SYSTEMATIC RECOGNITION OF DATATYPES AND RESOLUTIONS FOR DEFINING THE DEPTH OF DISTRICT AND BUILDING LEVEL RETROFITS

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ABSTRACT

With the upsurge in the energy demand in Europe, the challenge to improve the existing building stock's energetic performance calls out for a district and building level intervention through retrofitting measures. Often the amount and type of data required for the retrofit interventions are unclear, and it leaves the decision-makers in a dilemma within the development of low to high quality models based on its value as perceived by stakeholders. There exists a lack of robust indicators that could guide the EU member states to channelise their resources in reducing energy consumption based on the input data for simulation at district and building level. In this paper a QFD (Quality Function Deployment) model is developed to study the relationships between the stakeholder interests as outputs and different input datatypes and requirements, based on the level of detail, for simulation (physical, operational, environmental, geometrical and contextual data) that could impact the optimal model development. Keeping in mind the inadequacy of coherent computational models and informing the users about the implications of acquiring different data, here, the input datatypes, their interaction and collection are simplified to a greater extent through the proposed approach.

INTRODUCTION

The EU member states are responding to global climate and energy challenges with ambitious energy policy. Central to the current policy is a commitment to the EU '20-20-20' targets: a 20% cut in greenhouse gas emissions, a 20% reduction in energy use through energy efficiency improvements and a 20% share of renewable energy deployment in 2020 (Lucha, et al., 2016). According to the 2030 framework for climate and energy policy of the European Commission (Gröger, et al., 2012), a key objective of the future climate and energy policy is to keep energy affordable for domestic and non-domestic consumers. But from a physical point of view, the challenge for urban planners, architects and scientists is to model the environment replicating the demands of the different consumers at district and building level. Though building energy models cannot be expected to capture the full complexity of real buildings and system performance, the amount and type of input data available do make a substantial difference in the outputs of these models and consequently affecting the decision-making significantly by these stakeholders. These models are often developed by technical teams using simulation tools in low, medium or high quality based on the application and purpose (Li B., 2017). These vary based on reliability, usability, complexity, and availability of the simulation tool. Within the retrofit value chain, the requirements of various stakeholders vary and moreover, for their satisfaction, the schedules and resource constraints must be clearly understood (Gooding & Mehreen, 2016). Hence, the information requirements for developing simulation models must be specified in detail.

According to a report (German Environmental Agency 2020), the working group on Energy Balance's latest country assessment found, that in Germany 14 percent less primary energy was used in 2019 than in 1990 making it much difficult to achieve its national energy efficiency target of 20 percent within 2020. Moreover, in order to reach the 2050 target of 50 percent, a constant reduction of 2 percent per year 2020 onwards is required. Whereas, it is still expected to meet its 2030 renewable energy target of 30 percent, although Germany's renewable energy lobby warns the country might miss that goal too. To reduce the risk of failures and underestimation of energy targets, a crucial prerequisite could be demand side analysis using the urban scale simulations. Furthermore, Building Performance Simulation (BPS) of urban scale and building level models using a higher level of detail of the available data is of considerable potential that can provide the ability to dynamically quantify and compare the performance attributes of a proposed model in a realistic manner and at relatively lower costs and effort. Although, using available data efficiently and for the required purpose is still an area to be developed.

Decision-making approaches and tools such as AHP (Analytic Hierarchy Process) (Ereeş, et al., 2013), BIM (Building Information Modelling) (Berard & Karlshøj, 2011), BEMS (Building Energy Modelling Systems) (Senave & Boeykens, 2015) and GIS (Geographical Information Systems) (Bolstad, 2005) modelling require diverse input data to process retrofit measures. Both data-driven models and physical models are used for predicting different types of benefits at district and building levels, but both have

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their limitations (Li, et al., 2017). There exist several tools like CitySim (Robinson, et al., 2009), CityBES (City Building Energy Saver) (Chen, et al., 2017) and UMI (Urban Modelling Interface) (Reinhart, et al., 2013) that focus on estimating the impact of retrofitting by utilising the physical and data-driven models. The categorisation of the input information and its implications on the outputs have been significantly characterised as uncertainties in simulation by the research community (Macdonald, et al., 1999). However, this categorisation has not been studied extensively from the point of view of stakeholders interests and, therefore, presents a big gap in understanding the impact of stakeholder's requirements upon decision making for energy retrofits by reducing associated costs and risks.

