).$$

When a new data point is processed, both during training and detection, the search of the closest cluster needs to be efficient (and fast enough for the application). We need therefore an efficient indexing structure that helps to find the closest cluster to a given point. The cluster summaries, that constitute the normality observations, are organised in a tree structure. Each level in the tree summarizes the CFs at the level below by creating a new CF which is the sum of them. The search then proceeds from the root of the tree down to the leaves, which is efficient as it takes logarithmic computational time.

The implementation of ADWICE consists of a Java library that can be embedded into the platform. The required interface is a data pre-processing unit (a module that collects the parameters of the system under observation and generates the numerical feature vectors to feed the ADWICE algorithm) and the graphical interface that displays the output of the algorithm.

Phase 4 – Data analysis

If system under observation is not found to be operating in the modelled normal region and the deviation between the normality and the current situation exceeds a certain threshold, an anomaly is detected.

Phase 5 – Dashboard visuzlization

A notification event is araised through the Waternomics Platform to inform the users about the anomaly detected (Figure 6). The users will have the option to act immediately on the notification (Figure 6).

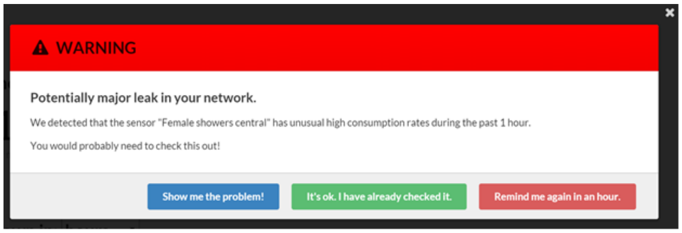

Fig. 6. Live notification

Conclusions

The model based FDD methodoly presented is helpful in detectin leakages in water networks. The method is based on the analysis of both pressure and flow variation produced by leakage in the WDS, for this reason this technique differs from the others we can find in the literature because it is not based on the transient analysis of the pressure waves but on the comparison of real pressure and flow data with their estimation using the simulation of the mathematical network model.

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Authors:

Domenico PERFIDO is a registered professional engineer in Italy in the field of civil engineering with specializations in hydraulic engineering, energy engineering and environmental engineering. He is a 2008 MSc. Eng. graduate of the University of Napoli "Federico II" and since has a has 5+ years of design and consulting experience on field projects including the design of drinking water, storm water, wastewater and water distribution systems, infrastructure-renewal planning, landfill design and management, methane production from solid urban waste, building design, construction management and wind tunnel research applied to rotary aircraft. He worked as a consultant for the Italian prime minister office and was a member of the integrated building committee of Roccarainola Municipality. He is a qualified construction site safety coordinator and his software proficiencies include Autocad, Sismicad, Primus, SAP2000, Epanet, Fognature and SWMM.
ORCID ID: 0000-0002-4490-7793

Massimiliano RACITI is a qualified professional computer engineer. He obtained a BSc and a MSc degree in computer engineering from University of Catania, Italy, in 2006 and 2009 respectively. His MSc thesis, entitled "A cloud-based Execution Environment for a Pandemic Simulator" has been carried out during an exchange period at Linkoping University, Sweden. From 2010 he took a position as a graduate student at the Real-Time Systems Laboratory at Linköping University, Sweden, obtaining the swedish Licentiate of Engineering degree in April 2013 with the thesis entitled "Anomaly Detection and its Adaptation: Studies on Cyber-Physical Systems". His research has been focusing dependability and security applied to critical infrastructures (smart grids and water distribution systems). During his graduate studies he took part to the EU FP7 SecFutur.
ORCID ID: 0000-0001-5098-5408

Chiara ZANOTTI holds a summa cum laude Master Degree in Environmental science form the Universita' Milano Bicocca. Her master thesis, carried out at the Politecnico di Milano within the environmental engineering department focused on statistical analysis of water data quality data in collaboration with the Milan water utility company MM Spa. Chiara is currently a research associate at the university Milano Bicocca within the DISAT department working on several environmental with a focus on hydrology and statistical techniques application. One of the main project she is currently working is titled "Lake, stream and groundwater modeling to manage water quantity and quality in the system of Lake Iseo-Oglio River project".
Chiara Zanotti: 0000-0002-3523-7791

Niall CHAMBERS is a graduate of NUI Galway (2014), in the new and innovative Energy Systems Engineering bachelor's degree course, in which he specialised in Mechanical Engineering and achieved a high first class honours. He was awarded a Research Masters Scholarship by the College of Engineering and Informatics in NUI Galway to work on the EU funded water management project, Waternomics . His

research is supervised by Dr. Eoghan Clifford and pertains to Fault Detection Diagnostics (FDD) applied to the water network and its subsystems in the NUI Galway Engineering building.
Niall Chambers: 0000-0001-5801-6417

Louise HANNON works as an employee at NUI Galway and as chartered engineer with 18 years' experience in a wide variety of civil end environmental engineering projects. She is currently a Senior Research Associate at NUI Galway and a lecturer in Galway Mayo Institute of Technology. She is the NUI Galway project manager working on WATERNOMICS a FP7 funded project. Louise has previously worked as an associate engineer and design team lead on some of the largest and most complex civil engineering projects in Ireland with values up to € 600 million. Louise also lectures undergraduate and postgradtuate students at NUI Galway and Galway Mayo Institute of Technology. She has extensive project management skills and has led large multidisciplinary teams.
Louise Hannon: 0000-0003-3041-6448

Dr. Marcus KEANE has extensive knowledge and experience in the development of integrated Building Information Models (BIM) that encapsulate the processes and data associated with holistic environmental & energy management in buildings and industrial processes. Dr. Keane founded the Informatics Research Unit for Sustainable Engineering (IRUSE) at University College Cork in 2000 and expanded IRUSE to be a dually affiliated research unit with NUI Galway following Dr. Keane's transfer in 2007. Dr. Keane has published over 100 academic papers and currently contributes expertise in the area of Fault Detection Diagnostics (FDD) for the Waternomics project.
ORCID ID: 0000-0001-6283-1246

Dr. Eoghan CLIFFORD is currently a lecturer in Civil Engineering, NUI Galway with 12 years' experience in the areas of water, wastewater, waste treatment and sustainable transport in the academic, research and private spheres. He is currently the Programme Director of the 1st year engineering at NUI Galway and lecturer in various water and transport engineering modules. Eoghan has have been involved as lead investigator, co-investigator or collaborator in €7 M worth of research funding and is currently the leading researcher of the Waternomics project for NUI Galway (€2.95 M). His current research team compromises of 16 postgraduate students and research staff.
ORCID ID: 0000-0001-6283-1246

Dr. Andrea COSTA is a qualified chartered engineer and building energy rating (BER) assessor in Italy and a Certifiend Energy Manager (CEM) affiliated to the Association of Energy Engineers (AEE). He is expert in building simulation with experience on an array of building energy simulation software and ISO 50001 certification tools. Andrea is originally a graduate from the Politecnico di Milano where he obtained a BSc(Eng) in Building Engineering in 2005. In 2007 he was also awarded a summa cum laude Masters of Science degree in Building Engineering. During the master degree programme, he was awarded an Erasmus Scholarship and studied at University College Cork in the academic year 2005/2006. He pursued and was awarded a PhD in Civil Engineering from the National University of Ireland Galway (NUIG) with a PhD topic of providing support to the energy manager in improving the building operation strategy with considerations on building energy use and occupant comfort throughout the building lifecycle. After his PhD, Andrea was awarded an industrially supported Postdoctoral Fellow co-funded by IRCSET (Irish Research Council for Science Engineering and Technology) as part of the Enterprise Ireland Partnership Scheme and D'Appolonia Spa in Italy. Andrea brings with him a balance of field and research experience including FP7 projects for energy efficiency with targeted focus for office buildings, airports, sport facilities, and schools.
ORCID ID: 0000-0001-7849-0052

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ENERGY BALANCING ACROSS CITIES: VIRTUAL POWER PLANT PROTOTYPE AND IURBAN CASE STUDIES

Michael Oates[1], Aidan Melia[1], Valeria Ferrando[1]

[1,] Integrated Environmental Solutions Ltd, Glasgow, G20 0SP, United Kingdom

E-mails:[1] mike.oates@iesve.com

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Abstract. This paper summarises Virtual Power Plant (VPP) development within the European Seventh Framework Programme (FP7) project Intelligent URBAn eNergy tool (iURBAN).In the context of this work the VPP is considered as a high level design tool based upon load aggregation of near real-time metered energy demand and generation data at building/apartment levels. Selected data can be aggregated up to city level, or user defined and selected levels such as district, neighbourhood, low voltage electricity network, district heating network etc. Two types of analysis can be performed by the VPP: 'as is' model(s), representing the structures and consumption patterns currently in place (the status quo), and 'what if' (variant) model(s), representing possible alternatives such as adding photovoltaics (PV) at building and/or distribution levels. Target users, city planners and utility companies, will be able to use the VPP to gain an understanding of energy demand/generation at user defined and selected levels of interest ranging from high level city planning to the selection of individual buildings or user defined energy networks and so on. 'What if' scenarios aid in future development and planning of cities.

The paper outlines an example VPP case study from the iURBAN project (grant agreement N° 608712).

Keywords: Virtual Power Plant, City model, ICT tools, High level city planning, distributed energy resources

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1. Introduction

There a number of Virtual Power Plant (VPP) (Mostafa, 2017), (Othman, 2015) definitions. Landsbergen (2009) describes a VPP as a system that integrates several types of power sources, (such as micro combined, heat and power (CHP), wind-turbines, small hydro, photovoltaics (PV), back-up generators, batteries etc.) so as to give a reliable overall power supply. Navigant Research (Asmus, 2014) defines a VPP as a system that relies upon software and a smart grid to remotely and automatically dispatch and optimize Distributed Energy Resources (DER)s via an aggregation and optimization platform linking retail to wholesale markets. Due to increased activity in smart meter installations and other smart grid technologies, as well as challenges in balancing variable renewable generation on the grid it is reported that total annual VPP vendor revenue will grow from $1.1 billion in 2014 to $5.3 billion in 2023 (Navigant Research. 2014).

This paper outlines Virtual Power Plant (VPP) development within the European Seventh Framework Programme (FP7) project Intelligent URBAn eNergy tool (iURBAN) (iURBAN, 2016). In the context of the iURBAN project it was agreed that the VPP should not follow that of detailed network modelling software available on the current market, such as GridLAB-D™ (GridLAB-D, 2012). The VPP is developed as a high level design tool. And that the modelling approach of the VPP is to be based upon load aggregation of near real-time metered energy demand and generation data and modelling of electricity and heat generation at building/apartment and district level.

Fig.1 gives a simplified overview of the iURBAN Information and communications technology (ICT) architecture, its main focus being on the relationship between the VPP and connected components. The broader overview of the i Fig URBAN ICT architecture includes components that combine to form a Smart Decision Support System (SmartDSS). The SmartDSS consists of; Local Decision Support System graphical user interface (LDSS-GUI), LDSS part of the Smart City Database (SCDB-LDSS), Smart City Prediction Algorithms (SCPA), and meteorological data parsed from Weather Analytics (WA) (Weather Analytics, 2016.). Demand and generation metered data from buildings within the iURBAN demonstrations cities is parsed to the SCDB-LDSS. This data along with meteorological data from WA is parsed to the SCPA. The SCPA component performs analysis on the data and generates forecast demand and generation data up to 72 hours ahead, which is stored in the SCDB-LDSS. Within iURBAN the LDSS-GUI is a tool used by occupants of private buildings, apartments and public municipality buildings such as kindergartens (schools), offices, leisure centres. The LDSS-GUI includes demand response (DR) actions but its primary focus is to educate users on how and where energy is being consumed with a view to encouraging users to make savings, energy and monetary, and reduce greenhouse gas emissions. The work of the LDSS-GUI is not covered in this paper.

