4DStock: Adding an organisational dimension to a 3D building stock model

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Abstract

Building stock models, such as University College London's 3DStock, help us understand energy use across a building stock across time and space. 3DStock is currently used for decision-making and evidence gathering at the national and local policy levels in the UK. A novel innovation proposes to add an organisational dimension to the existing 3DStock model, turning it into a 4DStock model. This conceptual paper articulates some of the anticipated benefits and challenges of this effort, introducing why and how three dimensions could become four. The fourth organisational dimension is eventually intended to incorporate trends in building ownership and usership, with a particular focus on non-domestic buildings and commercial real estate. This organisational dimension is critical for setting agendas, creating agreement, and stimulating action because low-carbon technologies do not adopt themselves. By focusing exclusively on physical buildings and premises, stock models generally omit the human dimension of energy use, including ownership and usership. Organisational characteristics are particularly important in commercial real estate (CRE), which includes 50–75 % of the non-domestic building stock. Different sizes and types of building ownership—for example, large/SME; public/private/listed; owner-occupied or tenanted—have been shown to affect the shape and nature of organisational participation in energy efficiency schemes. Different sizes and types of building usership are also important. The concerns, capacities, and conditions of occupiers have been shown to affect their energy practices and cultures. Understanding these dynamics is essential as we move from theoretical models to practical actions. We need a better grip on both 'achievable potential' (the subset of technologies that are actually installed in practice) and 'social potential' which includes both how these technologies are used and other organisational behaviours. As an initial sketch of this field, the paper concentrates on how a 4DStock model would incorporate both technical and organisational variables related to occupiers. Further developments will be more useful for ongoing carbon accounting and planning in academia, government, and business.

Introduction

In recent decades, energy and environmental policy objectives for the built environment have ratcheted up from "cost-effective" to "Net Zero". These broader policy imperatives bring with them additional forms of thinking about innovation and change. Nudges are not enough as they provide only incremental change (Moezzi & Janda 2014) at a time when more radical changes (e.g., decarbonising heat) are on the table. Policymakers in the UK are beginning to understand that we have to change *more* things, more *quickly* to reach net zero. As Nick Eyre described at the outset for the UK Centre for Research into Energy Demand Solutions (CREDS), we need to go further, faster, and more flexibly (Eyre 2017).

Our starting point for this paper is that technology adoption in the built environment is a socio-technical problem (Biggart & Lutzenhiser 2007). Therefore, we argue that a socio-technical model of the built environment will help researchers and policymakers understand a broader set of possibilities and limitations for change than just a physical-technical model. Social opportunities and challenges have long been identified in the built environment, particularly in housing (Lutzenhiser 1993), but are not as well understood in non-domestic buildings and organisations (Strachan, Janda & McKeown 2015). Social dimensions are often explored through case studies of particular buildings or projects, which may be located spatially but not at scale, and generalisability is difficult. Current physically-based models of the built environment can tell us about technical potential at scale, but they are silent about what has been called the social potential for change (Janda 2014; Moezzi & Janda 2014). In this paper, we argue that people and organisations are capable of moving faster than things. Policy needs to better understand how people and organisations make decisions because technologies do not adopt themselves, certainly not at the rate needed to reach Net Zero. Adding organisational context to non-domestic buildings in a physical model of the built environment is novel from a research perspective.It is also an important step in connecting the social and the technical in a policy-relevant way (spatially and at scale).

This paper is a conceptual investigation of why and how to attach organisational dimensions to a novel and evolving physical model of the built environment-- developed over the last decade at University College London (UCL)-- called '3DStock'. This paper represents the first effort to map a relationship between the physical characteristics of buildings/premises (through the lens of 3DStock) and the organisations that use them. This endeavour provides a basis for adding a 'fourth dimension' to the model, hence '4DStock'.

The paper begins with two 'what and why' sections. The first of these describes *technical* approaches to modelling the built environment, arguing that they focus on technical potential and miss other important aspects of change. The second addresses *social* and *organisational* issues that have been examined through case studies at the level of buildings and portfolios (but not an entire stock). The third and fourth sections are two 'how' sections. The third section provides the conceptual heart of the paper. It develops a "layers of change" approach to the *socio-technical* challenge of identifying information on organisations that could be added to 3DStock, with a focus on occupiers, facilities managers, and owners. The fourth section discusses a subset of challenges for accessing data sources for 4DStock by focusing just on occupiers. As a first foray into this area, this paper provides an example of using an occupier lens instead of a building area lens with respect to potential energy performance benchmarking regulations. Further policy implications of the proposed 4DStock approach are discussed. In conclusion, we note that for further iterative and collaborative research with public and private entities it will be necessary to successfully and usefully augment 3DStock with insights from organisational research.

A technical approach: building stock models

WHAT AND WHY?