District and building level retrofits massively influence the overall energy demand of a country (Sebi, et al., 2018), however, often there is a constant struggle in outlining the required input data for simulation to predict the demand and the accuracy that can be achieved with the available data. The level of analysis is invariably different from case to case and, thus, a systematic and methodical recognition of the required input datatypes, quality and quantity, to make decisions can save drastic amounts of resources in planning and development phases. In the next section, the dataflow in simulation of district and building level is discussed with the existing focus of the industry. Furthermore, the input data requirements and its depth are elaborated in detail.

DATAFLOW IN SIMULATIONS

Based on the best practices in the industry for developing, validating and using simulation models for decision-making, a range of general issues that affect the input and output accuracy in results are (i) model definition, (ii) model purpose and its use, (iii) model evaluation and (iv) challenges in using the model (Kuntz, et al., 2013). As it can be seen in Figure 1 for achieving better accuracy in simulation model for retrofits, a higher level of quality and precision in input data is required whereas this requirement is reduced if the retrofit depth is considered shallow or medium.

Extending over the domain of different applications, input information available for district and building level simulations adheres to different modelling standards. These standards treat the data-flow based on the concept of Levels of Detail/Development (LODs) such as stated in CityGML (Gröger, et al., 2012) and BIM modelling standards (Reinhart, et al., 2013). CityGML, an open XML based modelling standard, has gained popularity in many different applications for storage, processing and exchange of virtual 3D city models.

In context of the domain of Building Energy Management Systems (BEMS) and BPS, CityGML, when coupled with energy specific information extension, is a useful modelling language for energy specialists to deal with large sets of information, setting up district level simulations and visualisations for decision-making. CityGML is based on several standards from the ISO 191xx family, the Open Geospatial Consortium, the W3C Consortium, the Web 3D Consortium, and OASIS (Gröger, et al., 2012). Depending on the details of the different modelled objects, five consecutive Levels of Detail (LOD) are differentiated both over the geometrical and thematic properties. The concept of LOD also enables the visualisation of different attributes related to different buildings. As shown in Figure 2, LOD0 is essentially a two and a half dimensional Digital Terrain Model over which an aerial image or a map may be draped, and buildings are represented by their footprint only. LOD1 is the well-known blocks model comprising prismatic buildings with flat roof structures. LOD2 has differentiated roof structures and thematically differentiated boundary surfaces. In LOD3 architectural models with detailed wall and roof structures – potentially including doors and windows – are provided and LOD4 is mainly composed of rooms, interior doors, stairs, and furniture.