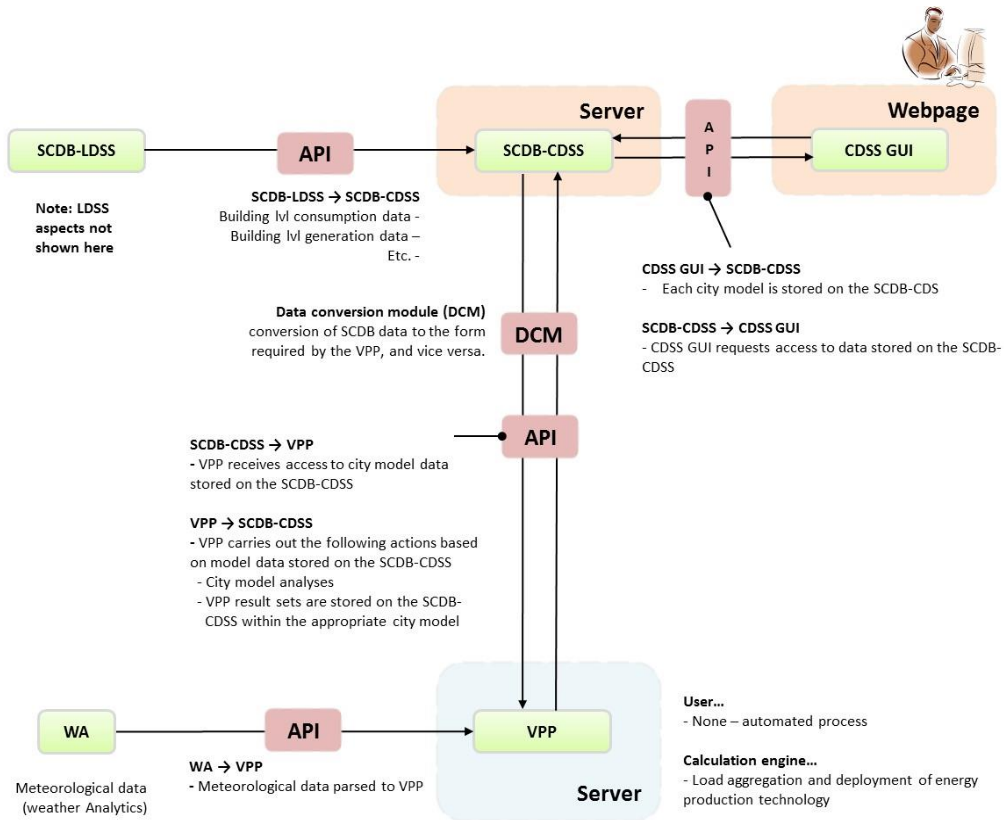

Fig.1. iURBAN ICT architecture - CDSS/VPP relationship diagram

Source: iURBAN, 2016

In addition to the LDSS aspects of the SmartDSS, the Central Decision Support System GUI (CDSS-GUI) is a tool used by utilities and municipalities. The CDSS-GUI enables users to view metered data at a city scale and focused areas of interest such as district and neighbourhood level, to make informed decisions on high level planning. In addition the CDSS-GUI is to act as an interface to the VPP. The VPP, developed by IES (IES Ltd, 2016), is a back-end calculation engine to the CDSS. Via an application programme interface (API) layer the VPP is passed city model data stored on the CDSS part of the Smart City Database (SCDB-CDSS), and writes the results of the calculations back to the SCDB-CDSS for access by the CDSS graphical user interface (GUI). There is also an API that exists between the SCDB-LDSS and the SCDB-CDSS which parses stored metered and forecast data from the SCDB-LDSS to the SCDB-CDSS. The SCDB-CDSS and CDSS-GUI are both developed by the iURBAN partner Vitrociset (Vitrociset, 2016).

2. VPP modelling approach

As outlined within Fig.1 the VPP is a component of the iURBAN ICT architecture. The VPP will analyse city models stored on the SCDB-CDSS. Different models may be created for different purposes by the CDSS-GUI user – for example to focus on particular regions of the city, particular types of building, particular energy supply and management technologies, or degrees of modelling detail appropriate to particular tasks.

City models managed by the CDSS-GUI user may be conceptually divided into two categories: 'as is' city models representing the structures and consumption patterns currently in place (the status quo), and 'what if' city models representing possible alternatives. Examples of 'what if' variant city model(s) include the addition of distributed energy resources (DER), electricity storage, modified demand from buildings and electric vehicles. 'What if' variant model(s) can answer questions such as:

- What is the likely effect of adding PV arrays to certain buildings?
- What is the likely effect of adding electricity storage at a certain point in the electricity distribution network?
- What is the likely effect of introducing a district CHP plant to serve a certain area?
- What is the likely effect of introducing a large-scale PV farm to serve a certain area?
- What is the likely effect of introducing tariffs in monetary and energy consumption terms?

Users of the CDSS-GUI such as city planners and utility companies will be able to undertake VPP analysis to gain an understanding of energy demand and generation and the associated costs at selected levels of interest, ranging from high level city planning to the selection of individual buildings or user defined energy networks.
To avoid ambiguity city model data passed to the VPP is referred to as the VPP city model. The VPP city model is formed around the following features, Commodity, External supply, Commodity account, Fuel, carbon emission (CO^2) emissions, Distribution network, Network node, Transmission channel, Prosumer object, DER object, Generator, Storage device and manger, which are illustrated in Fig.2.

Fig.2 illustrates an electricity distribution network defined for a city model. In this diagram rectangles with dashed borders represent CDSS-GUI objects, which serve as receptacles for VPP objects. VPP objects fall into three basic categories: nodes (coloured discs), DER objects (colour-filled rectangles) and managers (colour-filled diamonds). DER objects are further categorised according to type such as electricity network; power station, CHP, PV array, wind turbine, electricity storage and heat network; heat generator, electric heat pump, CHP, solar water heating, thermal storage. The filled rectangles at the base of the diagram are prosumer units by means of which demands represented by input Timeseries are connected to the system. Other VPP objects function algorithmically as a function of other variables in the model.

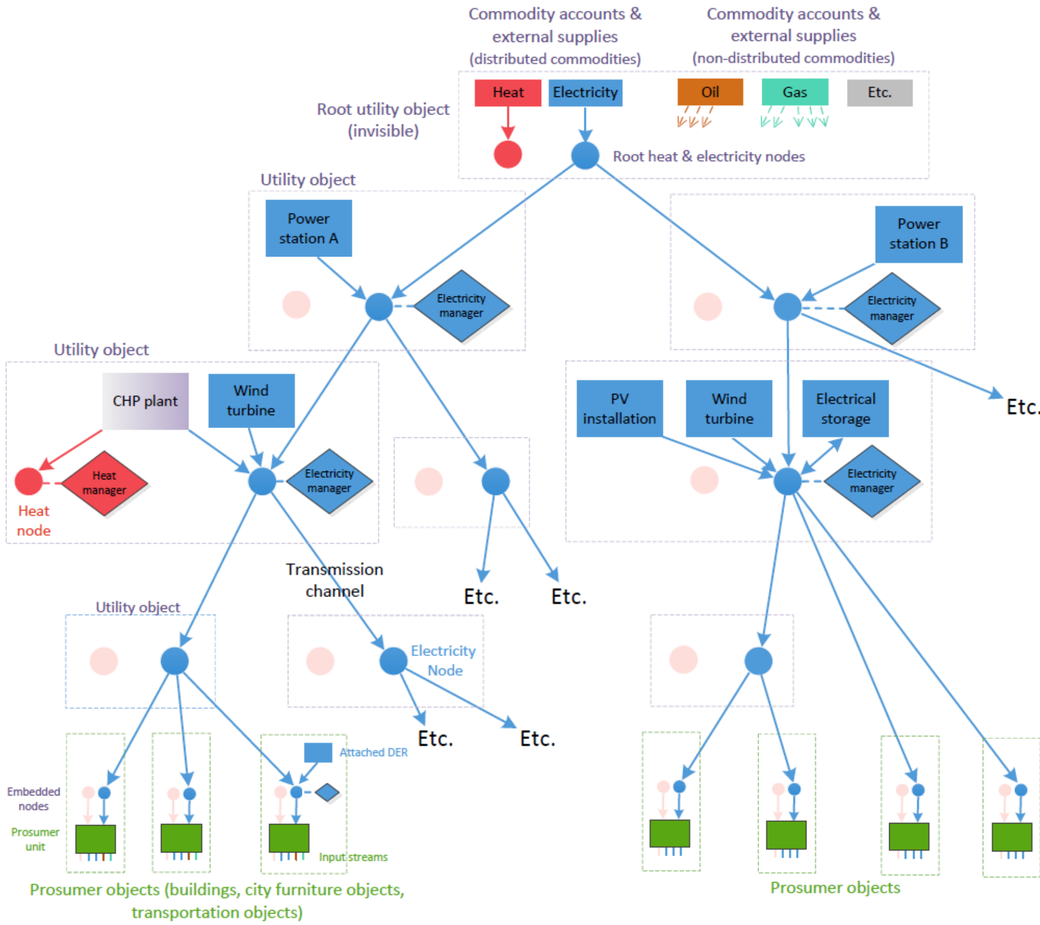

Fig.2. Part of an example city model focusing on the electricity distribution network

Source: iURBAN, 2016

3. Example case study

The CDSS-GUI, SCDB-CDSS and VPP development and integration is finalising completion in July 2016. Due to development still taking place within the CDSS-GUI, it is not possible to present a CDSS-GUI network diagram in this paper. Instead a depiction of the iURBAN example case studies is outlined in VPP diagrammatic form. Due to the sensitive nature of participant's details and metered data used within the project, the diagrams refrain from using sensitive details such as building names.

4. Case study - Rijeka, Croatia

A CDSS-GUI city view of Rijeka denoting iURBAN metered installations is shown within Fig.3. There are 3 public Kindergartens, 4 public schools, 12 residential, 4 sports centres, 2 culture centres and 7 heating plant installations. Refer to Fig.3 for CDSS-GUI legend notation.

Fig.3. CDSS-GUI - Rijeka, Croatia. Red dashed circles denote defined building clusters and CDSS-GUI legend

Source: Vitrociset, 2016

'As is' scenario

Fig.4 illustrates a simple VPP electricity network model.

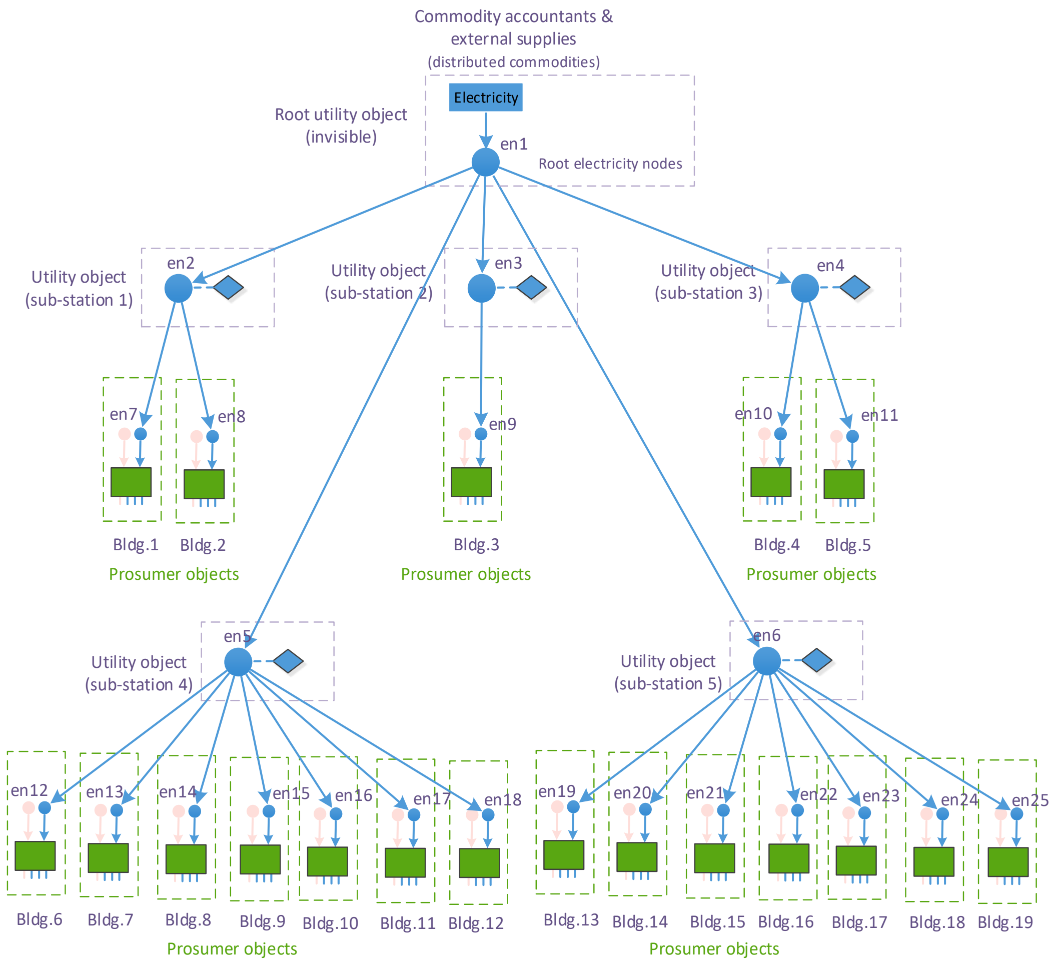

Fig.4. Simple VPP electricity network model - Rijeka, Croatia

Source: Author

Due to the sparse nature of the building locations, limited network topology information and metered installations within the framework of the iURBAN project the Rijeka case study has been simplified, refer to Fig.3. Buildings within close proximity have been grouped together and linked to a utility object representative of a sub-station. 5 sub-stations are shown in Fig.4. In time the network model will be refined as more detail is known about network connections within Rijeka.