Building stock models, focussing on the use of energy in non-domestic buildings, have been developed since at least the 1990s. As Steadman et al. (2020) describe, stock models can be used to assess energy demand in large numbers of buildings in relation to a range of variables, including built form, age, construction and activities. Poorly performing buildings can be identified, and the potential for retrofit—including renewable technology installations—evaluated using the same variables plus information contained in Energy Performance Certificates (EPCs). Policies for addressing fuel poverty can be evaluated by making links to confidential socioeconomic data on occupants. In conjunction with a dynamic building energy-simulation tool, scenarios can be investigated for retrofit, the potential for renewables and issues in demand-side management. Additional uses are in the precise measurements of density and of the three-dimensional character of the urban fabric. There could be applications in public health, the modelling of indoor and outdoor air pollution, and the tracking of material flows. Threedimensional stock models might also be integrated with digital twins of infrastructure systems and networks.

Stock models may be statistically-based (Choudhary 2012), often using archetype buildings (Heiple & Sailor 2008), or based on the physical dimensions of buildings and /or the energy uses associated with the activities happening in the buildings (Huang et al. 1991; Pout 2000; Bruhns, Steadman & Marjanovic 2006; Evans, Liddiard & Steadman 2016; Steadman et al. 2020). In some cases recorded energy consumption is included (Howard et al. 2012). Some are geospatial, whilst others can only describe an entire building stock within the administrative/geographical boundary of the model. In spite of these varying levels of detail, information on the occupiers of the premises and buildings of non-domestic stocks – other than the activity recorded for premises – has not yet been added to stock models.

University College London's 3DStock model (Steadman et al. 2020) brings together several (mostly) publicly-accessible data sources to create a geospatial, geometrical model of Greater London, UK, that includes the activities occurring in non-domestic premises and associated buildings. The model uses a bottom-up approach that includes significant levels of detail, such as overall premises activity (e.g. office, warehouse, school), areas (m^2) and floors given over to sub-activities (e.g. kitchen, storage, retail, workshop), matched to building map footprints and Energy Performance Certificates, where present. The third dimension of 3DStock is height. This is added by Light Detection and Ranging (LiDAR) data matched to the map footprint, giving the height of the building (Evans, Liddiard & Steadman 2016). Although 3DStock currently covers only Greater London, there is work ongoing to expand the model to cover all of England and Wales

ISSUES

Building stock models are designed to represent the physical building stock and help depict the complexity of its use types (particularly in the non-domestic sector). They tell us what has been built and, over time, they can provide evidence of change. They can also model changes into the future, but only to the extent that they are accurate for the present. Necessarily, as will be discussed, they use data where they are accessible.

One problem that data accessibility raises is that stock models are better at modelling buildings where data exist than where they do not. Focusing just on available data can create "blind spots" in policy analysis (Stern 1986).Paul Stern likens this to looking for your keys under a lamppost where there is light, whereas you may have lost them in the surrounding darkness. At a city-wide scale, it has been noted that informal settlements and slums are poorly represented in the available data for urban building energy models, which perpetuates an essentially elitist view of the built environment (Janda et al. 2019; Fennell, Lambert, et al. 2019; Fennell, Ruyssevelt, et al. 2019).

More importantly for this paper, physical data-driven models are built with a view to mapping technical and economic potential for change. *Technical potential* is a technologically optimistic view of the world, where installation is seamless, transaction costs are nil, and actors are perfectly rational. It is an artificially imagined best case scenario on a frictionless plane. Another form of potential is *achievable potential*, which is what happens when technologies are adopted in the real world. There is friction on the plane: costs are higher than planned, material lengths do not fit the spaces exactly, specified equipment is out of stock, things are not installed correctly.

Both technical potential and achievable potential are similar in that they are working with "sticks and bricks" and average assumptions about "behaviour". They can tell policymakers what has happened but are not very good at explaining *why* technical potential and achievable potential vary from each other and in different circumstances. These mechanisms can neither predict nor explain why cost-effective energy efficiency measures are sometimes rejected, or why expensive features are sometimes purchased. In a nutshell, these variations occur because people and organisations are not uniform, nor are they entirely economically rational actors. Some of these groups may be economically rational much of the time; others may exhibit their own rationality. But as long as models focus on variations in sticks and bricks, the agency and capacity of people and organisations will be either invisible or hidden behind a neoclassical economic veil of "rational action."

A social approach: organisational characteristics

WHAT AND WHY?

The non-domestic building and organisational infrastructure in the UK is highly varied. Most larger organisations operate in a mix of older and newer properties with different physical and technical energy characteristics. Some organisations have energy managers; others do not. Some organisations have smart meters and data to analyse; some even have analysts to work with the data, but many do not. Some organisations are owner-occupiers; others are landlords or tenants. To make it even harder, even though the buildings might be located in the UK, the organisations that own, manage, and/or use them might be international corporations with business practices and decision-making structures located outside the UK. A lack of information about the distribution, combination, and effects of these variables turns energy management in the non-domestic sector into a stubborn and "wicked" problem (Rittel & Webber 1973) rather than one that is "tame" and easy to solve.

The carbon reduction problem is particularly acute for many SMEs, typically without an energy manager, who have been shown to not be able to understand their existing energy bills, let alone improve their energy usage profiles using comparative feedback (Payne 2000). Further, there may be problems with access to data, control, and authority in premises and buildings that are leased rather than owner-occupied.