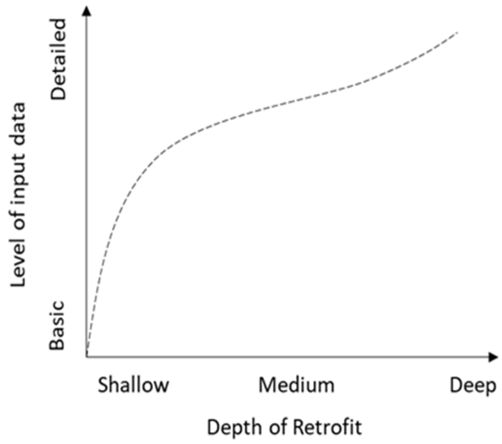

Figure 1: Model input data relationship with depth of retrofit

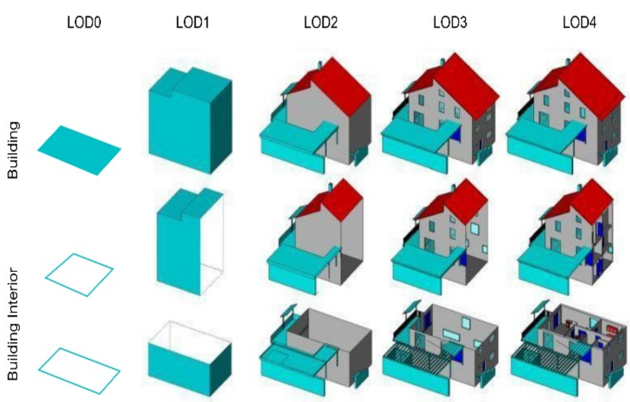

Figure 2: Levels of detail (LODs) in CityGML (Gröger et al., 2012).

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The Energy Application Domain Extension (Energy ADE) for CityGML data model has been implemented to enable the urban planners and researchers to store and manage energy-related data at urban scale such as energy demands, time series data, user occupancy and further data for energy retrofit simulations and decision-making (Agugiaro, et al., 2018). With the increasing popularity throughout the information modelling community and with the vision to be widely accessible for different applications, simulations and analysis, CityGML does require some additional features and attributes to be more useful. Since it is a wide-domain modelling standard, there exist gaps in the recognition of key input data that are important for the energy and retrofitting analysis and communication to the decision-makers. In this paper, a few attributes from different LODs are considered to formulate the stakeholder's requirements at district level analysis such as geographic information, building typologies, year of construction, district heating/cooling networks, etc.

Similarly, BIM can be understood as an information system where product data is stored and used for supporting decision making in Architecture, Engineering and Construction (AEC) processes (Berard & Karlshøj, 2011). It is being used as a collaborative and communication tool to avoid conflicts in projects. BIM application standards outline the Level of Development (LODs) (i.e. attribute to be attached to an element) to be followed for modelling buildings, assigning the attributes and their analysis. The fundamental specification definitions are provided based on AIA BIM protocol document G202-2013 for LOD 100, 200, 300, 400 and 500 (Reinhart, et al., 2013). The purpose of this definition is to make the model authors or further co-operators aware of what the models can be relied on and for what it was originally intended for. In LOD100, model elements are graphically represented but do not have any attached information. LOD200 has additional information attached to the element such as size, orientation and approximate quantity. Further, in LOD300, the model element is a specific system and it has accurate quantities over the details in LOD200. LOD400 and 500 represent a higher level of information that can be used for fabrication, assembly, installation and are field verified (as build). However, there also exists other classification systems based on the Level of Geometry, Information, Coordination and Logistics (LO-GICL) and these range from LoG0 to LoG5 (van Treeck, et al., 2016).

Although BIM models are highly detailed, they do not necessarily ascertain the filtration of data required for building energy modelling (BEM) which was not their prime purpose while development. Generally, BIM data is exported to other building energy simulation tools as the integration of BEM is not yet fully implemented (Senave & Boeykens, 2015) and they require rigorous work before being used by a static or dynamic simulation tool. In an attempt to standardise the information exchange between BIM and BEM a method was recently developed using Information Delivery Manual (IDM) and Model View Definition (MVD) methodologies (Pinheiro, et al., 2018). Industry Foundation Classes (IFC) based schema translated the requirements for BIM and BEM. The LODs support new construction but there is a lack in the development of LODs for retrofits and using the models for iterative workflows addressing energy efficiency along with other aspects of cost, structure, sustainability and others.

There is consistent guidance available for energy modellers for district and building levels (Reeves, et al., 2015; Lilis, et al., 2018; ASHRAE, 2018), however, it is quite vague with respect to the target stakeholders. The absence of built-in interactions between decision-makers and technical teams is one of the barriers in effective utilisation of simulation models (BPIE, 2018). In order to bridge this barrier, based on the different level of detail/development simulation input data categorisation and their relationships with stakeholder requirements, an overview and application of Quality Function Deployment (QFD) method for this purpose is presented in the next sections.

