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TRANSITION PROCESS FOR SMART GRID COMPATIBILITY IN RESIDENTIAL BUILDINGS

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Abstract:
Urbanization itself accounts for a vast amount of energy and cities are centres of resource consumption and buildings can account for 40-60% of the urban energy usage which mostly relies on high Green-House-Gas (GHG) emitting fossil fuels. Climate change and other environmental concerns drive the policy initiatives to be renewable energy oriented. Increasing the share of renewable sources in the energy mix may damage the infrastructure due to the nature of current energy grid. Significant increase in the energy demand and the case of renewable energy penetration to the grid makes it inevitable to improve the transmission grid. Smart grid technology emerged as a result of these requirements. Smart grids provide higher quality of power that will enable saving money wasted from outages, they are more efficient and they have higher capacity for penetration of intermittent power generation sources. UK policy points that a transition to smart grids is in the agenda and will be implemented initially until 2020 and developed further until 2050. This paper justifies the requirement for a transition strategy in terms of retrofitting and design solutions at building level and neighbourhood scale in order to be fully compatible with Smart Grids. It is discussed in the paper that Smart Grid implementations and appropriate energy retrofitting in residential buildings would be the major drivers of achieving the UK Zero-Carbon Homes target and other national and EU wide environmental sustainability schemes. This paper indicates the visionary stage of a wider PhD research which adopts case study research methodology.

Keywords:
Smart Grid, Renewable Energy, Zero Carbon Homes, Green House Gas (GHG)

1 Introduction

To cope with building related climate change, through its “*Building a Greener Future policy statement”* in 2007, the UK Government has committed to reducing carbon emissions from domestic buildings to ensure that all new homes will be zero-carbon by 2016 (Communities and Local Government-UK, 2010). As simplified by BRE Environmental Assessment Model (BREEAM), zero carbon describes the case when the amount of energy taken from the grid is less than or equal to the amount put back through renewable technologies (BREEAM, 2010). The implementation of the policy stated above is the package of regulations called the Code for Sustainable Homes which is an assessment and rating system covering key areas including water, energy and CO2 and the aim of the code is to improve the impact of new homes build after May 2008 (Communities and Local Government-UK Code for Sustainable Homes, 2010).

The Code for Sustainable Homes, on the overall seems to be a good approach against climate change, but when it comes to the implementation, three critical questions emerge. Firstly, as the 'zero carbon' scheme offers feeding the grid with renewable sources, how suitable is the electricity grid for two way energy distribution? Secondly, since the renewable sources are intermittent or periodically fluctuating, is the electricity grid reliable enough to accommodate uncertain oscillations of power? And finally, what is the efficiency of the grid hence the efficiency will affect the quality and quantity of the renewable energy generated by "zero-carbon homes" circulating within electricity distribution and transmission infrastructure?

The given questions above point out that a sustainable carbon reduction implementation strategy should focus not only on the building regulations but also the electricity grid.

Butler argues that the UK electricity supply industry (ESI) and the National Grid Company (NGC) currently have the ability to cope with 10% intermittent energy (mainly renewable energy types like wind and solar) but with an increased interest in clean energy sources, current grid needs an upgrade to enable increased security and reliability to embed larger proportions of renewable energy sources into to energy scheme (Butler, 2001). This upgrade requirement of the grid emerges the smart grid concept.

This paper covers a part of a PhD research that seeks an answer to research question "What is the optimum implementation strategy to build a 'Smart Grid Compatible' neighbourhood?" Based on the research question, the aim of this research is to develop an implementation strategy framework for effective design and build of the smart grids at neighbourhood level. Salford Energy Hub will be used as a test-bed throughout the research and the research methodology to be adopted is the case study research that will mainly cover on-site feasibility studies, measurements of appropriate physical parameters and data analysis.

2 Literature Review

US department of energy states in their "Grid 2030: *A National Version for Electricity's Second 100 Years*" report in 2003 that over the past 50 years, electricity networks have not kept pace with modern challenges such as:

- Security threats, from either energy suppliers or cyber attack
- National goals to employ alternative power generation sources whose intermittent supply makes maintaining stable power significantly more complex
- Conservation goals that seek to lessen peak demand surges during the day so that less energy is wasted in order to ensure adequate reserves
- High demand for an electricity supply that is uninterruptible

Moreover, Paskal (2009) highlights that a big proportion of current energy infrastructure lies in areas that are predicted to become negatively affected by environmental change.