Further to sensitivity analysis carried out on the SCDB-CDSS data the below period of analysis is considered for selected meter installations. The period of analysis was selected on the criteria of having the maximum number of meters with non-missing data for 1 whole week.

Data summary:

- Location: Rijeka (CityModelName calls Weather Analytics (WA) API for Rijeka weather data)
- Latitude: N/A (WA API)
- Altitude: N/A (WA API)
- Scenario: As-is - electricity network
- Start date/time:2016-03-01 [00:00]
- End date/time: 2016-03-07 [23:00]

- Reporting period: Hourly (on the hour)
- Electricity installations devised into 5 hypothetical electricity sub-stations, refer to Fig.3.

Within the iURBAN framework the project does not have access to all utilities, such as electricity, district heating, gas and water, meter readings for each installation. For the electricity network 19 out of 34 building installations have electricity meter readings. Table 1 list building types used within Rijeka case study and denotes available electricity consumption and production meters.

Table 1. Hypothetical electricity sub-stations 1 to 5

Hypothetical Sub-stations	Prosumer object name	Type	Meter (Consumption)	Meter (Production)
1	Building 1	Public kindergarten	Yes	Yes
“	Building 2	Sports Centre	Yes	Yes
2	Building 3	Public school	Yes	No
3	Building 4	Public school	Yes	Yes
“	Building 5	Public kindergarten	Yes	Yes
4	Building 6	Residential	Yes	No
“	Building 7	Sports Centre	Yes	No
“	Building 8	Residential	Yes	No
“	Building 9	Residential	Yes	No
“	Building 10	Residential	Yes	Yes
“	Building 11	Culture Centre	Yes	No
“	Building 12	Culture Centre	Yes	No
5	Building 13	Residential	Yes	No
“	Building 14	Sports Centre	Yes	No
“	Building 15	Public school	Yes	No
“	Building 16	Residential	Yes	No
“	Building 17	Residential	Yes	No
“	Building 18	Public kindergarten	Yes	No
“	Building 19	Public school	Yes	No

Source: Author

From the above data the following Extensible Markup Language (XML) files have been created for parsing to the VPP engine:

- CityModel.xml
- Commodities.xml
- Run.xml
- Timeseries.xml

Electricity network topology has been input into the CityModel.xml. Meter readings from the SCDB-CDSS, formatted within Excel, have been input into the Timeseries.xml. The Commodities.xml defines commodity attributes such as CO^2 emission factors. Run.xml defines the VPP run specifier settings such as start / end date and time.

‘What if’ - scenarios

Table 2 outlines selected DER installations for prosumer objects (buildings 1 to 19) and utility objects (sub-stations 1 to 5) across 8 scenarios.

Table 2. Scenario parameters

	Bldg.1	Bldg.2	3,4 …, 16, 17	Bldg.18	Bldg.19	Sub-station 1	Sub-station 2	Sub-station 3	Sub-station 4	Sub-station 5
Scenario 1										
PV (kW)	1	1	1	1	1	-	-	-	-	-
Scenario 2										
PV (kW)	6	6	6	6	6	-	-	-	-	-
Scenario 3										
Wind (kW)	1.5	1.5	1.5	1.5	1.5	-	-	-	-	-
Scenario 4										
Wind (kW)	15	15	15	15	15	-	-	-	-	-
Scenario 5										
PV (kW)	1	1	1	1	1	-	-	-	-	-
Energy storage (kWh)	50	50	50	50	50	-	-	-	-	-
Scenario 6										
PV (kW)	6	6	6	6	6	-	-	-	-	-
Energy storage (kWh)	50	50	50	50	50	-	-	-	-	-
Scenario 7										
Wind (kW)	1.5	1.5	1.5	1.5	1.5	-	-	-	-	-
Energy storage (kWh)	50	50	50	50	50	-	-	-	-	-
Scenario 8										
Wind (kW)	15	15	15	15	15	-	-	-	-	-
Energy storage (kWh)	50	50	50	50	50	-	-	-	-	-

Source: Author

DER installation parameters are shown in Table 3 to Table 5, installation types refer to the number shown in Table 2. For example, scenario 1 includes a 1No. 1kW (small domestic) PV panel assigned individually to all 19 buildings, sub-stations have not been assigned DER installations. Whereas scenario 5 includes 1No. 1kW PV panel and 1No. 50kWh energy storage device assigned individually to all 19 buildings and so on.

Table 3. PV array parameters

Installation category	Area (m^2)	Azimuth (ºclockwise from north)	Inclination (º from horizontal)	PV module nominal efficiency	Nominal cell temperature (NOCT) (°C)
PV 1kW (small domestic)	7.2	180	35	0.1100	45.0
PV 6kW (large domestic)	43.2	180	35	0.1100	45.0

Reference irradiance for NOCT (W/m2)	Temp. coefficient for module efficiency (1/K)	Degradation factor	Shading factor	Electrical conversion
800	0.0040	0.99	1.0	0.85
800	0.0040	0.99	1.0	0.85

Source: Author

Table 4. Wind turbine parameters

Installation category	Rated power (kW)	Hub height (m)	Power curve [wind speed (m/s), Power output fraction %]
Wind 1.5kW (house)	1.5	5	0 0 4 0.1 7 0.5 12 0.8 25 1
Wind 15kW (farm)	15	5	0 0 4 0.1 7 0.5 12 0.8 25 1

Source: Author

Table 5. Electrical energy storage parameters

Installation category	Storage Capacity (kWh)	Initial storage energy (kWh)	Storage Method	Losses
lithium-ion Battery 50kWh	50	2	lithium-ion Battery	0

Source: Author

Results

Rijeka case study VPP results for 'as is' and 'what if' scenarios, discussed in the above sections, are shown in Table 6. Table 6 results are presented for the electricity commodity account, i.e. root node, not for each electricity node in the network.

Based on the selected 'what if' scenarios the results reflect the expected behaviour of the electricity network for scenarios 1 to 8 when compared against the 'as is' scenario i.e. the baseline scenario. Where renewables have been introduced, PVs and wind turbines only for scenarios 1 to 4, demand from external supply to the network has reduced. This is a result of renewables offsetting electricity demand from buildings 1 to 19. This also results in a reduction in CO^2 emissions within the model based on the reduction of fossil fuel based external supply to the network. There is a noticeable difference between the PV and wind turbine scenario results. This difference is due to the variation in wind speed for Rijeka based on its coastal location; average, maximum and minimum wind speed for the selected period of analysis is 3.44m/s, 10.19m/s and 0.89m/s. Also scenario 4 is based on a 15kW wind turbine. This may be considered unrealistic but it gives an indication of electricity generation range from 1.5 to 15kW installations.

In scenarios 5 to 8, which include electricity storage in addition to selected renewable technology, external supply and carbon emission reduce when compared to scenarios 1 to 4 with no electricity storage installations. This is a result of model set-up where electricity storage devices have been applied at building level. In some cases on-site electricity generation from renewables at building level exceeds electricity building level demands. In this case excess electricity generation charges on-site storage prior to being fed back to the electricity network upon electricity storage equalling storage capacity. In other instances electricity demand at building level exceeds on-site electricity generation. This results in an electricity residual demand from the electricity network, sub-station and then parent node, which in turn equates to an increase in external supply and CO^2 emissions to the model. This could be adverted with better electricity storage controls and storage at sub-station level. Future scenarios will look to address this.

Table 6. Rijeka VPP results, percentage difference against 'as is' baseline model

Scenario	External supply (% diff)	External indirect CO^2 emission (% diff)
as-is (baseline model)	-	-
Scenario 1 - 1kW PV	0.30%	0.30%
Scenario 2 - 6kW PV	1.75%	1.67%
Scenario 3 - 1.5kW Wind turbine	0.78%	0.77%
Scenario 4 - 15kW Wind turbine	7.40%	7.30%
Scenario 5 - 1kW PV and 50kWh storage	0.31%	0.31%
Scenario 6 - 6kW PV and 50kWh storage	1.45%	1.39%
Scenario 7 - 1.5kW Wind turbine and 50kWh storage	0.73%	0.73%
Scenario 8 - 15kW Wind turbine and 50kWh storage	5.64%	5.58%

Source: Author

Conclusions

The VPP tool developed in iURBAN is considered a prototype since there is a small set of available data from iURBAN demo cities, refer to case study description. With this in mind the CDSS-GUI and the VPP provide means to scale up metered demands using multiplier factors so that they sum to realistic values at the district and city levels.

The VPP has been developed in a way that is scalable and repeatable. However, like most simulation tools data is critical to the inputs and outputs of the tool. As discussed within the case study example a simple network model can only be constructed unless there is sufficient information on the network topologies and access to a wide range of metered data. In response to the lack of metered data the VPP has been developed to receive both metered and simulated data. The IES Virtual Environment (IES-VE) (IES Ltd, 2016) is a building modelling tool capable of generating building related energy demands and generation in Timeseries format. Energy profiles could be produced from a range of IES<VE> building models and the outputs fed into the VPP. This is outside the scope of the iURBAN project.

Future work to consist of refining the Rijeka case study based on detailed electricity network topology. Other work to include the modelling of the second iURBAN case study in Plovdiv, Bulgaria. This work is to take place from July onwards as part of the iURBAN ICT tools evaluation and validation period, upon the integration of the CDSS and VPP.

Future VPP development to include district cooling, water networks and optimised control strategies.

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Authors

Michael OATES PhD, is technical analyst on commercial, and research and development (R&D) projects. Working for IES for over 3 years Michael has been technical lead /analyst on 6 European projects, FP7, H2020, and Marie Curie etc., http://www.iesve.com/research. Research project topic areas included glazing (electrochromic glazing), retrofit technologies, manufacturing, city modelling, and application development including gamification.
ORCID ID: 0000-0003-1339-0848

Aidan MELIA is a project manager working on commercial and research and development (R&D) projects. Working for IES for over 3 years Aidan has managed 3 European projects, such as FP7 and H2020. These focus on the areas of smart cities and ICT developments, as well as more recently focusing on areas such as gamification. He has studied in a number of countries such as Ireland, the US, Spain and Germany.
ORCID ID: 0000-0001-5498-4576

Valeria FERRANDO PhD, is EU Head of Research. In 2013 Valeria joined the Research and Development (R&D) division of IES Ltd where she deals with EU funded research, managing projects ensuring that they lead to marketable products for the company and finding new funding opportunities and research grants at European level to support IES R&D, setting up partnerships and writing proposals.
ORCID ID: 0000-0003-2296-7346

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DATA-DRIVEN DEVELOPMENT IN THE SMART CITY: GENERATIVE DESIGN FOR REFUGEE CAMPS IN LUXEMBOURG

Daher, Elie[1]; Kubicki, Sylvain[1]; Guerriero, Annie[1]

[1] Luxembourg Institute of Science and Technology,
5, avenue des Hauts-Fourneaux. L-4362 Esch-sur-Alzette. G.D. de Luxembourg

E-mail: [1]firstname.lastname@list.lu

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Abstract. The paper addresses computational design as a key technological asset in the development of the smart city. In particular, the research targets context-aware adaptation to usage requirements at urban fragment level. Indeed, cities' policy makers have to take into account many factors in a development policy, such as situational, technical or human-related factors as well as anticipating future usages. Moreover, nowadays, cities are key resources to answer growing humanitarian needs in terms of sheltering and camps. Indeed these situations are increasing due to different factors related to the nature, climate change or human activities. Resilience is therefore essential at the levels of districts, cities and territories. In Luxembourg, a public program aims to develop three container villages for refugees. The objective of this work is to help policy makers and humanitarians in the optimization of the spatial design of camps. The use of parametric modeling approach enables the optimization of space layout planning. It is applied on a case study allowing policy makers to explore scenarios for the decision-making in the camp space planning.