QFD AND ITS APPLICATIONS

One of the main tools that have been regarded as very successful in meeting the requirements of customers has been QFD (Akao, 1997). QFD is meant to translate the needs of stakeholders into technical requirements of a process or product development in a systematic manner. Though, it has been used for various other applications. In building construction, it can be used to focus on the needs of the stakeholders to deliver and coordinate their requirements (Pheng, & Yeap, 2001) and for other applications such as building integrated photovoltaic (BIPV) design (Paul, et al., 2010). It has also been used for the development of software along with a wide range of problem areas in the architecture and construction industry (QFD Institute, 2011). The basic QFD 'House of Quality' (see Figure 3) is the tool that drives the process using a relationship matrix where a client requirement is related to design options so that quality can be achieved for valuable characteristics. A basic House of Quality (HOQ) comprises six main parts. The client's interests and their importance rating are given by the client. The design requirements are the set of alternatives available for the client and a co-relation matrix describes their relationship with each other. The main part of the HOQ is the relationship matrix where the relevant design requirements can be linked with the client's interests. Often, the stakeholders have real issues in retrofit projects connected with quality, budget and time. Determining the quality of input data for model development for district or building retrofits using these relationships can enhance the interaction of tools and their usage and as a result, can assist in the decision-making based on the specific interests of the stakeholders (e.g. thermal energy demand, carbon

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emissions). Therefore, in this study an application framework is developed based on the QFD approach to bridge the gap of built-in interaction between the stakeholder interests and which input data, required for model development, must be focused on by the technical teams.

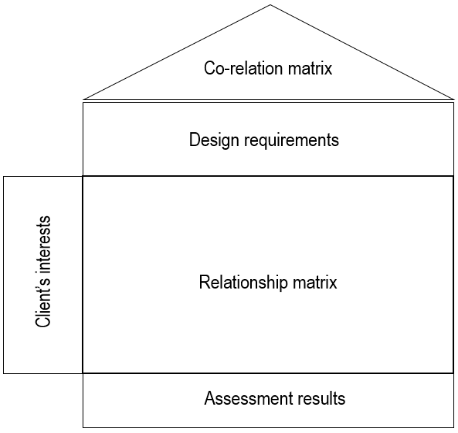

Figure 3: A QFD House of Quality.

METHODOLOGICAL APPLICATION FRAMEWORK

The presented framework aims to outline the selection process of the input simulation data through the deployment of the QFD approach in district and building retrofit while developing simulation model. It would help in planning and requirement of resources for data collection and using it for model development. The developed HOQ in Figure 4 has five major parts (i) stakeholders interests, (ii) input data requirements, (iii) importance rating to the stakeholder interests, (iv) relationship between stakeholder interests and input data requirements, and (v) technical assessment results. Initially, a simple HOQ has been taken where a useful extension of importance ratings to stakeholder interests is added and the co-relation matrix is omitted due to a large number of requirements.

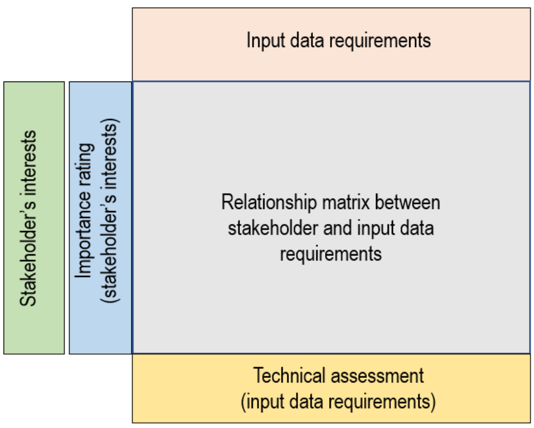

Figure 4: QFD for systematic recognition of input data

A HOQ can be used for assessing the input data requirements in terms of basic or detailed information and decision-maker (stakeholders) interests as shown in Figure 4 to address the specific needs by providing requirement specification for input data. It can also be highly useful for aligning the data requirements and utilising them for appropriate interventions given the complexity of interactions at the district and building levels.