The difference in decision-making structures was noted in a 2012 rapid evidence review performed by the Centre for Sustainable Energy and the Environmental Change Institute for the UK government Department of Climate Change (CSE & ECI 2012). This study reflected earlier findings that differences between organisational energy behaviours are strongly linked to size and sector and that energy efficiency strategies differ across organisations and reflect their different motivations and emphasised the importance of market segmentation frameworks. Earlier studies also highlighted various characteristics of ownership. One such study by Reed et al. (2004) discussed the differing importance of international and regional players in commercial building markets and how policy would need to interact differently with these kinds of players. Research by Janda and Brodsky (2000) similarly found differences between large private commercial landlords and publicly traded real estate investment trusts (REITs), as well as between those two groups and their regional counterparts. In an investigation of the first 100 Energy Star certified buildings, Janda & Brodsky (2000) found that the highest scores for the buildings benchmarked were from privately held firms, and the most active participant in the benchmarking programme was a regional real estate investment trust. Looking at firm types in a cross-national comparison, Janda (2008) found differences between the types of organisations that participated in the Energy Star Buildings program in the US and the Carbon Reduction Commitment in the UK. International organisations that could have participated in both programmes only participated in one but not the other. Differences between countries and data conventions may also play a role in promoting or inhibiting how different organisations approach their environmental options (Strachan, Janda & McKeown 2015).

Research into energy management in "understudied" organisations (Janda, Bottrill & Layberry 2014) and the retail sector (Janda et al. 2015) developed a framework for thinking about what non-domestic buildings look like on the ground, including some of the organisational and ownership characteristics that influence decision-making with respect to energy and carbon emissions. This approach (see Table 1) used the concepts of "data rich" and "data poor" to identify and map energy-related infrastructure, as well as barriers to and opportunities for change. Janda et al. defined "data rich" as a Platonic ideal archetype: an organisation that is able to gather, analyse, and use energy data to manage its premises in perfect harmony with its core strategy and central concerns. The reality is somewhat messier and inexact. Real organisations fitting this category will have lots of data—generally achieved through automatic meter reading (AMR)—and an energy manager of some description. In contrast, a "data poor" organisation is one without access to real-time data and lacking the in-house analytical capacity to measure, map, and understand energy issues.

This typology can help define and categorise research assumptions about the nature and distribution of commercial real estate firms and organisations with respect to energy and carbon issues. The horizontal categories recognise that there are (at least) three kinds of ownership types in the market: owner-occupiers, landlords, and tenants, each of which is subject to a different kind of legal infrastructure. The categories on the right split these three ownership types into data rich and data poor categories, resulting in a typology of six different firm types (A to F).

Table 1. Data access and building ownership/ usership matrix.

Segmentation of the UK Non-Domestic Market by data access and ownership/usership	Owner Occupied	Leased Space	
		Landlords	Tenants
Data Rich (e.g., an organisation with AMR and an energy manager)	A	B	C
Data Poor (e.g., an organisation with legacy meters and no energy analysis)	D	E	F

Source: Janda, Wallom, et al. (2016).

This model was used in an exploratory EPSRC project on energy management in the UK retail sector (Janda et al. 2015; Janda, Wallom, et al. 2016). The data showed that one size does not fit all: SMEs and multinational corporations need different energy management solutions. Smart meters will not solve everything: further analysis is necessary to turn numbers into knowledge, not least because frequently very little is known about what is on the downstream side of the energy meter, i.e. the equipment that is actually using the supplied energy. Changes to legal infrastructure (e.g., leases) will be needed to assist tenants and landlords in sharing data to enable both groups to monitor, measure, and report energy use (Janda, Bright, et al. 2016). Additionally, how organisational cultures frame employee duties, behaviours, and expectations requires further investigation.

ISSUES

From a policy perspective, the organisational view is bottom-up and incomplete. It provides glimpses into typologies, but does not tell who, where, or what the general population of actors involved in various building types looks like. We believe, for example, that approximately 50 % of commercial buildings are rented and approximately 50% are owner-occupied (can be up to 75 % rented, as in Australia) (Janda, Bright, et al. 2016). But is the owner-occupied population evenly distributed across the country? Are there uneven clusters? We know that principal agent problems exist in commercial real estate and that leasing arrangements matter. As yet, however, there is no spatial mapping which could enable researchers and policymakers to see where owner-occupied/tenanted commercial properties are located, and whether building owners/occupiers are a member of their local community compared to a national or international chain. These attributes can affect which policies apply to organisations, as well as the types of levers that are likely to effect organisational change. We know that some buildings have better EPCs and/or DECs than others. Might some of these exemplars be geographically disparate but organisationally coherent?

A socio-technical approach: reconceptualising how buildings (and people) learn

4DStock is interested in combining the technical and organisational approaches into a socio-technical model. In doing so, it builds upon previous conceptual work by Duffy (1990) and Brand (1994) which use a "layers of change" approach to understand buildings as complex entities.