Owing to indicated weaknesses, it seems inevitable to improve the current electricity infrastructure. The initial step logically should be reducing the stress over the grid. Although the main purpose lying beneath was to supply affordable housing, higher environmental standards are also at the core of Eco-Towns approach (Cooper, 2007). Along with approaches to embedding sustainable behaviors among the community, Eco-Towns are planned in a way which supports low carbon living (HM Government, 2010). The study conducted by Campaign to Protect Rural England (CPRE, 2010) show that there are already some Eco-Towns or similar eco developments in England and in other European countries:

- Northstowe (UK): It is a new community in Cambridge and occupies 9500 new homes that are aimed to consume up to 50% less energy and water
- Vauban (Germany): It is a district of 5000 homes which offers 50% less traffic by car share scheme and also occupies 100 energy producing houses.
- The BO 01, Malmo (Sweden): It consists of 600 homes that are 100% reliant on renewable energy
- Nieuw Terbregge, Rotterdam (The Netherlands): It contains 860 homes and CO2 emissions are up to 55% lower than new housing produced in 1996.

It is seen from the examples that, the most common property of these eco developments are generating whole or a proportion of their energy usage, which can more broadly be explained by “microgrid” concept. Microgrids are generally defined as low voltage networks with Distributed Generation (DG) sources, together with local storage devices and controllable loads (e.g. water heaters and air conditioning). They have a total installed capacity in the range of between a few hundred kilowatts and a couple of megawatts (Homer Energy, 2010). The Microgrid technology, as stated in the examples, reduces the stress on the grid and helps to achieve low carbon living at a neighbourhood level. However, when it comes to meet high load demands with renewable energies such as heating requirements in extreme climates, microgrids may not be self sufficient. Bulk penetrations of renewable energy sources require more holistic solutions and that is the point where Smart Grid concept emerges.

Greenpeace and the European Renewable Energy Council (EREC) support the smart grid concept because it is an innovative approach to accommodate high percentage of renewable energy in a reliable and cost effective way and which is highly protected via intelligent management systems against blackouts and brownouts (European Renewable Energy Council, 2009; Energy Future Coalition, 2008). The Strategic Research Agenda released by the European Union Technology Platform (2007) indicates that EU adopts a Smart Grid vision to renew its aged transmission systems with a highly reliable, accessible and cost effective power supply across Europe.

European Smart Grid Technology Platform describes that a smart grid is not a piece of hardware or a computer system but, rather, a concept. As its name implies, the smart grid is about an intelligent electric delivery system that responds to the needs of and directly communicates with consumers. While there are many facets to the concept, the smart grid is really about three things: managing loads more effectively, providing significantly more automation during restoration after an outage event, and enabling more interaction between energy providers and consumers (European Commission Community Research, 2006).

ESRI White Paper on Smart Electrical grids summarizes the main drivers of smart grid as below:

Greenhouse gas reduction: In response to growing concern over climate change, smart grid technology will contribute to the utility industry goal of cleaner emissions. It will do this by flattening peak demands, thereby reducing the need for less efficient and more environmentally damaging plants to come online just to meet the peak demands.
Customer price signals: Smart grid aims to create an understanding among consumers that electricity pricing varies significantly during the day. Allowing consumers to readily see this will influence their behaviour, perhaps initiating wiser use of energy.
Integration of renewable energy sources: The two most common sources of commercial renewable energy are wind and solar rays. Both are intermittent and tend to be more geographically dispersed than conventional power generation. So the grid will have to be smarter to deal with these less-conventional energy sources, especially as they become more prevalent. (ESRI, 2009).

3 Research Methodology

Boyd (2010) describes that research methods (quantitative, qualitative and mixed) are the tools which have been used for gathering data or evidence such as survey, interview, participant observation, questionnaire, etc and it does not mean ‘methodology’. As mentioned by Collis and Hussey, (2003, p. 55) the term methodology "refers to the overall approach to the research process, from the theoretical underpinning to the collection and analysis of the data”.