Furthermore, based on the individual stakeholder's importance rating, using the approach in Menassa & Baer, (2013), is assigned to stakeholders' interests in HOQ. The relationship matrix is prepared for the input data requirements and stakeholder interests. The technical assessment is done by calculation of absolute importance and relative importance (absolute weight and relative weight) to establish the targets (Shrivastava, 2016).

Table 1: Example of a stakeholder-requirements table for building and urban level retrofits.

Urban Planners	**Architects**	**Equipment manufactures**	**Energy Service Companies**	**Policy makers**
Thermal Energy Demand	Building Information Summary	Energy Demand and delivered energy	Energy Market Prices	Life-cycle Costs
District Heating Network Layout	Construction Data Summary	Building Construction Summary	Energy demands	Annual Emissions
Carbon emissions	Weather Analysis	Load Profiles	Imbalances Markets and Reserves	Renewable Potential
Building typology and block layout	Conditioned and Unconditioned Area of the Building	Weather Analysis	Building typology and block layout	Disaster Management analysis
Building Cluster	Annual Emissions	Life-cycle costs	Renewable Potential	Network Layout
Utility Network layout	Comfort Indicators	System Sizing	Utility Network Layout	Thermal Energy Demand
Weather Analysis	Indoor Air Quality	Renewable Potential	District Primary Energy	
Planning Costs	System Sizing	Occupancy Profiles	Delivered Energy	
Conditioned and Unconditioned Area of the Building	Life-cycle costs	Utility Network Layout		
Renewable potential		Domestic hot water demand		

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In order to formulate different requirements for implementing the HOQ approach, it is quite important to identify some of the key stakeholders and their interests for district and building level retrofits. The key stakeholders for energy retrofits as identified by Liang, et al. (2015) do range from an individual person such as Owner/Client to a large institutional body such as banks. Whilst, for the presented approach in this paper, a small example list of different stakeholders and their interests have been identified in Table 1. An example is illustrated with assumptions in the next section elaborating on the use of methodology.

THEORETICAL DEPLOYMENT

The process begins by listing the stakeholder interests and input data categories based on building or district simulation. Examples of HOQ assuming a particular stakeholder for district and building retrofits are given in Figure 5 and Figure 6. The following main steps that were followed in the application of QFD for simple HOQ are:

1. Listing the decision-maker requirements (stakeholders) based on related research and studies
2. Listing the input data requirements for model development based on multiple simulation platforms
3. Development of relationship matrix and depicting strength of relationship (where, blank=no relationship, 1=weak relationship, 5=moderate relationship and 9=strong relationship)
4. Assignment of importance rating to the decision-maker requirements (0=null, 1=low to 9=high)
5. Calculation of absolute and relative importance

The motivation and the perceived benefits for the stakeholders does include social, environmental, economic and technical aspects (Menassa & Baer, 2013), but at building and district level energy simulations apparently, they do not include the social aspects. In Figure 5, the example stakeholder ranks the interests in order of their priority such as thermal energy demand and CO_2 emissions has the highest importance and VOCs have null importance.

Considering the different level of development or detail (LOD) for GIS standards, BIM and BEMS, a detailed ramification of the decisive data is carried out for substantial retrofitting influences. With different LODs at district and building level, the data categories can be combined to inform the users about their use in modelling based on the decision-maker to achieve the required accuracy. An approach introduced by (Quan et al., 2015) aims to understand the influence and the role of urban data in energy analysis substantiates the identification of the model development input data and the assignment of importance rating in the HOQ matrices. A case study of the Civil Engineering Building, at University College Cork, demonstrated in (Murray, et al., 2014), highlights upon a multi-variable optimisation technique for building retrofits. Using this study, some of the important parameters that were used for developing the set of equations for optimisation, are now characterised for the development of the HOQ matrices in this paper. Consequently, input data, highlighting over the technical, economic and environmental aspects, in building performance simulation is broadly classified into 6 categories in Figure 5 (i) program, (ii) material, (iii) district energy, (iv) equipment, (v) cost, and (vi) emissions. Whereas, for building energy simulation the input data is classified in 7 categories (i) program, (ii) material, (iii) HVAC, (iv) equipment, (v) costs, (vi) emissions and (vii) others.