Keywords: Smart city, Computational design, Data-driven development, parametric modeling, Humanitarian need, Generative alghorithm, Space planning, Usage requirements.

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Additional disciplines: Design, Environmental Engineering, Computer Science

1. Introduction

Computational design is a technological paradigm involving Information Technology and Computing in the practice of design activities in multiple domains. The development of computing capabilities for design support started in the early 1980s, following major research achievements in the field of design theory (Gero 1990; Gero & Kannengiesser 2004).

A wide research effort exists in "design computing" notably in the field of architecture and construction, where "construction informatics" forms an international scientific and industrial community (Türk, 2006; Björk, 1992). The application of computational design is also increasing in the Architecture, Engineering and Construction Industry (Boeykens, 2012). "Building Information Modeling" (BIM) and "Parametric Modeling" both reflect recent trends in computing design in academic research and market innovation. Another challenging aspect in design is the involvement of multi-expertise disciplines. Each expert addresses the design project according to his domain of expertise and his own viewpoint (Boton et al., 2013) which implies multiple views modeling in design support systems (Rosenman & Gero 1996). Therefore the optimization in design requires procedures to merge these multiple viewpoints and criteria in order to support the decision-making.

At the level of city development, implications for computing support are also challenging. In the last decades, both city and land-related data modeling mainly addressed the representation of information layers in Geographical Information Systems. Reasoning and decision-support has mainly been developed in research literature through the application of Multi-Criteria Decision Analysis techniques (Malczewski 2006). An object-based modeling approach is also applied in GIS systems (Shekhar et al. 1997). It notably enables the mapping and interrelation between building, infrastructure and land datasets in research (El-Mekawy et al. 2012; Peachavanish et al. 2006) as well as in commercial products such as Autodesk InfraWorks 360 or Vianova Novapoint.

On the other hand, the humanitarian response is a collection of interventions during and after crises to answer to the housing needs of displaced populations. The humanitarian design is quite similar to the usual collaborative approach in the design and construction industry. It involves multiple actors with different missions, interests and expertise (Balcik et al., 2010), such as the architectural design and construction (Kubicki et al., 2006). The planning, implementation and monitoring of humanitarian projects are the results of the collaboration of many stakeholders. The knowledge of these interventions is often based on previous experiences (Santos et al., 2013). The involvement of different stakeholders into the management process is very important as preparation and interaction of communities, business structures and NGOs with the public authorities can enhance awareness and response to various possible or present threats, help to mitigate consequences of crisis, and enable a recovery process for the population (Survila et al, 2016).

Moreover the diversity of stakeholders makes it sometimes difficult to find and implement the appropriate collaboration network (Charles et al., 2010). The humanitarian needs in terms of shelters and camps are increasing due to different factors related to nature or human activities. This article describes a research project aiming at studying the contribution of computing design methods for supporting humanitarianly in emergency situations. Worldwide, developing and managing refugee camps is increasingly significant, and the design must meet multiple constraints. Another aspect lies in time constraints. Indeed refugee camps planning should be completed as soon as possible to answer unpredictable flows of persons.

2. Design computing paradigms for the smart city

2.1 Challenges and operational concepts of the smart city approach

The development of city and urban fragments perfomed by different kinds of planners involves "complex systems *[dealing]* with food supplies on an international scale, water supplies over long distances, and local waste disposal, urban traffic management systems, and so on; (...) and the quality of all such urban inputs defines the quality of life of urban dwellers (The Science Museum, 2004)", cited by (Caragliu et al. 2011). These authors operationally define a city as a "smart" system when "investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance". One important challenge is to ensure a sustainable development for the population. Indeed, the sustainable development represents a *commitment to advancing human well-being with the added constrain*t that this development needs to take place within the ecological limits of the natural resource (Korsakienė et al., 2011).

From infrastructure and policy development to the everyday urban life one can recognize that the trends are nowadays in inter-linking physical and digital spaces. Interrelations between these environments in the concept of the smart city usually describe the increased citizen-city interactions that can be enabled. Thus, beyond it, new forms of planning, design, and development as well as usage of urban spaces are to be defined in order to implement the smartness approach at city level.

Key societal challenges should be directly tackled by this new paradigm, and in particular the "global environmental challenges, with real and potential risks to our natural and built environment, including global climate change, increasing population and population density, increasing resource scarcity and both traditional and asymmetric forms of conflict" (Marsden and Rezgui, 2010). These authors proposed an evolution of sustainable urban planning approach in order to emphasize the dimension directly related to planning (land use, infrastructures, transport etc.) as well as the central role of ICT (Al Qahtany et al. 2013).

Computing researchers previously emphasized the importance of knowledge management principles and techniques. Semantic technologies have been applied to connect these multiple and heterogeneous data sources at the scale of the city. The City Service Ecosystem (CSE), for instance, is a digital environment for the governance of urban services, based on semantics for improved interoperability of city services (Celino & Carenini 2014). Recently, (Anjomshoaa 2014) introduced the concept of Web of Buildings (WoB) as "a uniform information space that connects various BIM schemas and their corresponding instances (building) that are located in a specific geographic area […]".

2.2 BIM and generative design for development of the city and urban fragment

In the smart city environments, "urban processes, citizen engagements, and governance unfold through the spatial and temporal networks of sensors, algorithms, databases and mobile platforms" (Gabrys, 2014). This new way of considering the city implies new approaches for city planning which should contribute to its resilience. Design and engineering research communities provided important knowledge and experience to the smart city development issues. In particular the role of computing has been identified in spatial planning and building design for managing complexity, enabling the design of advanced morphologies, by enabling performance-driven design approach (Asl et al. 2014), as well as for managing information across projects' stakeholders (Turk, 2006).

The authoring of Building Information Models as well as the management of Information Exchanges are central concepts in the development and industrial implementation of Building Information Modeling. Indeed, BIM comprises both object-oriented modeling and process-related implications, as it is defined as a "new approach to

design, construction and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format" (Eastman et al. 2011).
Beyond that, the application of computational design is increasing in the Architecture, Engineering and Construction Industry. "Parametric Modeling" reflects recent trends in computing design in academic research as well as in market innovation. It allows the designers to control the generation of visualized 3D objects from an overall logical computing script or scenario (Davis et al. 2011). They embed mathematical formulas, constraints and control functions to derive a geometric model from series of input data through a generative process, and thus enable a performance-driven reasoning. The characteristic of this approach is that it produces more than static geometry, i.e. a model with a collection of primitive shapes (Fernando et al. 2012). Parametric models embed dynamic and real time relationships within different components integrating mass amounts of information and constraints data, used in different applications.

At the urban level, computing brings a lot of opportunities to designers and developers, e.g. in simulating the impacts of land uses, estimating urban development strategies or enabling involvement of citizens in decision-making thanks to mobile applications or Virtual Reality tools. Openness, interoperability and integration of multiple datasets remain key challenges in the development and exploitation of such tools.
Regarding decision-making linked to development strategies at the scale of urban fragments, computational design approach enables design-support and simulation. The parametric relashionships defined in such approaches in addition to the constraints that will be "limiting" design options enhance the smart urban design. Some researches previously focused on the development of smart cities and the relation with the parametic modeling and computational design approaches. The intrusion of parametric methods into the urban context development was carried out within different projects and researches. (Steino et al. 2005) showed the capabilities of a parametric approach in urban design through a case study. According to this research, urban components share a similarity that can be defined parametrically. Aspects such as density, functions, forms, and spaces, can be translated into parameters. This approach helps in evaluating different scenarios and enables to reach an optimum solution. In addition, Saleh showed in his research that the usage of a parametric approach in urban design can lead to a sustainable result (Saleh and Al-Hagla 2012). In his research, he examines the use of a parametric method in sustainable urban development. The case study developed was the generation of an Arabian city taking into account constraints such as wind and solar envelopes. Different plug-ins for parametric systems have been developed also to study the urban behaviour and to propose some urban solutions for the usage requirement extension and emplacement.

2.3 Computational applications for humanitarian needs

Computational methods are more and more involved in the design process and the generation of forms for contemporary architecture, and it should be mentioned that a few applications appeared in the humanitarian field. Yeung focused on the application of digital architecture in low-tech reconstruction of the Solmon Islands (Yeung et al., 2011) targeting a set of parametric tools applied to latrine construction. Another example was the case study of the post-earthquake Haiti (Benros et al., 2011); automated systems were developed to create houses, this example focused on the resulting documentation as a set of construction drawings. Jinuntuya focused in his research on the use of digital tools and games' 3D virtual environment engines for developing a decision-making support system for humanitarian needs (Jinuntuya et al., 2007). Recently, the authors addressed the contribution of the parametric methods in emergency architectural design (Daher et al, 2014). The parameters needed for shelters have been identified and classified. The result was a parametric prototype taking into consideration physical parameters and allowing humanitarian stakeholders to generate sheltering solutions.

2.4. Humanitarian situation in Europe and Luxembourg

Factors related to natural environment and human activities are increasing the risk relating to housing. Migrants and refugees are still crossing into Europe, sparking a crisis as countries struggle to cope with the influx. Countries are

trying to deal with this situation and to respond to the emergent demand for a rapid, sustainable and effective post-disaster response.
Luxembourg is directly involved in the refugee crisis in Europe and worldwide. Emergency refugee accommodation in Luxembourg is being provided at former hospitals and the Luxexpo (Exhibition and congress center). The CHL Maternity hospital on the Route d'Arlon provides 130 beds, the former speech therapy centre in Strassen has 300 beds, the Centre Hospitalier Neuro-Psychiatrique (CHNP) at Ettelbrück has 220 beds and Hall 6 of Luxexpo hosts 360 campbeds. In addition to this intervention, and in order to meet the growing influx of refugees in Luxembourg, the Luxembourg Government decided to create new temporary emergency centres by mid-2016: three "container villages" will be set up to take over as primary reception centres. The first three "container villages" to temporarily house asylum seekers in Luxembourg are to be installed in Steinfort, Mamer and Diekirch cities.

"The resilience is the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard (Jha et al., 2013)". Focusing on human and social capital as well as ICT, Smart cities are more responsive to and efficient in facing a situation of risk. They become more resilient. The situation related to the influx of refugees requires of the city of Luxembourg adapting itself. Our proposition contributes to increase its resilience in this situation by supporting the phase of planning of refugee camps. The next sections present a design decision framework, accompanied with an experimental prototype, directly related to this context and inspired by real requirements observed.

3. Data-driven decision framework

3.1 Requirements and technological choices

The requirements for a design decision framework were centred on providing the ability to rapidly test scenarios of camp development on several terrains. The framework should enable to link usage requirements (mostly quantitative data) to an automatically generated possible spatial design, optimizing it by basing on constraints and limits identified by the user.

The software programmes Rhinoceros and Grasshopper were chosen for the development of this project. This is justified by the ability of the software to easily design and manipulate algorithms based on visual objects. Grasshopper a plugin of Rhino 3D has a set of predefined components classified according to their operation. These components perform geometric operations modeling. The connection of different components enables operations that do not exist by default in design software systems. According to its nature, each geometric operation is based on parameters that can be manually modified. The modification of parameters will result in real-time modification of the 3D geometry.