Due to the nature of the conducted research, the following methodology is proposed to be applied:

- Research paradigm of the study is positivism paradigm as the research seeks for physical solutions to the research question.

- Research approach is inductive because theory building for smart grid modeling for neighbourhoods is applied during the study

- The research requires multiple levels of analysis within a single study and that is why research strategy adopted is exploratory case study research as it focuses on the dynamics present in single settings.

- The research choice is mix-method as the study requires both qualitative and quantitative manners where appropriate – i.e. identification of criteria and validation contains qualitative approach whereas data analysis requires quantitative approach to be applied.

- The research requires cross sectional time horizons because loops are involved in the proposed process and additionally the proposed is framework is flexible and due to change along with the ongoing data collection.

- Data collection will include semi structured interviews with the experts in built environment and energy areas. Additionally, on-site measurements of parameters and technical reports will be used as source of data.

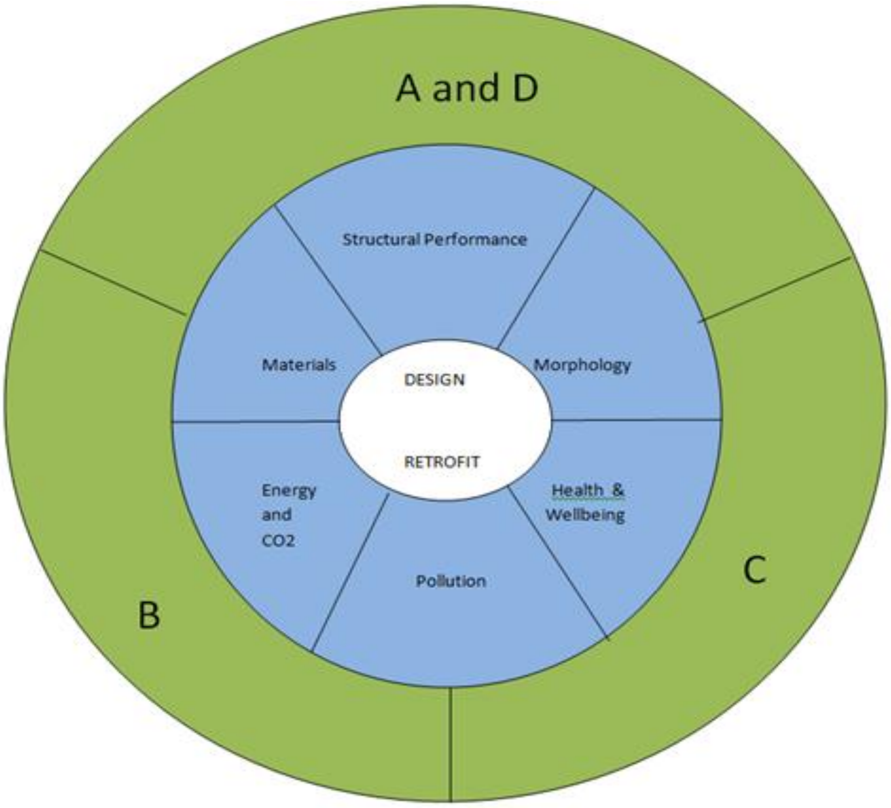
4 Findings and Discussion

This study is seeking to develop a framework that can be generalized for the decision making process of transforming or designing smart grid compatible neighbourhoods. Given Figure 1 illustrates the initial form of the framework which is due to change and revised during the data collection and analysis. A more mature framework is expected to be obtained after the interviews and field experiments. The overall aim of this framework is to create environmentally friendly built environments at a neighbourhood scale. As they are key elements of a neighbourhood, the framework starts dealing with building itself and enlarges to larger scale. The framework will enable necessary changes via design/retrofit in order to be smart grid compatible and it will also take into account that lowering energy demand is the key issue of achieving 'Zero-Carbon Homes' target.

The given framework works for two different quality and age of buildings. The scope of the research covers residential buildings only but the framework can be generalized to office buildings and industrial facilities after modification of inputs and the ontology.

Building types in the proposed framework are classified as new built and existing buildings.