A HOQ is used to establish relationships and integrate the data categories with stakeholder interests. The data types and their relationships are worked out in a relationship matrix for the systematic recognition based on the needs and objectives of the user such as performance, cost and quality according to the retrofit interventions. As in Figure 6, for building level retrofit decision making, U-value of the building envelope is an important input data requirement for architects to analyse the energy performance of the building. The relationships between the interests and input data requirements have been identified as examples based on the reasoning how models are developed and have hierarchy with model dependent and independent data inputs. The definition of the input simulation data sources along with the process of data acquisition for formulating the stakeholder requirements has been a homogeneous concoction of multiple approaches and related research.

A characterisation of the important input data for district energy performance simulations, as presented in (Wate & Coors, 2015), has been used for the calculation of absolute (as a whole number) and relative importance (in percentage) based on the relationship matrices of the decision maker interests. One such example from Figure 5 could be the higher importance of the building co-ordinates and district heating network layout for urban planners in context to the energy simulations for retrofit decision making. In Figure 6, a higher importance to occupancy, U-value of envelope, ventilation, set points and heating and cooling energy source could be attributed for detailed and quality data acquisition for developing the simulation model as per the stakeholder interests. The calculations of these above-mentioned important examples help in setting up the targets of data acquisition and more focused use of available data in simulations with higher efficiency. Moreover, by identifying specific stakeholders and their interests for practical implementations, the authors are motivated to put into practice the introduced approach in real-time algorithms using the sensitivity analysis (Menberg, et al., 2016; Wang & Augenbroe, 2017) to build the relationship matrices.