Beyond producing a geometrical representation of a design solution, another aspect of design computing is the multi-criteria or multidisciplinary design optimization (MDO), which has been developed in aerospace engineering mainly addressing technical design and focusing on quantitative aspects (Geyer et al., 2010). MDO provides a powerful means to support the design process. Genetic algorithm (GA) is one of the methods of optimization often used in architecture. It is a procedure based on Darwinian notions where selection and recombination of genes or operators are used among candidate solutions to achieve the best performance (Goldberg 1989). The strength of GA lies in its adaptability to fit any kind of problems. Initially a set of solutions is selected randomly to form the initial population, and then the optimization with GA focuses on making a set of individuals evolve, using crossover and mutation operations. GA has been used in many activities and fields. Poblete shows how GA can be used to generate possible solutions for buildings with low cost energy consumption (Poblete 2011). Multi-criteria evolutionary optimization was also used in urban design to automate the generation and evaluation of urban street patterns (Chee et al., 2013). The chosen system to implement the demonstrator is based on visual programming and containing plug-ins and Live Physics engine for interactive simulation and optimization directly within Grasshopper (e.g. Galapagos, Kangaroo).

3.2 Using datasets in generative process

3.2.1 Variables
Moving from an explicit design to a parametric model is a process where geometry is a result driven by the designer's inputs and data values, which can affect the form. This process is executing some "usual" design activities but more efficiently and in a more iterative way due to input variables. The modification of these variables gives more options to be evaluated in the design process. The parameters identified are based on numerical values related to physical forms, geometries and dimensions. These physical parameters can be easily expressed numerically, while contextual and climatic parameters are more complex to be translated into quantitative (or numerical) values. Such variables are implemented in our design definition as data inputs (through a link with an external dataset) and manipulated by the user thanks to ad-hoc sliders.

3.2.2 Constraints
Identifying limits for the design is important in order to eliminate undesirable results. Limiting the entries of variables will also lead the design to options satisfying all the usage needs and requirements. In other terms, these limits are called design constraints. Even numerical values, shapes or relationships bind objects and elements. Constraints can be grouped into two types:

a) The constraints related to quantitative numerical values and requirements such as the number of person by container and the maximum height of the building. These constraints will be implemented in the system definition as numerical values.
b) Other constraints are related to the contextual environment and contextual requirements. Graphical representation, shapes and relationships will determine design elements. In this project the contextual constraints are: the site, the program, and other requirements such as the mandatory superposition of toilet containers, services and others.

4. Implementation

4.1 Summary

This work makes the hypothesis that the requirements (in terms of design of the container village) and the constraints (related in particular to the programme and site conditions) can be connected to a parametric digital model. The generation of design options that fit the requirements involves the identification of an algorithmic definition implemented with the appropriate constraints and variables. The design process is therefore related to the site and to the input variables. Performing a preliminary constructability review is essential to start the implementation. The target terrain is examined in order to determine whether it has a specific topography to take into account and to define the site's physical constraints as well as its access.
After selection of the site, an optimization of the graphical space programme for usage areas is processed, while taking into account the site constraints and the requirements for relations across the different spaces. The final step is dedicated to the choice of the configuration layout for the containers.

4.2 Optimization framework

For the space planning, a force-based approach was used. Kangaroo - a plug-in for Grasshopper - adopts this approach for related geometric optimization applications. It embeds physical behaviour directly to the 3D modeling. Kangaroo contains various ways of generating the forces that can affect the particles (objects having masses, volume…) in the simulation. In our case study spaces are addressed as mass elements, i.e. particles in Kangaroo.

Information regarding the orientation, the site limit and the relations between different spaces will be computed. These constraints are used to identify the position of each space.
The force-based approach drives the behaviour of spaces caused by the identified forces. Many types of forces can be combined in the Kangaroo plug-in for finding the final form. (https://docs.google.com/document/d/1X-tW7r7tfC9duICi7XyI9wmPkGQUPIm_8sj7bqMvTXs/preview)

In our case study, we have combined the three following types of forces: (1) Plaw, (2) Springs from line, and (3) Pull to surface:

4.2.1 Plaw
This shows a power law force with exponent -1, which means that the strength of the attraction is proportional to the inverse distance between the particles. This force was used to keep the particles (spaces) adjacent after the simulation process.

4.2.2 Pull to surface
This force is used to constrain or pull particles (spaces) to a defined surface. It was used to orient our spaces/particles position according to the following constraints:

- Orientation, where habitation clusters were "pulled" to the south in order to have more solar gain.
- Entrance, where the surfaces related to the entrance and service were "pulled" to the site access.
- Site limit, in order to maintain spaces inside the limit of the site, all of them were "pulled" inside the site limit. This operation was computed manually, by defining fictive surfaces representing the site limit. Alternative solutions were possible. However, the created definition helped us to execute the desired requirement.

4.2.3 Springs from line
This force was used to maintain the constraints related to the linking between spaces. Once the identification of the relations between different spaces defined, these relations were maintained after the simulation of the above-mentioned forces by using the "springs" force.

On the other hand, the notion of space syntax was useful for understanding the relation between the multi-spaces, this component was used to express one aspect in the analysis and the optimization of spaces: identifying structural connections in the layout of the network. To achieve these connections between the spaces, it was necessary to introduce this calculation to a parametric environment. The Space Syntax plug-in aims to optimize this approach using a computational method in Grasshopper and Rhino 3D system.

4.3 Application scenario

Wars in the world have forced millions of people out of their homes and communities, some living in camps across different countries, and others having to restart their lives in foreign countries like Luxembourg. For the refugees coming to live in the Grand Duchy, there appears to be hope, as Luxembourg is providing 3 terrains where the construction and implementation of container villages will take place. Our demonstrator was based on a real case terrain situated in the municipality of Diekirch in northeastern Luxembourg. It consists of 3.6 hectares of land in front of the military barracks "Grand Duke Jean".

The Google Map's terrain is first transformed into a numerical entry in a 3D software system (Rhino 3D). A first analysis of the selected site is performed in order to identify the constraints that should be implemented in the algorithm definition for the macro-planning layout. The overall capacity expected for the village is 300 beds (600 in case of an emergency situation). A first design choice was to separate three distinct clusters, dedicated to three ethnographic groups based on the origins of refugees. The development of the village requires 7 spaces dedicated to (1) clusters, (2) reception area, (3) feeding centre, (4) educational area, (5) services, (6) gathering, and (7) entertainment.

Fig. 1. Diekirch site in Luxembourg

Table 3. Usage requirements regarding the living clusters, as input design dataset

	Clusters	3		
Clusters configuration	**Origin ID**	**C1**	**C2**	**C3**
	Nb of person	75	100	125
	Nb of containers needed	28	50	63
	Couples	7	10	16
	Kids (<18)	16	24	34
	Singles	15	20	41
	Old	5	11	18
	Cluster surface	2250	3000	3750
Services	Nb of latrines needed by cluster	4	5	7
	Optimum distance of latrine from household (m)	< 50		
	Nb of showers needed by cluster	1	1	2
	Feeding center	1		
	Water waste tank retention			
	Water point	1	2	2
	Distance from furthest dwelling to water point (m)	< 200		

4.4 Implementation of constraints

In this application, the constraints are related to the site conditions and to the usage requirements in terms of respecting area and international standards.

4.4.1 Contextual constraints

Site accessibility: The accessibility of the site by roads will help in determining the land uses in dependence on this constraint (e.g. services and central reception area). In this village one access for the site from external roads is identified. This access was logically placed in the south part of the site (existing road).

Site orientation: The orientation for the land uses is defined according to the sunlight exposure. It is expected to maintain a comfortable environment for living. The southern part of the site is the one most exposed to the sun.

Site constructability: The identification of specific physical elements on site (river, trees…) helps in evaluating the site constructability in order to avoid these elements in the automatic design development. In the Diekirch site, no boundaries related to geographical aspects were identified.

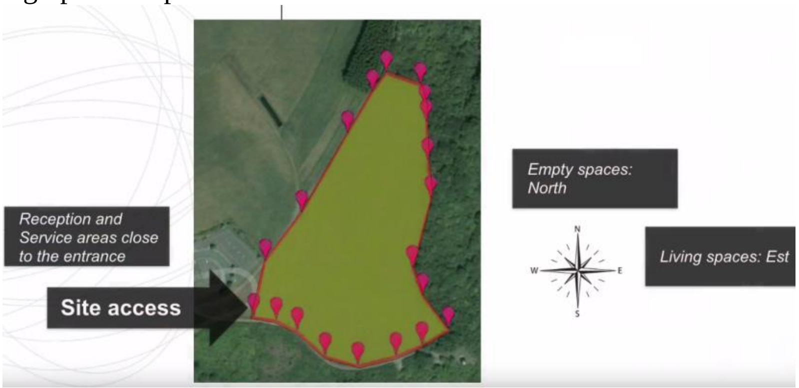

Fig. 2. Some of the site-related constraints identified

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Usage requirements: The requirements in term of usages and the relationships between these usages are expected to be maintained in the design process. Space Syntax was used to generate the graphical representation of the relations between the different usages.

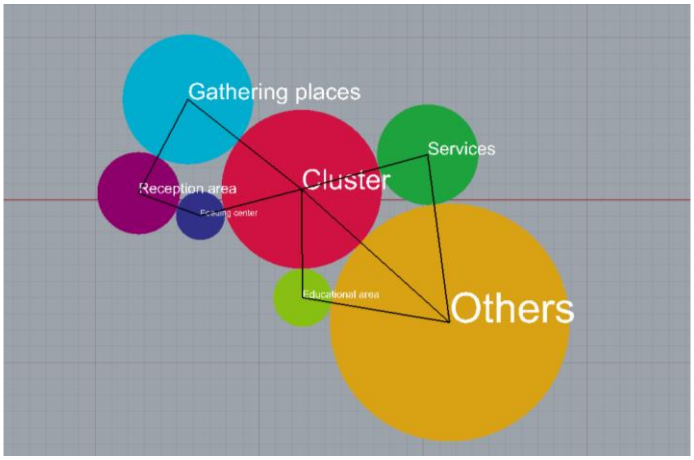

Fig. 3. Usage requirements relations, space syntax representation

This graphical representation is projected to the site conditions. Usage spaces are computed together with the identified constraints, in order to distribute and optimize the spaces of the site taken into account: (1) the constraints and (2) maintaining the relations between them. The relations between spaces were implemented using “Kangaroo” plug-in for “Grasshopper”.

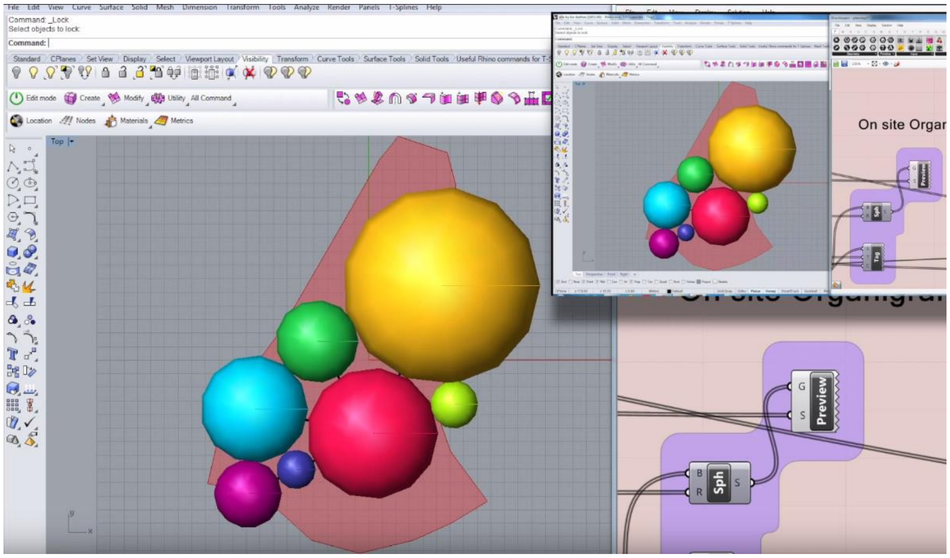

Fig. 4. On site optimization (Rhino 3D, Grasshopper)

4.4.2 Numerical constraints

Number of persons: The number of persons is defined as 2 persons per container; this will lead to have 150 containers in the village. As a result, the number of required sanitary facilities is a fixed value. These two values are implemented in the generative design process.
Dimension of the containers: This attribute can be interpreted sometime as constraint or as variable.
The dimension of the containers might change from one container to another, but in this example we have referred to a specific type of containers to use in the whole village.
Specific requirements: The design of containers should take into account that sanitary containers should be superposed in order to facilitate the evacuation of used water. In addition, the areas of different spaces have been respected according to international guidelines and standards.