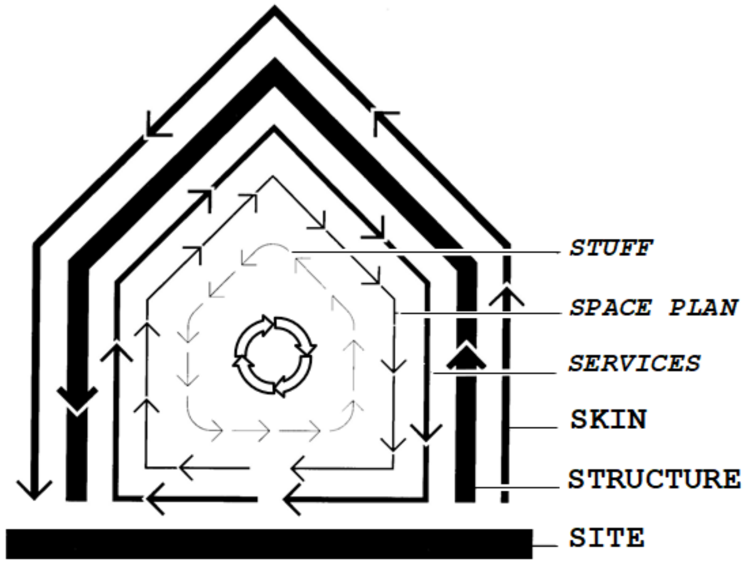
By adding a 'people' or organisational element to the layers of change, the interaction between the building, its occupiers, managers, and owners may be examined within a single conceptual framework. This section outlines how the social and technical elements could be combined at a conceptual level, with a particular focus on relating rates of change to physical layers of a building to organisational dimensions of decision-making. This endeavour is important because in most models, ownership, occupation, and management are extraneous variables. However, in reality, these variables are critical because owners, occupiers, and managers are neither perfectly rational nor completely aligned in their goals.

LAYERS OF CHANGE

Duffy (1990) describes how a building may be analysed as a set of life cycles: Shell (structure); Services (plumbing, cabling, elevators etc.); Scenery (partitions, false ceilings etc.); Set (furniture and non-fixed equipment). Subsequently, in his highly influential book "How Buildings Learn", Stewart Brand (1994) took Duffy's four life cycles and developed the model of building change shown in Figure 1.

Brand's model is divided into six layers of physical characteristics – the shearing layers of change. Five of these layers are generally subject to change, with the size of arrows indicating the rate of change. The Site layer has no arrow because it is unlikely to change, as it is a legally defined area, bounded by other adjacent sites. This may be a point of contention, as once a building has been demolished, its site may be partitioned and sold-off piecemeal, limiting what can be built on it. Alternatively, contiguous plots of land might be amalgamated. Brand provides an example of a series of alterations to a retail building, then its demolition, followed by a new construction (Brand, 1994, pages 76–77). The series of changes demonstrates amalgamation of a number of buildings into a single commercial entity, rather than partition. The overall site is unchanged, with alterations constrained by the surrounding streets, as is the new building. However, from an energy perspective we might want to add site as a parameter of change. This is particularly relevant to urban planning and permissions.

In terms of the rate of change, Brand believes the "slow" elements of the building dominate the "quick" elements due to a form of inertia (Brand, 1994, page 17). This means that the



SMALL ARROWS (FAST CHANGE)		
Layers that change	SOULS:	The occupiers of premises/buildings, with various operational procedures, constraints and decision-making structures.
	STUFF:	The ephemeral contents of the building – that which the occupants bring with them – for example furniture and computers. These characteristics can change easily and quickly.
	SPACE PLAN:	The internal layout of the building, including (mostly) non-structural walls/floors*, doors, partitions etc.
	SERVICES:	The services are fixed into the internal spaces, or may be embedded, within the building and are problematic to change.
	SKIN:	Also called the façade: may change due to building fashions, but unlikely to be changed more frequently than every 20-30 years.
	STRUCTURE:	Unlikely to be altered as it is the basic fabric of the construction. Alteration usually entails demolition, thus change is very slow.
LARGE ARROWS (SLOW CHANGE)		
SITE:		The area of land on which the building rests: change is rare.

Figure 1. Shearing Layers of Change.
*Adapted from Brand (1994, page 13) * Brand does not make it clear whether walls are structural or non-structural.*

Site and Structure layers will dominate the inner layers of the building. But this is only the case in terms of physical presence and longevity, not energy consumption. This time-based classification of building elements provides an alternative to the more commonly used activity-based models, when describing the characteristics of a building. The time-based classification would also suggest a hierarchy of characteristics to record when surveying buildings. For long term policy/planning/management decisions, the Site, Structure and Skin should be evaluated. For the medium and short term, the Services, Space Plans and Stuff should be analysed. These layers, however, do not address the behaviour of occupiers, organisational norms, or technology adoption decisions that occupiers make in the process of occupying a building.

LAYERS OF SOCIO-TECHNICAL CHANGE

To engage with the human behavioural factors that affect buildings, Brand suggests an additional layer, which he terms "Souls". However, the suggestion is that humans are dominated by Stuff. However, people in organisations use the Stuff, choose the Stuff, run the Services, can augment the Skin, change the Structure, and alter the Site. The question is: which people do what and for what reasons? In Brand's conception of Figure 1, Souls are equated with occupants, rather than owners or managers.