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	Input data requirements		Program																		Material			District energy			Equipment								Cost					Emissions
	Stakeholder interests	Importance rating	Weather Analysis	Geographic Location	Year of Construction	Orientation	Tilt	Co-ordinates	Building height	No. of stories	Conditioned and Unconditioned Area of the Buuilding	Street layout	Building typologies	Infiltration rate	Ground properties	District Heating Network	Occupant load and schedule	Grid and distribution network node model	Building Block	Building Block Sides	Roof Type and Area	Wall and Window Properties	Solar shading factor	District energy supply system and details	District Heating/Cooling generation efficiency	District Heating/ Cooling distribution efficiency	Light load and schedule	Lighting efficiency	Equipment load and schedule	Equipment efficiency	Solar PV & efficiency	Wind turbine & efficiency	Biomass and geothermal	Solar Collector	Utility tarrifs	Planning Costs	Procurement and Setup Costs	Components costs	Energy Prices Forecasts	Emission factors
District Thermal energy demand	Heating demand	9	9	9	9	5		9	9	9	9	1	9	9	5	9	9	1	5	9	5	9	5	9	9	9				5					5			1	5	
	Cooling demand	9	9	9	9	5	1	9	9	9	9	1	9	9	5	9	9	1	5	9	5	9	5	9	9	9				5					5			1	5	
District Delivered energy	Heating energy	8	9	9	9	5	1	9	9	9	9	1	9	9	5	9	9	1	5	9	5	9	5	9	9	9				5					5			1	5	
	Cooling energy	8	9	9	9	5	1	9	9	9	9	1	9	9	5	9	9	1	5	9	5	9	5	9	9	9				5					5			1	5	
	Lighting energy	6	9					9		9			5				9	9					9				9	9										1	5	
	Electrical energy	6	9					9		9			5				9	9					9						9	9								1	5	
District Primary Energy	Electricity	1		9				7		1	1						5							9											9			9	9	9
	Coal	1		9				7		1	1						5							9											9			9	9	9
	Oil	1		9				7		1	1						5							9											9			9	9	9
	Gas	1		9				7		1	1						5							9											9			9	9	9
	Renewable sources	1		9				7		1	1	5					5							9											9			9	9	9
	Domestic hot water demand	9	9	9		5	1	7	5	5	1	9	9	9	9	5	9							9											9	9		9	9	
	District renewable potential	8	9	9			9					9			9				9	9	9		9								9	9	9	9	5	1	9			9
	Disaster Management	6	9	9	5	5	5								9	9		9	9	9				9												9				
	Energy Markets	7	9	9													9							9	5	5	9	5	9	5					9				9	
	Imbalance Markets and Reserves	7	9	9													9							9	5	5	9	5	9	5					9				9	
Annual emissions	CO2	9																						9			9		9											9
	NOx	0																						9			9		9											9
	SOx	0																						9			9		9											9
	VOCs	0																						9																9
	PM	0																						9			9		9											9
	Load Profiles	9	9			5					9			5		5			5	5		5					1		1											
	System sizing	8	9			5			9	9	9					9			5	9	5	1		9	9	9	1	1	1	1										
	Life-cycle costs	8	9			5			9	9	9					9			9	9	1	1	1	9	5	5	9	5	9	5					9			9	9	
	District Heating Network Layout	8						9				7					9	9						9	6															
	Utility Network Layout	8						9				7					9	9						9	6										8					
	Building Cluster	6						9				6					9	9	9	9				8	7										7					
	Carbon emissions	9									5					5	9							9	9	9	9	5	9	5										9
	Absolute technical importance		1134	756	336	460	145	712	540	652	634	385	528	558	458	684	866	340	498	666	290	412	358	1053	584	488	359	172	359	342	72	72	72	72	670	224	72	316	626	189
	Relative technical importance		6.6%	4.4%	2.0%	2.7%	0.8%	4.2%	3.1%	3.8%	3.7%	2.2%	3.1%	3.3%	2.7%	4.0%	5.0%	2.0%	2.9%	3.9%	1.7%	2.4%	2.1%	6.1%	3.4%	2.8%	2.1%	1.0%	2.1%	2.0%	0.4%	0.4%	0.4%	0.4%	3.9%	1.3%	0.4%	1.8%	3.6%	1.1%