4.5 Implementation of Variables

Problem solving requires the extraction of specific variables in terms of parameters (physical and contextual) and relations between them. Among the list of identified variables, parameters are chosen for the design and modeling demonstrator. The chosen parameters are specified according to their importance in the container village design. In this demonstrator, the chosen variables are mostly related to physical aspects.

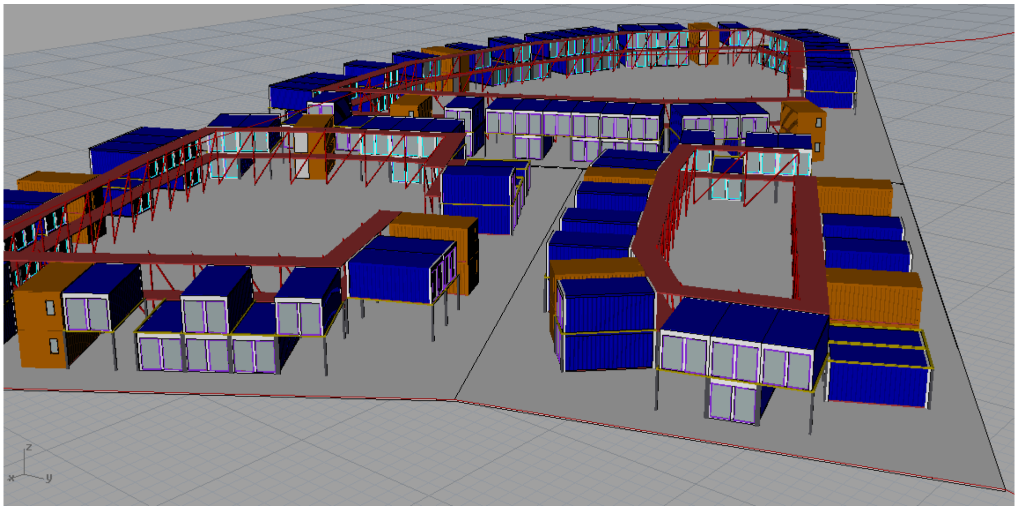

Fig. 5. Visualisation of the final automated configuration of clusters

These chosen variables are: (1) the general configuration layout of the clusters, (2) the definition of the entrance to the clusters, (3) the number of stories, (4) the parameters related to the passage between stories, (5) the structural elements.

Conclusion

This paper describes a research work carried out to investigate the potential application of computational design to assist humanitarian activities. It addresses the capability of parametric modeling in assisting the development of container villages for refugees, in order to help architects, humanitarian people and policy makers in the strategic planning and decision-making. It starts with developing a design process for the container village. This process is based on the optimization of the spatial layout related to expected usages, taking into account contextual constraints (e.g. site accessibility, orientation, etc.) and numerical constraints (e.g. containers dimensions or number of received migrants, etc.).

The output of this research consists of a prototype capable of generating a village of parametric containers from data requirements. This prototype is based on generative design where the constraints and part of the design process related to refugee camps are computerized. This approach contributes to the resilience of cities and territories facing the problem of migrant flows.
The current prototype has some limitations. The research focuses on the identification of parameters for modeling a prototype shelter and a layout of a camp. Aspects related to construction materials and costs are not considered in the implementation, at the moment.

The originality of the proposed idea relies on the innovative capacities of intervention in urban planning based on generative design for more responsiveness and efficiency. The parametric approach proposed should help in (1) enhancing the quality and reducing the time needed for the planning, especially in the initial steps, (2) enabling a smooth collaboration and information exchanges between different stakeholders, (3) allowing non-experts to contribute to the development of urban planning, through the rapid 3D visualization, and (4) providing a generative decision-support computer system based on computable parameters.

As future research work, this generative and iterative process will be implemented in other use cases to generate design alternatives regarding the expected usages allowing deeper testing and evaluating of the effectiveness of this design process. In order to review this system, different experiments describing different scenarios will be created instantly by modifying the parameters to test the ability of the design process to answer scenarios similar to real cases. The research will also focus on the optimization of the interior elements of containers in order to answer the needs of refugees in terms of functions and usages.

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Authors

Elie DAHER, Arch. He studied Architecture in Lebanon, (he is graduated from the Institute of Fine-Arts, department of Architecture, Lebanese University, Tripoli, Lebanon, in 2009). After four years of experience acquired in well recognized construction projects in several countries, he pursued the Master of "Global Design, specialty Architecture, Modelling and Environment" at the "Ecole Nationale Supérieure d'Architecture" of Nancy, France in 2014). Since February 2015, Elie Daher is a R&D engineer at LIST. His applied works are covering the design computing, BIM processes, BIM management, BIM implementation, 3D coordination, 4D BIM simulation, parametric architectural modelling and optimisation.
ORCHID ID: 0000-0003-4423-2914

Sylvain KUBICKI, Dr. Arch. He studied Architecture in France and Switzerland. He was graduated from the Architecture School of Nancy, France, in 2003. He got a PhD in Architecture Science, with a thesis entitled "Assisting flexible coordination in building construction activity. A model-driven approach to design cooperation context visualization tools". He is now Senior Research and Technology Associate at Luxembourg Institute of Science and Tehnology, working on Building Information Modeling and construction technologies, both through research projects and consultancy services.
ORCHID ID: 0000-0003-2985-0378

Annie GUERRIERO, Dr. Arch. She is a senior research engineer at the Luxembourg Institute of Science and Technology (LIST, Luxembourg) where she workds since 2005. She is an architect graduated from the Victor Horta Institute (Brussels, 2001) and she performed a master in "Modelling and simulation of built spaces" (Henri Poincaré University, Nancy) in 2002. She obtained her PhD in April 2009 in Architecture Science at the INPL (Institut National Polytechnique de Lorraine). Her thesis, entitled "Representation of trust in the collective activity. Application to the coordination of the building construction activity", suggests a new approach for coordinating the AEC (Architecture, Engineering and Construction) activity based on trust assessment and multi-visualisation. This work received a distinction by the Academy of Architecture (France) in 2010. Currently, her research works is led at the LIST in the field of Building Information Modeling, smart systems and collective decision-making support dedicated to the construction sector.
ORCHID ID: 0000-0002-8804-1995

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BUSINESS MODEL STRATEGIES: FLEXIBILITY TRADE IN LOW VOLTAGE DISTRIBUTION NETWORKS[12]

Patrick Lynch[1], Jamie Power[1], Richard Hickey[1] & Thomas Messrevey[2]

[1] RIKON-Waterford Institute of Technology, Waterford, Ireland

[2] R2M Solution, Pavia, Italy

E-mail to Corresponding Author: [1] plynch@wit.ie

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Abstract. Empowered by information and communication technologies (ICT) analytics and smart technologies, the energy model landscape is changing with flexibility at the core of a new energy market design. In particular, multi-sided platforms (MSPs) has gained prominent attention as a business model that creates value by enabling direct interactions between several distinct groups of actors who need each other in order to deliver products to their customers. However, as MSPs are less familiar within the energy market, there has been little investigation in modelling this emerging and dynamic ecosystem. Utilising the business modelling methodology of value network analysis and the key informant technique, value flows were modelled within the context of a MSP to understand the creation, delivery and capture of value in a network of interdependent relationship, its networked position and the stakeholder interactions required for delivery of local flexibility. Supported by this analysis, this paper focuses on the LV area of the smart grid, and presents the Local Flexibility Market (LFM) as a Multi-Sided Plarform. In comparison to the traditional utility model, the complexity of this recharacterization of the industry ecosystem is significant. While it presents new opportunities for incumbent energy providers to collaborate and develop new products, the proposed LFM market design will also dramatically reshape the value model of the industry.

Keywords: Smartgrid; Low Voltage Grid; Flexibility Management; Local Flexibility Market; Local Flexibility Aggregator; Prosumer; Local Energy Community; Multi-Sided Business Models

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Additional disciplines : Software Engineering, Sociology

1. Introduction

Developing infrastructures, technologies and supporting business models to unlock energy market flexibility is currently one of the core questions discussed in various key energy policy circles in Europe (European Commission 2015 a; b; EC Europa 2015). In an environment of increased deregulation, competition and collaboration, achieving a demand-responsive smart-grid depends not only on the intersection between ICT and energy infrastructure but equally on sustainable business models and stakeholder collaboration (Mourshed, et al., 2015). The technologies, methods and aspects surrounding the smart grid are disruptive innovations that present both challenges and opportunities to utility business models and the actors involved (Lynch et al., 2016a; b; Ala-Juusela et al., 2014). For the power industry, business as normal will likely not be possible and those maintaining traditional practices will likely fall to competitive pressures. Driven by both technology developments and policy targets, Europe's energy system is and will continue to undergo significant transformations, with flexibility as a cornerstone of emerging energy market design. *"We are transitioning away from a power system in which controllable power stations follow electricity demand, to an overall efficient power system where flexible producers, flexible consumers and storage systems respond to increasing intermittent supply of wind and solar power*" (BNE, 2015: 1). Within this vein of transformation, increasing focus is being placed at exploring the local level markets. Decentralised energy (DE) is energy generated at or near the point of use and involves offers buildings (including both domestic and residential) doubling up as power stations via their usage of generating technologies such as solar panels, wind turbines or cogeneration units. The growing interest in local energy communities is further fuelled by the increasing adoption of both distributed energy resources (DERs), and residential Internet of Things (IoT) devices.

These advancements are paving the way for paradigm shifts in the energy generation/distribution system. Indeed, moving from a unidirectional electricity grid system that delivers energy from centralized power plants to customers through transmission and distribution lines represents a disruptive shift (Wainsteina & Bumpus, 2016). Such transformations in energy systems, necessitates the need for exploring the role of innovative business models and adapting, and in some cases creating new stakeholder roles, to realise the opportunities available associated with flexibility in local market contexts from the context of Prosumers ("pro" in prosumer comes from production) and aggregators (Steinheimer and Ulrich, 2012; Rathnayaka, et al., 2011). In comparison to the traditional utility model, the complexity of this recharacterization of the industry ecosystem and business model is significant. To date, energy market actors have primarily focused on technology advancement within the smart grid which is within their comfort zone, however, this recharacterization will also require a call to action to engage in business model transformation which is new to most (Valocchi et al., 2010)

In this fashion, the main contribution of this paper is that from an ecosystem perspective, the business modelling methodology of value network analysis (VNA) was utilised (Peppard and Rylander, 2006) to develop a multi-sided business model (MSP) for a local flexibility aggregator to facilitate flexibility management between Suppliers, Wholesale Market Aggregators (WMAs), Distribution System Operators (DSOs), Consumers and Prosumers in the Low Voltage area of the grid. This paper argues that empowered by ICT, analytics and smart technologies, the emergence of the Prosumer as an active participant in the energy value chain will herald the era of multi-sided platforms (MSPs) which fundamentally changes the energy model landscape with flexibility at the core of a new energy market design. The rest of the paper is structured as follows. In the next section we discuss the business model shift to MSPs. Section 3 defines the Local Flexibility Market (LFM) and the actor's roles. Next we present our intial findings around the conceptualsing the LFM as a MSP. Finally, Section 5 states the concluding remarks and discusses some directions for future works.

2. Business Model Shift

The traditional power grid was designed only to carry energy from few central generation points to the final users. Today however, the power grid is facing a series of new demands (Mourshed, et al., 2015). Following the adoption by EU countries of the Directives for the reduction of CO_2 emissions, the last 10-15 years have seen the increasing penetration of Renewable Energy Resources (RES) on the grid. Typically located at the Medium Voltage (MV) and Low Voltage (LV) levels, these intermittent and fluctuating distributed energy resources (DERs) require management to maintain grid stability and balance. The grid also continues to electrify. More users have higher demand profiles. Especially in urban areas, increasing grid capacity and avoiding grid congestion is a challenge. This will continue to worsen with the welcome increased penetration of electric vehicles although as storage systems their batteries can also provide solutions (Dupont et al., 2012). More and more, there is the need to manage and plan grid operations at the low voltage level where Consumers, Prosumers, Suppliers, WMA and DSOs will need to act and collaborate in new ways (BNE, 2015).