We have further redrawn Brand's work with an eye toward developing a typology that differentiates between various organisations involved in commercial real estate and maps these onto physical layers (see Figure 2). This reconceptualisation is significant because commercial real estate is an example of an important market segment (roughly 50–70 % depending on the location and building type) that is not currently distinguished from owner-occupied buildings in stock models.

In terms of the rate of change, within the lifespan of a building, the people who use it are the most changeable characteristic; for example, as they move around the interior of the building, turning things on and off, opening windows and doors to either assist (or interfere) with the heating, ventilation and air-conditioning equipment. This is the result of the

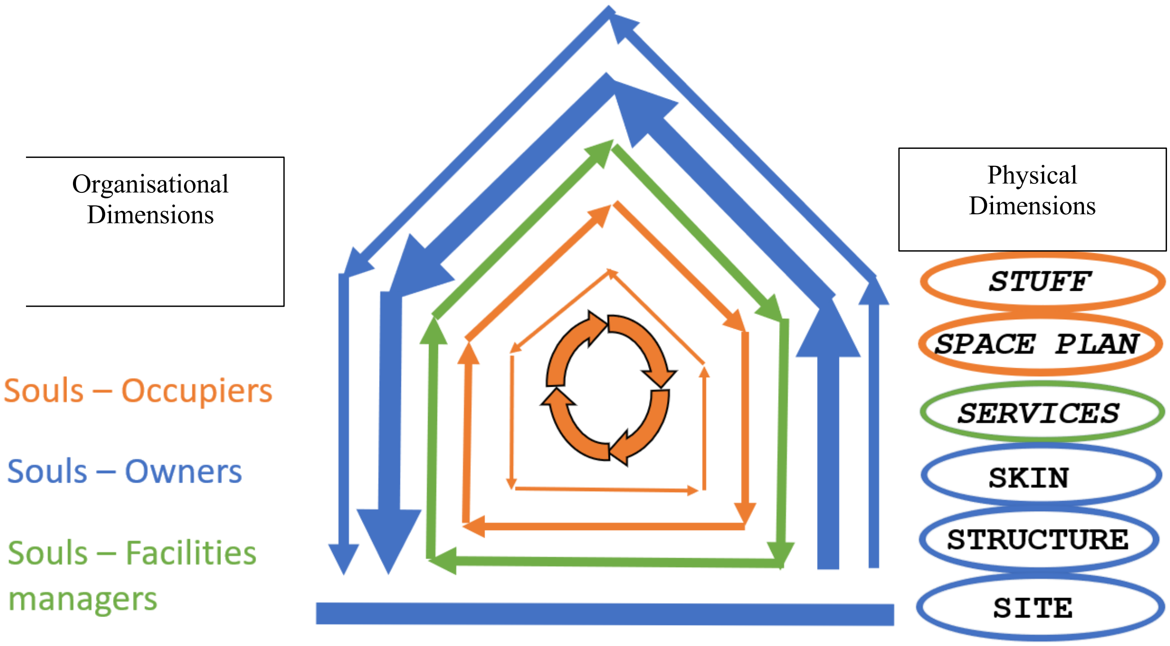


Figure 2. Organisational and physical dimensions of building change in commercial real estate.

many influences that act upon their behaviour and can change in very short time frames. Additionally, patterns of occupation generally have a marked effect upon energy use in buildings, as demonstrated by occupancy factors being applied to energy benchmarks (Field 2008).

However, it is still the equipment (Stuff and Services) that consume energy in a space as measured by gas and electricity meters. The "layers of change" diagram (Figure 1) is useful in showing that from an energy perspective, the other layers influence energy demand and consumption by Stuff and Services but *are not directly measured by meters*. The difference between passive and active elements of a building are recognised and accounted for by building physics. There are, however, important organisational aspects of these layers as well (left side of Figure 2).

Figure 2 shows (in a simplified form) how different organisations have various levels of interactions with the physical layers around them. Consider, for example, a hypothetical retail space that has just been rented by a major grocery chain that subcontracts their facilities management to a specialist company. The grocery chain will be the *occupier* and will fit out the space with Stuff (lights, chilled display cases, shelving, etc.) and decide on a Space Plan. They will also choose the Souls who sell ready meals and work the tills, decide the operating hours and so forth. The *facilities management* company controls the building services and may also organise cleaning of the premises. They may or may not augment the equipment currently onsite (as depends on the lease). The *building owner* will collect rent from the occupier and legally expect that neither the occupier (nor its customers) will perforate the Skin, weaken the Structure, or amend the Site. Getting to Net Zero in this space is likely to require participation from all these groups. But, as yet, no stock model recognises owners, occupiers, or facilities managers as distinct decision-making entities or distinguishes between their likely levels of participation in the layers of change.

LAYERS OF ACCESS TO DATA

In Figure 2 above, it will be noticed that the layer labels, to the right of the graphic, are in standard or *italic* text. This distinction is a further incremental refinement of Brand's model to denote how the Site, Skin and Structure layers (in non-italic text) can generally be determined from outside the building, whereas the inner layers, Souls, Services, Space Use and Stuff (italic text) can only be accessed from inside the building, or through access to a relevant source of this information.