Figure 5: Example HOQ for stakeholders for district retrofit

	Input data requirements		Program										Material							HVAC						Equipment					Other				Cost		Emissions
	Stakeholder requirements	Importance rating	Weather	Location	Orientation	Floor area	Building height	No. of stories	No. of zones	Opaque wall area	Window area	Occupancy	U-value of envelope	Solar transmittance	Solar heat gain coefficient	Reflectance of opaque wall	Solar shading factor glazing	Shading device	Building thermal inertia	Ventilation schedule	Thermostat setpoints	Heating &Cooling energy source	Heating/Cooling generation efficiency	Heating/ Cooling distribution efficiency	Fan & pump size, efficiency and schedule	Light load and schedule	Lighting efficiency	Equipment load and schedule	Equipment efficiency	Water supply	Daylighting	Solar PV & efficiency	Wind turbine & efficiency	Solar collector	Utility tarrifs	Components costs	Emission factors
Thermal energy demand	Heating demand	9	9		5	9	9	9	9	9	5	9	9	5	5	1	5	5	9	9	9	9				1		5		1				1			
	Cooling demand	9	9		5	9	9	9	9	9	5	9	9	5	5	1	5	5	9	9	9	9				1		5		1							
Delivered energy	Heating energy	0																		9	9	9	9	9	9										5	1	
	Cooling energy	0																		9	9	9	9	9	9										5	1	
	Lighting energy	8																								9	9				9					1	
	Electrical energy	8																										9	9							1	
	Fan and Pump energy	2																							9												
Primary Energy	Electricity	1		9		1		1	1													9			9										9	9	9
	Coal	1		9		1		1	1													9			9										9	9	9
	Oil	1		9		1		1	1													9			9										9	9	9
	Gas	1		9		1		1	1													9			9										9	9	9
	Renewable sources	1		9		1		1	1													9			9										9	9	9
	Renewable energy produced	7	9	9																											9	9	9	1	1	9	
Annual emissions	CO2	9																				9			9	9		9									9
	NOx	0																				9			9	9		9									9
	SOx	0																				9			9	9		9									9
	VOCs	0																				9															9
	PM	0																				9			9	9		9									9
	Temperature trends	4	9		5					5	5	9	9	1	1	1	1	1	9	9	9					1		1									
	Comfort indicators	4	1		5	1			1	1	5	5	9	1	1	1	1	1	5	5	9					1		1			1						
	Indoor Air Quality	2	5									9								9																	
	System sizing	0	9		5	9	9	9	9	9	5	9	9	5	5	1		9	9	9	9	9	9	9	9	1	1	1	1								
	Life-cycle costs	8				9	9	9	9	9	9	9	9	1	1	1	1	9		9	9	9	5	5	9	9	5	9	5	9		9	9	9	9	9	
	Occupant productivity	9	1		5							5	9	1	5	1	1	5	5	9	9					1		1									
	Carbon emissions	9										9									5	9	9	5	5	9	5	9	5			1	1				9
	Absolute importance		280	108	155	239	234	239	239	254	182	414	351	111	147	39	111	211	243	369	396	441	121	85	261	337	157	409	157	90	135	144	144	88	124	196	207
	Relative importance		3.8%	1.5%	2.1%	3.2%	3.2%	3.2%	3.2%	3.4%	2.5%	5.6%	4.7%	1.5%	2.0%	0.5%	1.5%	2.8%	3.3%	5.0%	5.3%	5.9%	1.6%	1.1%	3.5%	4.5%	2.1%	5.5%	2.1%	1.2%	1.8%	1.9%	1.9%	1.2%	1.7%	2.6%	2.8%

Figure 6: Example HOQ for stakeholders for building retrofits

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The implementation of the QFD House of Quality approach largely depends upon the identification of the stakeholders and their requirements with respect to the analysis domain. In the scope of the presented approach, the identified interests were considered broadly over the stakeholders for building level and district level energy simulations and can be developed suiting the application in simulation model development. Although, the scope of QFD approach is quite large, certain limitations do exist in its implementation. Each relationship matrix created to assess the depth of retrofits required has its specific validity boundaries. Though, depending over the stakeholder's interests, the formulation of the relationships also changes significantly with climatic conditions, district and urban context (Palme & Salvati, 2018) and the building typologies. With an inclined importance over the stakeholders, a proper communication of the requirements and interests is also one of the crucial aspects. Assigning the relationship importance ratings for the presented approach do need a proper communication channel in building and district level energy retrofit analysis. Likewise, simulation scientists and energy analysts can adhere to the QFD approach at a much larger scale by constraining to their respective stakeholders.

CONCLUSIONS AND FUTURE WORK

An extensive range of simulation tools are available for the technical teams to develop models using a detailed range of input data. It often results in high costs and more time, but their development based on the requirements of the stakeholders could significantly affect district or building retrofit decision-making. In this paper, an approach to quantify the important input data for building and district level energy simulations for retrofit decision-making based on the interests of different stakeholders have been presented. With the implemented HOQ, input simulation data for energy analysis with higher importance scale such as geographical location for district level and ventilation schedules for building level retrofits can be identified. With QFD ranging over a large domain of applications, an HOQ for multiple stakeholders depending on their interests and requirements for energy retrofits could be implemented and modified to suit the needs of the retrofit industry. This study provides a basis of including QFD to accelerate the process retrofit decision-making as it considers bridging the gap between the stakeholders and technical teams.

In the presented paper, example building and district level stakeholders were considered on a coarse level. Further investigations and implementations, by segregating the stakeholders in a much more detailed way depending upon their specific requirements, will be an important step towards optimised decision making for energy retrofits. In future, the authors would like to examine the importance ratings of stakeholder interests and robust interpretation of the input data relationships based on surveys and other means of simulation-based techniques.

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