Converging evidence indicates that there is a real opportunity to resolve or mitigate some of the current challenges through the harnessing information and communication technologies (ICT), analytics, control strategies and smart devices for automating changes in how and when consumers consume, generate or store electricity (Euopean Commission, 2015a). When Consumers or Prosumers agree to change their planned consumption profile, this is called flexibility and the consequent shifting of loads can provide one tool to manage network capacity, congestion, and to achieve balance at local levels. If homes can individually and collectively level their demand load profile, then the generation, distribution and storage of electricity at the LV level (and indirectly at higher voltages) can be optimized (Lennard et al., 2015). Indeed, the increasing rate of intelligent domestic devices provides a real impetus for a smarter distribution network by creating a novel market energy model to maximise the advantages of DERs through smarter coordination of a prosumer community and DERs to provide more flexibility at the LV level. Smart consumers and prosumers are defined as those that use demand response to shift their flexible loads. Prosumer communities imply a collective force that would theoretically influence, and be influenced by the local energy market (Lynch et al., 2016a). Local flexibility is at the cornerstone of this new emerging energy market design (Rathnayaka, et al., 2011).

Bringing this opportunity to a reality, the formation of prosumer communities implies that they should have an intermediary to help manage DG (Distributed Generation) and DS (Distributed Storage) with regards to the injection of unused capacity to the LV-grid. A new role of a flexibility manager (Hagui, 2015) or aggregator (Valocchi et al., 2010; 2012) is foreseen in the energy value chain to act as an intermediator and facilitating agent between prosumers and traditional market players. The role being developed is one that combines the main aspects of flexibility management (Rochet, 2003) and aggregation (Ondrus, 2015) labeled the Local Flexibility Aggregator (LFA). The LFA represents a community of prosumers who through their own smart technologies will also become an integral part of the value chain as providers of flexibility. DSOs will be able to buy flexibility from LFAs to locally deal with congestions and increase grid performances and reliability (Lynch et al., 2016a).

In comparison to the traditional utility model (see Richter, 2012), the complexity of this recharacterization of the industry ecosystem is significant. While it presents new opportunities for incumbent energy providers to collaborate and develop new products and services, it will also dramatically reshape the value model of the industry as a whole and the value propositions required by the market (Wainsteina & Bumpus, 2016). As energy, information and revenue flows can happen in various combinations, the nature of value has changed as there are far more types of reciprocal value and combinations of actor exchanges to deliver value. Moreover, as new types of reciprocal value will be generated, new value added businesses and services and new participants to the ecosystem that traditionally would not have been directly involved in the industry will emerge (Mourshed, et al., 2015). Consequently, the value capture opportunities available to the ecosystem participants will continuously increase, as will the complexity of the business models to capture and exploit that business value opportunity such as “platform-based business models” that services interdependent customer segments in an ecosystem concept (Hagiu, 2014). In particular, multi-sided platform (MSP) has gained prominent attention (Ondrus, 2015) as a business model that creates value by enabling direct interactions between several distinct groups of actors who need each other in order to deliver goods or services to their customers (Rochet, 2003). The real challenge of understanding such an emerging and dynamic complex business platform is to map out the flexibility business model opportunities that will take advantage of the new network-enabled capabilities that will allow companies to reap as much of the ecosystems' new value (Rochet, 2003; EURELECTRIC, 2011). However, there has been very little investigation in modelling this dynamic ecosystem beyond viewing business model value creation from the perspective of an individual actor which is not very effective when trying to ignite network based business models. It is the network of collaborative relationships that provides the key to understanding and realizing the business model opportunities within the ecosystem concept associated with flexibility in local market context (Steinheimer and Ulrich T, 2012; Rathnayaka, et al., 2011).

3. Conceptualising the Local Flexibility Market as a Multi-Sided Business Platform (LFM)

On an individual level, flexibility is *“the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system”* (EURELECTRIC, 2014: 5). The parameters used to characterize flexibility in electricity include: the amount of power modulation, the duration, the rate of charge, the response time, and the location. Emerging in EU are technologies that allow for a two-way exchange between consumers and their energy supplier. Prosumers can be highly active in balancing the supply and demand of electricity as entrepreneurs, by storing electricity through electric car batteries or other storage facilities and providing electricity generated from renewable energy sources (RES), such as solar panels, or micro CHPs. Flexibility can be derived from various types of Active Demand and Supply (ADS) from small commercial and residential Prosumers, representing all the energy-consuming or -producing appliances that have the ability to shift, increase, or decrease their energy consumption or production (programmability, automation, etc.). Smart consumers and smart prosumers are providers of flexibility. In a smart grid context each end user will use flexibility provided by his own smart technologies to reduce the costs associated with the energy bill of his house. According to Lynch et al. (2016a) the specific set of smart technologies end users will use flexibility to self-consume, move loads when cost of electricity is lower or for more complex management strategies. In most cases the reduction of the energy bill will be the first driver for consumers to become prosumers. However, besides using it in the house, prosumers can decide to offer their flexibility as a product to other actors.

Customers of flexibility acquired from residential and commercial sources include other Prosumers in the local community, the DSO that distributes energy to that local community and actors in the upstream value chain which may include other DSOs, aggregators of aggregators, balance responsible parties or TSOs. In simplified terms and as illustrated in Figure 1, depicted in the right proportion of the dotted line, the classical energy system market model involves the reliable and universal sale of energy at reasonable prices by utilities to consumers. Information flows (billing information from utilities to consumers) and revenue flows (from consumers to utilities) are unidirectional and the consumer plays a passive role (Lynch et al., 2016a). This ‘one-sided’ market model is called the “Utility” business model and has been largely unchanged over the last century.

The unbundling of energy markets and emergence of renewable energy technologies have begun to change the energy market model landscape (Dupont et al., 2012). The realization of the smart grid and emergence of a flexibility market will change it even more (Valocchi et al., 2010). This is depicted in the left portion of the dotted lines in Figure 1 which shows our conceptualization of a Local Flexibility Market model (LFM) where a LFA is between the consumer/prosumer and the upstream energy system actors (Lynch et al., 2016a). In comparison to the classical utility model, the complexity of the ecosystem is significant. Moving from a passive recipient of energy, within our conceptualsaion of the LFM, the Prosumer will now become an empowered and integral value chain participant offering flexibility (IEA-RETD, 2014). In a smart grid context each end user will use flexibility provided by his own smart technologies to reduce the costs associated with the energy bill of his house. According to the specific set of smart technologies end users will use flexibility to self-consume, move loads when cost of electricity is lower or for more complex management strategies (Rathnayaka, et al., 2011). In most cases the reduction of the energy bill will be the first driver for consumers to become prosumers. However, besides using it in the house, prosumers can decide to offer their flexibility as a product to other actors. In this sense, prosumers belonging to the community will be able to trade flexibility with each other in order to minimize the individual costs associated to their energy bill. One end user will not only rely on the flexibility provided by its own smart technologies, but will also be able to buy the flexibility provided by the other end users of the same community and globally reduce its bill. In addition, it will be possible to use flexibility in an aggregated - but still local – form to cope with local congestion problems (EURELECTRIC, 2011).

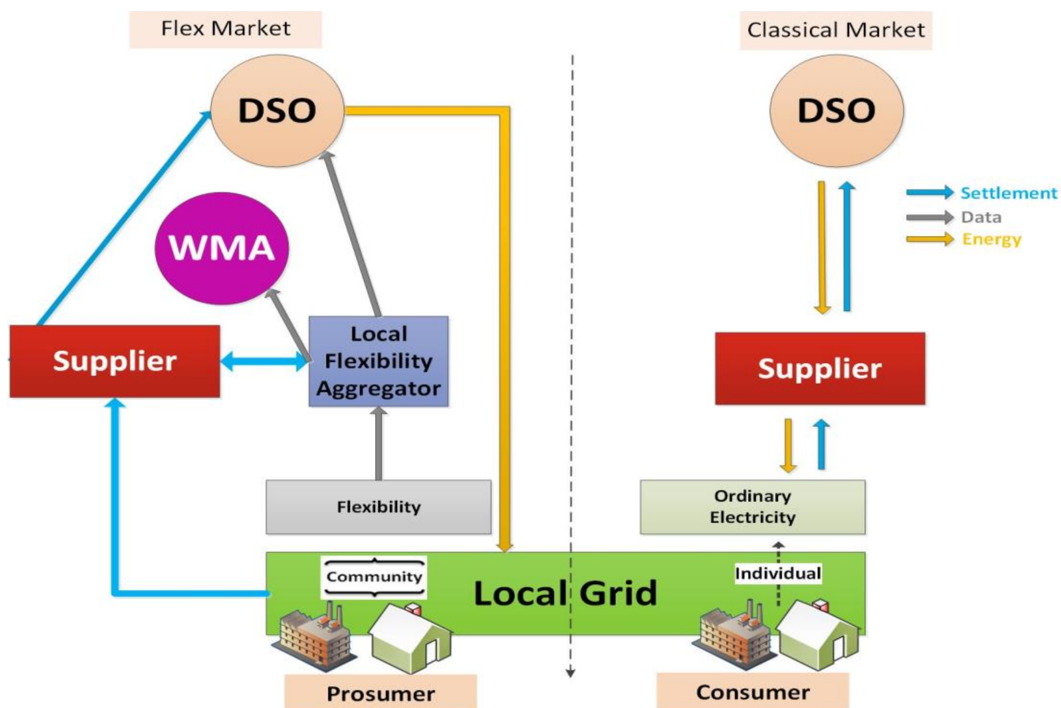

Figure 1. The Structure of the Local Flexible Market (LFM**)**

The LFA is responsible for acquiring flexibility from Prosumers, aggregating it into a portfolio, creating services that draw on the accumulated flexibility, and offering these flexibility services to the other market participants such as the WMA, DSO and other LFAs. Local flexibility is at the cornerstone of this new energy market design and is the added value of the proposed Local Flexible Market. The argument being proposed is that the centralised management of flexibility by the WMA is not always effective for congestion and capacity management and that local optimization of flexibility provided by the LFA ensures that flexibility is first used for in-home optimization; second traded at local level and; third aggregated for wholesale markets. For the DSO that provides services to a LEC, it is possible to use flexibility in an aggregated - but still local – form to cope with local congestion problems and capacity requirements. The DSO benefits from the local flexibility market in two ways. First, a more efficient and reliable distribution of electricity is possible because better balancing and predictability is attained at the local level. Second, investments to increase the capacity of the network can either be delayed or potentially avoided.

The problem with the evolution to the LFM proposed is that it is a grid of the future and the structure of the market place is uncertain. It will see the integration of the current market-based energy system and its players with new services and roles. These are required to unleash the added value provided by local flexibility, as described above. Table I presents a description of the actor roles and objectives in the LFM. There are additional actors in the ecosystem not depicted. These include telecom data services, security services and ancillary service providers. Key aspects when designing solutions for enabling flexibility management in the distribution network is that different actors and stakeholders will have different individual objectives that the system should optimize in order to guarantee their participation and interest to the proposed flexibility programs (Table 1).

TABLE 1. ACTOR ROLES & OBJECTIVES

Grid Actor	Roles in Classical Energy Market	Role in LFM	Objectives
Prosumer	The Prosumer is seen as a passive receipent and consumer of energy.	End users that provide flexibility. They may act through smart technologies or by changes in behavior. With renewables, they may generate to sell, self-consume or store electricity.	Save money and lower their electricity bills. Respect of comfort preferences and desired electricity use. Be more eco-friendly.
Local Energy Community	Aggregate the buying power of individual customers for energy savings. Focus on the integration of renewables.	Consumers and Prosumers that join together under a LEC to act in a coordinated way with respect to consumption, generation and storage. Financial and non financial benefits are possible. Potential to be a cooperative entity.	Save money and lower their electricity bills leveraging a community approach. Respect of comfort preferences and desired electricity use. Access to the Flexibility Market. Be part of an eco-friendly community.
Local Flexibility Aggretor	Does not exist	Central role in the MSP. Acts as an intermediary between the Prosumer/LEC and the flexibility market. Aggregates flexibility provided by Prosumer and LEC and sells it to the market players that require it.	Maximize the value of local flexibility for its portfolio, taking into account customer needs, economic optimization and grid capacity. Maximize profit. Build a client portfolio and position for cross selling opportunities between actors.
Wholesale Market Aggretor	Manage large amounts of load in a highly dispersed area in order to meet the requirements of producers, suppliers, BRPs and in line with the balancing requirements established by the TSO and the DSOs .	Will engage local agents such as LFAs to perform the customer acquisition role and local optimisation of flexibility to sell (Intenal) as a product offering to the WMA who performs the wholesale market role.	Maximize the value of wholesale market flexibility for its portfolio, taking into account customer needs, economic optimization and grid capacity.
Supplier	The role of the Supplier is to source, supply, and invoice energy to its customers. The Supplier acts as the single contract point for access to the electricity market.		Maximize its benefit when sourcing, supplying and invoicing energy to its customers.
DSO	Distributes electricity at MV and LV levels and ensures quality of supply while maintaining grid stability.	Acts as a purchaser of flexibility from LFA for congestion management and voltage control.	Use LV flexibility as a tool to reduce grid congestion, further ensure the security of supply and improve network capacity planning.