'New-Built' dimension of the framework mainly occupies design related process that include building orientation, BIM integrated design, Broadband over power line (BPL) capable electrical fittings and finally a smart meter for two-way communications and energy management.



A	Storage and reverse transmission to the main smart grid
B	Identify site specific energy generation options
C	Identify and prioritize renewable energy sources
D	Design microgrid infrastructure for efficient distribution

Figure 1. Implementation Framework

'Existing Building' dimension of the framework (which is the inner circle shown in blue) is strongly relying on retrofitting process and occupies BIM for renovation and energy performance increase, Smart meter and energy display implementation for a real time and accurate energy consumption monitoring and finally wireless sensor network installation for occupancy related energy management.

'Microgrid' dimension of the framework (which is the outer circle shown in green) covers microgrid design according to the renewable energy sources available on-site. A microgrid may incorporate any micro-generation technology including solar, wind, Combined Heat and Power, Air and Ground Source Heat Pumps, Micro-Hydro and Geothermal applications. Due to availability, each house (or an onsite energy centre) can occupy any of the energy micro-generation technology. A microgrid can enable managing how to implement on-site generation, how to store and distribute the generated power. Smart meters play a critical role for grid connected microgrids by enabling two-way conduction and communication between homes and the grid; accepting both of them as consumers and producers at the same time.

4.1 Key Technologies

This section describes the key technologies and tools that are required in initial implementation framework. (Their usage areas are illustrated in Figure 1.)

4.1.1 Building Information Modeling

"A Building Information Model is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward." (National Institute of Standards and Technology, 2004). In this definition the models are characterized by intelligent representations of building elements and components; that include data to describe how they behave (analysis); in a consistent, non-redundant and coordinated way. They are developed using various software packages.

4.1.2 Geographical Information Systems

A Geographic Information System (GIS) is a computer-based system designed to collect, store, integrate, manipulate, analyze & display data in a spatially referenced environment. It allows you to analyze data visually and see patterns, trends, and relationships that might not be visible in tabular or written form (www.gis.com).

4.1.3 CityGML

CityGML is a common information model for the representation of 3D urban objects. It defines the classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantical and appearance properties including generalization hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. This thematic information goes beyond graphic exchange formats and allow to employ virtual 3D city models for sophisticated analysis tasks in different application domains like simulations, urban data mining, facility management, and thematic inquiries (www.citygmlwiki.org/)

4.1.4 Microgrid Technologies

Flowers and Dougherty (2002) describe that HOMER and ViPOR are tools created by NREL (National Renewable Energy Laboratory, US) and this research will adopt them to design and simulate microgrids. HOMER is software that designs and simulates hybrid energy generation systems. ViPOR is software that optimizes how micro-generation power is stored and distributed.

4.2 Embedded Process

Proposed process for the model embeds two main stages. This section explains the stages of the process and how the key technology explained previously is embedded. The first stage is "Building Scale Process" and the second one is the "Neighbourhood Scale Process". The model is aimed to work for the conditions of "Existing Buildings" and "New-Built Homes", that is why the terms 'Design' and 'Retrofit' are both present in the implementation framework. When it comes to term ‘design’, than the process is about soft simulation whereas the term ‘retrofit’ is about performance increase.

4.2.1 Building Scale Process

Given Figure 2 illustrates Process Stage 1, which is the building scale process of the model. It accepts BIM data (such as HVAC and materials) to make energy and retrofitting / design assessment and produces output related to energy and retrofit requirements of the building. This output is assessed by the aid of an ontology (which is formed by defining indicators from the energy related building regulations commonly used in the UK and the US like ‘Code for Sustainable Homes’ (UK) and ‘LEED’ (US); regarding to energy and building conditions related to environmental sustainability issues at building scale) and the final assessment of Stage-1 is complete. This stage is a looping process, which means that if the assessment at the end of the procedure is “not satisfactory” the process starts from the beginning. At each start, an improvement should be supplied to the required fields to meet the required criteria of ontology in order to stop the loop and complete the cycle of Stage-1. Once the loop stops, it indicates that process Stage-1 is complete. The output of Stage-1 indicates the reduction in energy demand and CO2 emissions which are a set of preconditions for Stage-2. The given process which is illustrated in figure 2 covers the blue area (which indicates building scale) shown in the inner circle of the model that is illustrated in figure 1.