If data can be sourced directly from occupiers, this may provide access to knowledge about the layers of change that are most difficult to acquire, namely: Services, Space Plan, Stuff and Souls. In essence the interiors of buildings are accessed via their data: no physical access is required.

3DStock already contains a great deal of information on the physical characteristics of buildings and the activities within non-domestic premises, such that buildings containing multiple premises – and therefore probably multiple organisations – may be identified, rather than assuming all buildings are homogenous within their envelope. With the addition of data on organisations occupying premises and the buildings that contain them, it should be possible to apply the layers of change principle to the interaction of the building/premises layers *and* the occupier layer. This, in turn, may provide insights into which types and size of organisation occupy which types of premises/building, at the scale of entire building stocks, but at premises scale.

Challenges: finding data

We believe that the 'layers' approach provides a useful method of defining the digital representation of the components of a building in a building stock in such a way that encompasses things and people, and as modified above, their interaction.

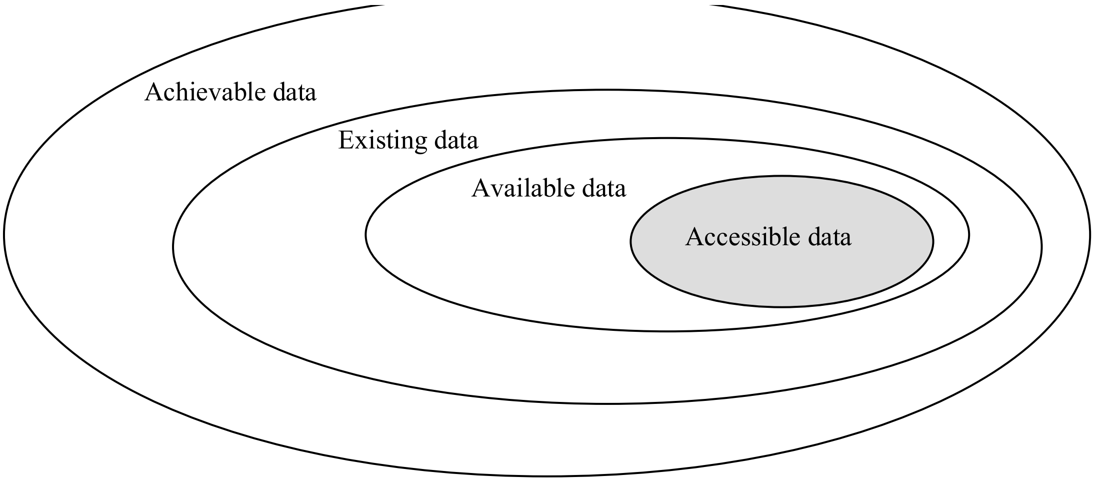


Figure 3. Layers restricting data that can be used for models of existing buildings. (Adapted from Thuvander 2002, page 135).

However, it is admittedly aspirational. Fitting these elements to organisational types will be a significant challenge. The 4DStock project will seek to bring useful existing pieces of the jigsaw together to begin to determine what information/perspectives are still missing. Each organisational element of the 'layers' model will need to be addressed, including information on owners, managers and occupiers. In this paper, we address data on *occupiers* as an example of the challenges in adding organisational aspects to a model like 3DStock. A key issue is data accessibility, including publicly and privately held data sources.

ACCESSIBILITY

The availability of data and the costs involved in collecting them are key to defining what can be collected for energy consumption models designed for existing buildings. In theory, it is possible to collect all the data that are "achievable" (Thuvander 2002, p. 135) – see Figure 3. However, Thuvander has identified that, for the building stock, data consist of layers that affect what can actually be used in a model.

In Figure 3, "achievable data" are those which it is possible to generate. "Existing data" have been generated. "Available data" are data that exist but may not be accessible due to strictures such as commercial confidentiality. "Accessible data" are the data that are physically accessible, in a format compatible with the model and can be collected/used within the operational constraints of the model.

For an energy model, operating at the building design stage, it is possible (though still unlikely) that all achievable data may be amassed, but for existing buildings, models are limited to accessible data and these may be very few in both data type and number of records.

Moving data across the boundary from "existing" to "available" data is frequently the most problematic aspect of data collection in the non-domestic sector, especially for large datasets. Historically, data about occupiers have been largely unavailable at premises level and at building stock scale, though such data have and do exist even if only within occupier organisations, especially those that are 'data rich'. A dataset, recently acquired for this project, contains limited (i.e. not always complete) data on occupiers. From this, we hope to gain a degree of access, via cross-referencing to yet more datasets, to the type of economic activity (Standard Industrial Code, or SIC) of occupiers.

The identification of "achievable" data should be part of a research design but is unlikely to produce a list of all the data and data types that might be achieved. For the physical measurement of parameters affecting energy use in buildings, the data that are (easily) achievable could, conceivably change over time as new instruments and methods become available, such as smart metering.