4. Conceptualising the Local Flexibility Market as a Multi-Sided Business Platform (LFM)

Many platforms are single-sided platforms, with a seller at one end and a buyer at the other and, often, intermediaries (distributors) between them that transfer the product from buyer to seller without changing it substantively. The electric power network has historically operated as a single-sided platform. However, within the LFM model presented, the LFA clearly holds the central position and provides the link between the supply of Prosumers flexibility on one side and demand for flexibility by the market players on the other side. From a business and market modelling perspective this type of market design is referred to as a two-sided or multi-sided business market (Hagiu, 2014). In essence, LFM should be viewed from a Multi-Sided Platforms (MSPs) perspective because it brings together different sets of actors who might otherwise not get the chance to engage with each other. Flows of interactions can travel from one side of the market model to the other and in a multi-directional fashion

Lynch et al., (2016c) presents a conceptualisation of the Local Flexibility Market as a Multi-Sided Platform (LFM) (see Figure 2). Table II presents a synthesised explanation of the interactions between the various stakeholders across a number of interaction flows.

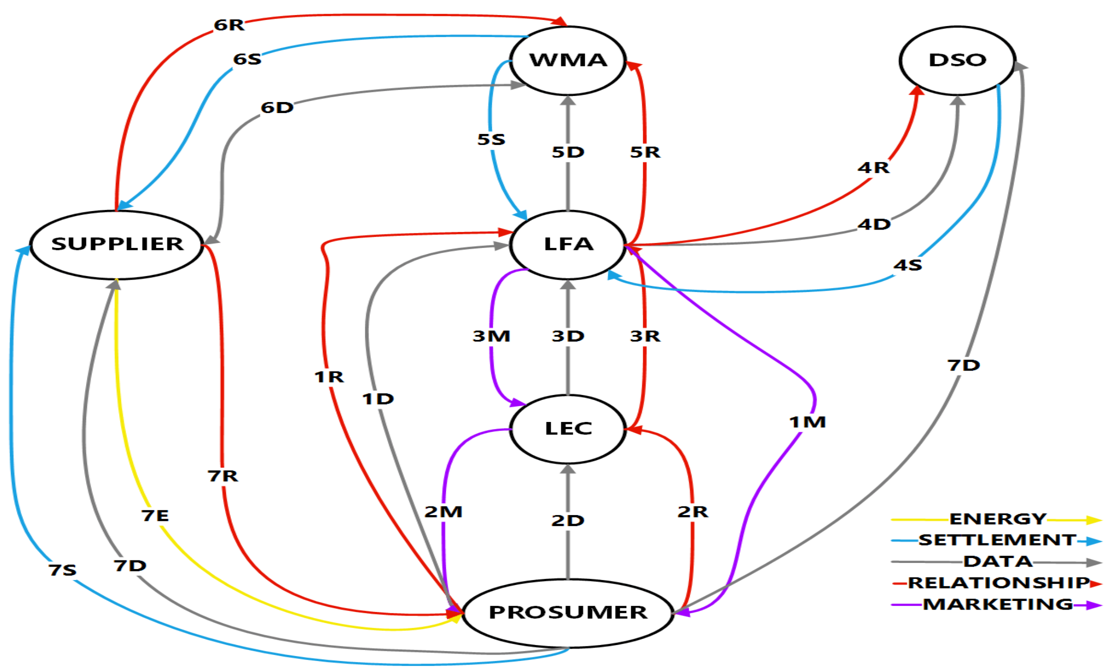

Figure 2. LFM and the LFA Relationships to other Energy Stakeholders

Table II. Actor Interaction Flow in LFM

Interacting Functions	Flow Type	Code	Flexibility Market Design
Prosumer – LFA	Relationship	1R	Prosumers are part of an LEC because they are associated to the same LFA by an individual contract. Prosumers have no knowledge of one another and are free to choose the LFA that they prefer
Prosumer - LFA	Data	1D	Prosumer provides flexibility to the LFA
LFA – Prosumer	Marketing	1M	Advertising flexibility services and education of market

Prosumer - LEC	Relationship	2R	Individuals sign up to a collective of local householders in order to manage the flexibility commodity (sale & settlement thereof).
Prosumer - LEC	Data	2D	Individual Prosumers pool their combined flexibility into a marketable commodity unit
LEC - Prosumer	Marketing	2M	Advertising flexibility services and education of market
LEC-LFA	Data	3D	The LFA buys the flexibility unit
LEC-LFA	Relationship	3R	The agreement governs the use of flexibility and settlement
LFA- LEC	Marketing	3m	Advertising flexibility services and education of market
LFA - DSO	Data	4D	The LFA provides the flexibility unit to the DSO.
LFA - DSO	Relationship	4R	Flexibility Service Contract. The agreement governs the use of flexibility and settlement.
DSO - LFA	Settlement	4S	Buying Flexibility for congestion management, voltage control and grid losses reduction.
LFA - WMA	Data	5D	The LFA provides an internal portfolio optimization for the WMA and occurs when the LFA receives a request from the WMA for the provision of flexibility in aggregated form (as per classical centralised management of flexibility).
LFA - WMA	Relationship	5R	Contract will be in place which governs the use of flexibility and settlement.
WMA - LFA	Settlement	5S	Buying Flexibility to optimise its function (portfolio optimisation).
WMA- Supplier	Data	6D	Information exchange in order to forecast future portfolio consumption.
Supplier - WMA	Relationship	6R	Energy imbalance service contract.
WMA- Supplier	Settlement	6S	WMA pays compensation to the Supplier based on market-based pricing of flexibility.
Supplier-Prosumer	Energy	7E	Supplier sells energy to Prosumer
Prosumer – Supplier	Settlement	7S	The Supplier agrees commercial conditions with its customers for the supply and procurement of energy.
Supplier – Prosumer	Relationship	7R	Contractual relationship
Prosumer – Supplier	Data	7D	Consumption Data. When flexibility contract is activated with the LFA, the Prosumer should inform the Supplier.
Prosumer-DSO	Data	8D	There is a data flow from the Prosumer to the DSO. Data is used to calculate distribution charges.

As a business modelling methodology, Value Network Analysis (VNA) facilitated the visualization, analysis and insight into the business exchange flows and network relationships within the MPS (Ondrus, 2015). Figure 2 clearly shows that the LFM involves a complex networked web of stakeholder interactions to create value. Indeed, the multi-directional flows of energy and data evidenced in the value flow map clearly shows a more sophisticated marketplace and provide us with a contextual understanding of how a networked economy or multi-sided business platform could potentially materialize (Lynch et al., 2016c). As the LFA is serving multiple customers and facilitating the interactions those customers have with each other, the market model clearly matches any definition of a multi-sided business model that is bring together two or more distinct but interdependent groups of customers (Rochet and Tirole, 2003).

In general, the LFM provides a mechanism for providers and buyers of products and services to interact and co-create value that could not be created individually. For Lynch et al. (2016a) this is what makes the business model for the LFA multi-sided and complex in that it will be required to create, deliver, and capture value to multiple actors in the market. No current actor in the traditional model has a multi-sided nature to their business model so this will require the development of significantly different business model for whoever takes on the role of LFA. Revenue models within the MSP will be quite complex as the different trades along the value chain in the LFM are answered for and settled (Hagiu, 2014). The revenue flow will not only consist of funds as owed power for flexibility, reduced penalties, and other new forms of value capture enter into the business models of the actors in the LFM. There will also be multiple types of buyers and/or sellers and, in fact, a single party can be both a buyer and a seller. While customers are becoming more demanding, they also have much more to offer in return to power providers and other participants than just payment for energy consumed. Some of these new elements of reciprocal value are primarily operational in nature; demand response, load profile flexibility, and distributed power and storage allow for optimization of system performance and asset utilization. Others, such as information on energy consumption patterns, other consumer demographic and behavioural information, and access to personal connections/networks for marketing purposes, are the foundation for new revenue sources for companies able to effectively leverage the increased information and existing infrastructures.

Conclusions

Local flexibility is at the core of the emerging energy maket model landscape. Although emboynic, complex and challenging, this new market landscape holds new business and collaboration opportunities for all stakeholders and is the focus of our ongoing research endeavors. The emergence of prosumer communities changes the roles of the consumers in the local grid from having an individual passive relationship to an active participant in the value chain. Indeed, for the first time, end users will be empowered to participate directly in the electricity market and with greater choice. Consequently, businesses will have to become far more attuned to the needs of the prosumer, design new value propositions to maintain and attract their business and utilize the collaboration potential of their value chain network to provide a more responsive and interactive service model. In this paper, we proposed a LFM that involved local energy communities and where a local flexibility aggregator facilitates flexibility management between supploer, distribution system operators, and consumers/prosumers. While it presents new opportunities for incumbent energy providers to collaborate and develop new products, this recharacterization of the industry business platform brings with it additional constraints and challenges. There are obvious constraints to prosumer participation in that the amount of savings possible is going to have to be greater than the cost of investment to enable participation. Another constraint concerns privacy issues particularly in relation to data ownership. A particular challenge of MSPs is that a critical mass of prosumers will be required to create the network effect whereby all the other business actors around the LFA will come on board, which is often referred to the chicken and eegg problem. Indeed, inorder to ignite the LFM, the LFA will have to devote much attention to designing innovative business strategies to get on-board as many early adopters as possible in order to drive this network effect.

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Authors

Patrick J. LYNCH is the director of RIKON-WIT, a business innovation research centre located in Waterford Institute of Technology in Irekand. He has published extensively on business models and networked innovation in top-tier journals and peer-reviewed conferences and has received numerous accolades including the 2013 Emerald Global Literati Prize for Excellence. He has amassed considerable industry, consultancy and applied innovation research experience in process optimisiation, business & market modelling & digital transformation. Patrick manages a team of 40 plus researchers and business strategirss and is the principal investigator on over 450 innovation and research projects that are recognised for making real transformational change in business and re-imaging how companies can identify tactical business opportunities to grow business volume and develop breakthrough strategies and innovative business models to seize those opportunities and transform their organization to execute the new growth strategy. Of particular interest to Patrick is the new data-driven business models that are transforming the energy supply chain and re-defining the role of the stakeholders in these new networked market models.
ORCID ID: 0000-0002-5406-3846

Richard HICKEY is a Business Development Strategist in RIKON-WIT and works closely with organisations to find solutions to their business model challenges by developing and applying various research methodologies and helping them achieve their research goals. ORCID ID: 0000-0002-4521-8295

Jamie POWER is the EU Research Programme Manager for RIKON and leads the development of RIKON's national and European project, collaboration and research funding activities in addition to coordinating the Group's knowledge transfer, publication and dissemination agendas. Jamie's research interest includes the evolution of business models and the interaction dynamics of stakeholders in networked business and market models.
ORCID ID: 0000-0003-1550-7982

Thomas B. MESSERVEY is the Chief Executive Officer, R2M Solution and has over 20 years of engineering experience spanning military service in the US Army Corps of Engineers, Industrial Experience with the Italian Engineering Company D'Appolonia, teaching excellence at the United States Military Academy at West Point, and Coaching services as the EU Facilitator for the Intelligent Manufacturing Systems program. He serves as an expert for the European Commission in textiles, manufacturing, and energy efficiency. His research interests focus on using sensor data to make better engineering decisions across design, assessment, maintenance, inspections, and energy management to include machine learning. He is passionate about linking international research efforts to boost competitiveness. He is a member of the International Association of Bridge Maintenance and Safety (IABMAS), the International Association of Life Cycle Civil Engineering (IALCCE), and a technical reviewer for the International Journal of Safety and Security Engineering and the Journal of Structure and Infrastructure Engineering. He is an organizer of the annual International Electronic Conference on Sensors and Applications.
ORCID ID: 0000-0003-1746-9975