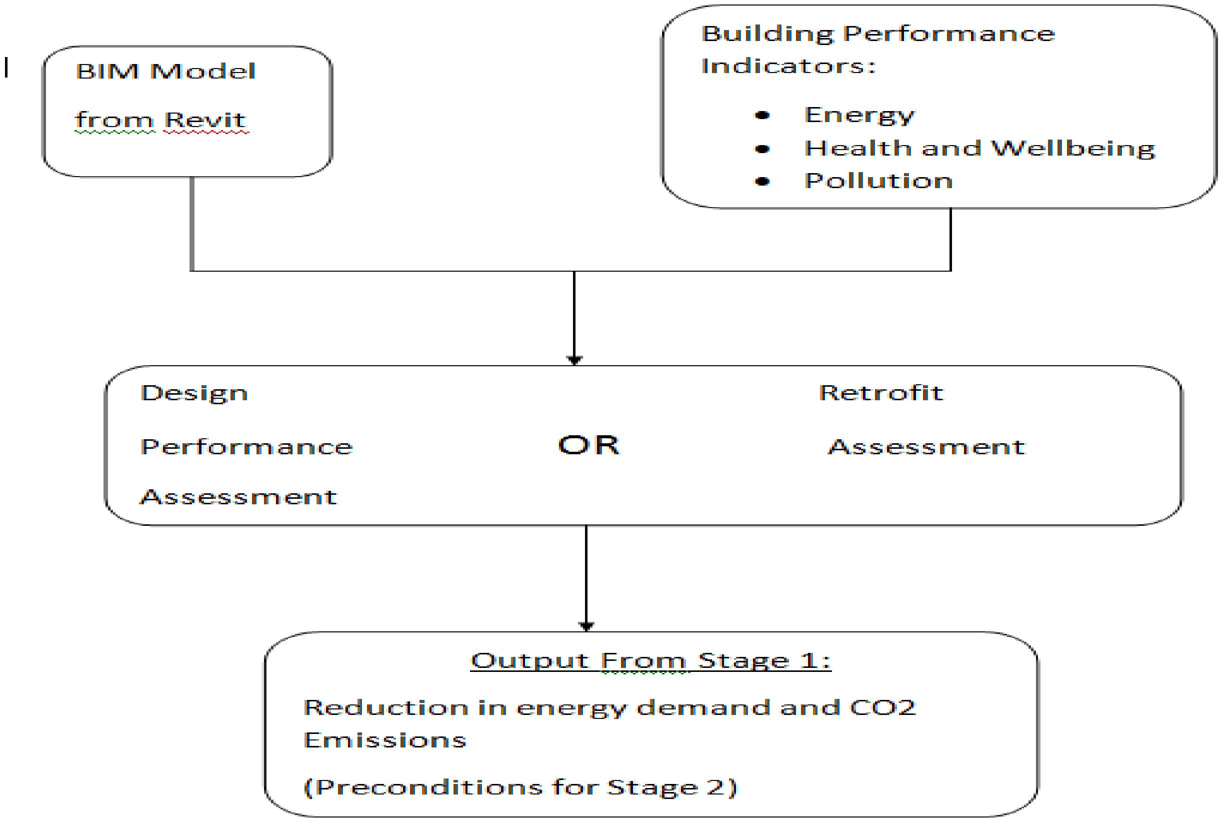


Figure 2. Building Scale Process Flow of the model

4.2.2 *Neighbourhood Scale Process*

Given Figure 3 illustrates Stage-2, which is the neighbourhood scale of the model. Energy supply from renewable energy sources is simulated and calculated via microgrid modelling technologies and this data is then processed in a 3-D GIS environment together with the energy and CO_2 reduction data and CityGML data for the surrounding environment. At the end of this stage, design of microgrid alternatives with storage and reverse transmission options are obtained. In other words, this process is an optimisation of building energy reductions, renewable energy generation and power distribution at a neighbourhood scale.