It is possible to change available data into accessible data, but there are issues to consider before such work is undertaken. The analyst needs to be aware of the information/data that may/will be lost and how these losses might affect the overall dataset and the resulting model. The cleaning process should not result in the loss of excessive amounts of information. Numerical data should be relatively straightforward, but may be complicated by inclusion of textual data, such as "n/a". Textual data can be problematic, especially where these are not specified by, for example, a drop-down list of possible inputs. However, fields containing textual records can be a rich source of information, if they can have the data extracted from them in a useful fashion, thus time spent becoming familiar with the data to be cleaned and analysed is usually worthwhile. In particular, preliminary analyses of the textual information in a dataset are likely to indicate the extractable data and the degree to which data fields are populated, which is itself a key constraint on usability and whether it is worth including, or indeed worth trying to include, the data as a model input. Great effort may be expended moving data from being available to being accessible.

DATA SOURCES

4DStock's first challenge is to review the available and accessible data. It will do this in two ways: top-down (external to 4DStock) and bottom-up (gathered in collaboration with 4DStock).

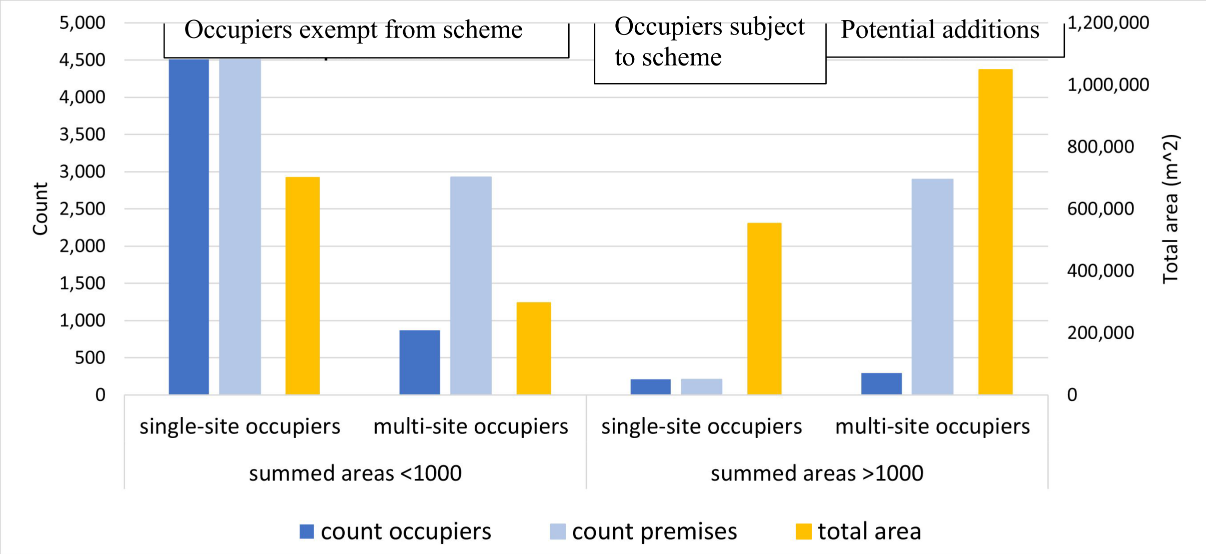


Figure 4. Breakdown of Camden VOA premises and their occupiers (where known, approximately 95%). Comparison of single-site and multi-site occupiers[1] and the total floor area they occupy (2019).

Top-down

In many cases these are data sources that can help build the model. They are also policies that can be informed by the model. These include organisational reporting requirements such as the UK's Energy Savings Opportunity Scheme (ESOS) or the Carbon Reduction Commitment (CRC).

Databases public sector bodies such as:

- Pan-National institutions (e.g. EU Commission, World Bank)
- Central Government departments
- Education, Health, etc.
- Local Government
- Government agencies

Private sector bodies such as:

- Business databases (e.g, Experian or Faust)
- Trade Associations (e.g., Julie's Bicycle, British Retail Association, British Property Federation)

Optional divulgence of data (sharing data):

- Voluntary benchmarks (e.g. Carbon Buzz, Better Buildings Partnership)

As with all large-scale data collection exercises, there are significant issues of using any data that are accessible due to data quality and specificity. For example, data may be anonymised so definitions are problematic. Data might not be collected/submitted consistently in terms of time spans, actual/estimated energy use.

Bottom-up

The team has had success in obtaining organisational, energy, and buildings data direct from occupiers and owners or through intermediary groups (e.g, the Better Buildings Partnership).These data can be paired with interviews and used to develop heuristic segmentation models that can be tested against the top-down data. This method represents an iterative and collaborative approach to co-developing research that can be used with both Local Authorities (Bull et al. 2015; Bull & Janda 2018) and commercial organisations (Janda et al. 2021).

Proof of concept and policy implications

Although the challenges are great to developing a robust method for adding organisational information to 3DStock, we are cautiously optimistic that efforts will deliver important insights for policies related to Net Zero.As a proof of concept, this section provides an example of what an occupier lens can tell us about a proposed benchmarking policy when the size of the premises is the operative threshold for regulation. It also discusses further policy implications of a completed 4DStock.