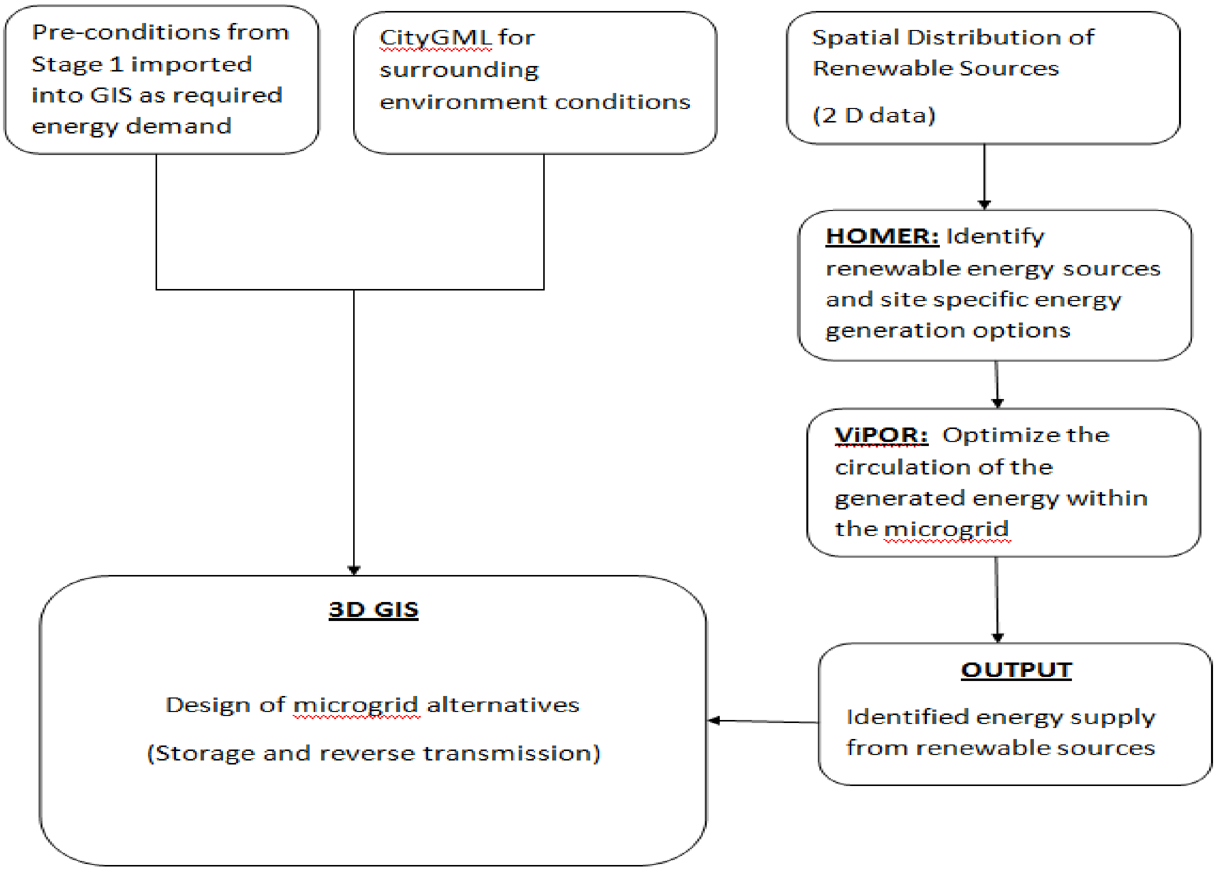


Figure 3. Neighbourhood Scale Process

5 Conclusion and Further Research

In order to obtain a low carbon neighbourhood, it is essential to apply energy related regulations in buildings to increase the use of clean energy generation technologies. Microgrid applications in small regions are good examples to low carbon communities but it should be concerned that renewable energy proportions in the energy mix are limited with the grid's capacity. Any climate change concerned development project should adopt long term sustainable smart grid solutions.

It should be noted that at this early stage of the research, the given process are visionary and they are developed to strengthen the vision towards achieving an implementation framework for a sustainable transition for Smart Grid compatibility in residential buildings.
In the next stage of the research, developing an interoperable platform for the aforementioned key technologies is essential for data collection, analysis, and demonstration and validation purposes.

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