EXEMPLAR ANALYSIS: ADDING AN ORGANISATIONAL LAYER TO A BUILDING-BASED POLICY

In 2021 BEIS held a consultation on a performance-based policy framework in large commercial and industrial buildings in England and Wales. The framework document suggested a 1000 m^2 threshold for a building to be subject to the possible energy performance benchmarking scheme. Under the proposed scheme, a single company occupying a single premises with a floor area of 1001 m^2 would clearly be subject to the regulations. However, a single company operating in many locations for which the sum of floor area is also 1001 m^2 – such as a large chain of coffee shops – would be exempt.

From both an organisational perspective and an energy-saving perspective, it is useful to ask: in what ways is a single site operation similar to or different from the multi-site operation? For example, the single operation could be an SME, and the multi-site operation could be part of a larger corporate entity with greater capability and agency to drive down their energy use.

A consultation response written by the authors and another UCL colleague shows the importance of looking at occupiers rather than buildings (Liddiard et al. 2021).This response was based on 3DStock plus occupier information. Figure 4 shows an analysis of Camden, London (Liddiard et al. 2021). The figure indicates that there is a small number of single-site occupiers in premises >1000 m^2. However, the figure also demonstrates that there is a very small number of occupiers with multiple sites that, when taken as a whole, exceed the proposed 1,000 m^2 threshold. *Including occupiers with multiple sites would almost triple the total amount of floor space within the scope of the proposed scheme*. Also, because the number of organisations in this last category is quite small, the administrative burden should be reduced for both the occupiers and the administration of the scheme.

This is only a snapshot of a single local authority. A completed 4DStock model would be able to show this effect across the whole of England and Wales and help demonstrate what missed opportunities might arise from the building-based policy. This exemplar analysis shows that adding an organisational layer could help close a policy loophole and give policy-makers a more nuanced way to decide which regulations apply to whom.

Other policies, such as the Carbon Reduction Commitment and the Energy Savings Opportunity Scheme (ESOS), focused on 'organisations' as the unit of analysis. Adding an organisational rationale for this buildings-focused policy, with the appropriate pros and cons, could promote a sense of joined-up policy as well as transparency.

BROADER POLICY IMPLICATIONS

A completed 4DStock model would include the ability to switch back and forth as needed between the lenses of building/occupier/owner/manager. It would integrate organisational data into a geographic form more meaningful to decision-makers than tables and spreadsheets. It could portray systems of building communities in two ways, each of which has different scalability implications: (1) portfolios that are organisationally diverse and geographically coherent (e.g., buildings within the area of a local authority) and (2) portfolios that are organisationally coherent and geographically diverse (such as a commercial real estate portfolio). With its focus on achievable potential (the portion of technical potential that gets adopted in practice) and social potential (innovative practices that might not be predicted by techno-economic theory), 4DStock will result in new understanding of both social innovation and its relationship with technological innovation.

The alignment of occupiers and their SIC to 'buildings policy', as proposed by 4DStock, would enhance feedback loops operating between building energy reduction policies and national scale statistical reporting such as the Digest of UK Energy Statistics. Similarly, the inclusion of SIC may enable improved comparisons of energy use against other analyses that employ the same classification system. In particular, there is the potential to subdivide SIC by building activity type, such that energy used in the office buildings of, say, supermarket chains, can be separated from the energy used in its retail stores. In turn, this should improve understanding of how energy is apportioned within SICs, in terms of building energy use.

ND NEED, as currently used by BEIS, is essentially an archetype model (DECC 2014). A 4DStock model would allow the development of more targeted and nuanced policies. It would also allow the impact of those policies to be more accurately measured and enable feedback for adjustment and improvement. It would have value at both National and Local level, with Local Authorities being able to use it as part of Local Area Energy planning that is inclusive of domestic and non-domestic actors.

Summary and conclusions

This paper argues that adding an organisational dimension to UCL's 3DStock model to create a 4DStock model is a useful (albeit complicated) enterprise. The benefits and drawbacks of current physical-based models were noted, as well as some of the contributions and challenges associated with organisational research into non-domestic buildings. A model that combines these two approaches would provide a better reflection of the socio-technical nature of the built environment. As such, it will help move away from the theoretical frictionless plane of techno-economic potential and toward the real world with all its friction, transaction costs, and complexity. Challenges are significant, but an initial example of using occupier data coupled with premises size shows that this lens exists and can be further developed.

There is no doubt that the world is moving towards better transparency and accountability in the energy and environmental sphere. As more data are generated, computing platforms are concurrently improving to handle more fields and variables. Users are becoming more sophisticated, and user interfaces are improving. Although all the data we would wish to use in 4DStock are not currently accessible in a national public database, we are cautiously optimistic that using the pieces we currently have will facilitate a project that will allow us to develop larger scale investigations. These investigations will result in specifying the need for these data, generating research programmes that will gather or access these data, and obtaining support for their analysis. Ultimately, the goal is to combine what is known about organisational decision-making, and couple it with a physical representation of the building stock. These two approaches are not currently explored in tandem. To succeed in this endeavour, cooperative and collaborative research with both public (e.g., Local Authorities) and private (e.g., commercial real estate owners, managers, and occupiers) will be required. To achieve Net Zero in practice, we feel it is the right time to try.

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