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Bleil de Souza, Clarice; Tucker, Simon; Belafi, Zsofia Deme; Reith, András; Hellwig, Runa T.

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3 Occupants in the Building Design Decision-Making Process

Clarice Bleil de Souza, Simon Tucker, Zsofia Deme-Belafi, András Reith and Runa T. Hellwig

Summary

In this chapter, we will discuss the challenges of integrating considerations of building occupants and occupant behavior into the decision-making process of building designers. We acknowledge the complexities of occupant-centric design within newly deployed information management systems and will propose a framework that integrates occupant considerations into these systems so that these considerations are robustly transferred from design to buildings in use while informing best practice.

3.1 Introduction

Building design practice is a complex scenario full of unknowns and permeated by liabilities. Contractual documents provide clarity on the information required by and for various members of the design team to enable ongoing design discussions and procurement. By framing design processes as the timely exchange of information between team members and different disciplines, in this chapter, we provide clarity on how occupants fit into these processes and how their needs can potentially be accommodated.

We open the chapter with a discussion of how recent changes in design practice that aim to facilitate performance and risk assessment in relation to legislation, regulations, and clients' portfolios can affect building occupants. We then examine the role of information management in coordinating these changes to propose how information and decisions about occupants could flow throughout the design process in a coherent and coordinated way. Next, we consider the impact of design decisions on occupants within built spaces, and then we provide an overview of design considerations affecting and affected by occupants, with a particular focus on the different types of interactions that occupants have within and with buildings as well as with the environment surrounding them. We close the chapter with a proposal for the construction of occupant-centric design patterns (OCDPs) that record and support information transfer regarding occupancy and occupant behavior throughout the design decision-making process and that can

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fit within and support current industry tools such as building information modeling (BIM) and building performance simulation (BPS).

3.2 Recent Changes in Design Practices

The occupants of a building will affect how the building performs; it is also the case that the way in which a building is designed, built, and eventually occupied will influence the behavior of its occupants. More specifically, how a building performs when in use will depend on how the building design responds to what the occupants need, the amount of control the building designers have afforded occupants, and how well the design team anticipated how occupants will want to use the building and its systems in the future. The way and extent to which occupants are considered throughout the decision-making process of any building design project depends on how design decisions are balanced to achieve overarching project targets, negotiated among project team members, propagated into the information flow of the design process, and subsequently revised as the project develops. Several stakeholders play a role and influence each other in this process, which is primarily shaped by the interests of the client (who may or may not be the occupant) and the procurement process put in place to design and deliver the project. In the following section, we examine the role of the client in shaping information about the likely occupants and the way in which this information propagates throughout different delivery design stages. The client's role is examined in the context of the most recent standards[1] and documents issued by professional accreditation bodies[2] (i.e., deployed in practice between 2018 and 2020) that push the construction industry to implement building information management systems as a true record of the design process from design and construction to buildings in use.

3.2.1 Occupant Information for Clients and Design Teams

The client is the "entity, individual or organization commissioning and funding the project, directly or indirectly" (CIOB, 2014:315) and therefore the ultimate decision-maker in the project. Clients might occupy the building, or they might own the building and let or lease the building to occupants (de Wilde, 2018). When the latter is the case, clients are very likely to see "buildings [as] financial assets that figure in forms of market exchange, the operation of which often revolves around shared conventions and agreed forms of standardized description, measurement and provision" (Cass and Shove, 2018:277). This perspective will be particularly true if building occupancy is anticipated to have a large turnover.

A project's ultimate goals always reflect the client's objectives. If the client is the occupant, the client's objectives align with the occupants' objectives; if the client is not the occupant, however, different scenarios are possible. It is always easier to obtain information about occupancy when the client is the occupant, as the client is consulted at different points throughout the design process to ensure the design objectives are aligned with the client's objectives. However, when the client and occupants are distinct, consultation with occupants rarely occurs, as they are either unknown or out of the scope of the client's objectives for various reasons (capital costs, operational costs, etc.).

Different types of information about occupants are used throughout the design process. Table 3.1 illustrates the types of information, their source, examples, their role in practice with regard to their relevance to projects, and their respective impact in contractual arrangements and responsibilities. Mandatory information about occupants (e.g., from building regulations) is always required and considered an important milestone for project approval. Projects also commonly use normative information (i.e., evaluative standards) about occupants, as, for instance, energy performance and comfort standards (e.g., ASHRAE 90.1) are generally used to set project targets, and ergonomics information forms part of the vast majority of project layout proposals. Parts of normative information may be overwritten by business-oriented information (e.g., client's operational targets) and/or lessons learned (e.g., metering, monitoring, post occupancy evaluation (POE)) and/or information from consultations with occupants, especially in cases where the client is the occupant. However, overwriting based on lessons learned and/or consultations with occupants is unlikely to happen if the client is not the occupant, as this process requires special contractual and project management arrangements in which risks and liabilities are shared. Chapter 2 of this book discusses the origins of occupant data in normative information in more detail, while Chapter 4 discusses several methods useful for consulting occupants. Chapters 6 and 7 explore in depth how lessons learned can be generalized and used in new design projects from an engineering perspective through the development and applications of occupant behavior (OB) models.

Performance-based legislation and regulations are starting to more emphatically promote the use of lessons learned in new projects toward developing fit-for-purpose design, as occupants play a key role in influencing operational efficiencies. The phases from design to buildings in use are now being seen as a continuum (BSRIA, 2018), with targets set up during the design process and verified through monitoring during the operational phase, which places joint responsibility on the client and the design team in terms of their needs and aspirations for the occupants.

In an attempt to ensure information transfer from design to buildings in use, plans of work are being modified to include information management standards related to building design and construction (EN ISO 19650-1, 2018; EN ISO 19650-2, 2018; EN ISO 12006-2, 2020) as well as asset management standards (EN ISO 55002, 2018; EN ISO 19650-3, 2020). These changes are further supplemented by documents such as BSRIA Soft Landings (BSRIA, 2018), which was written specifically to support construction

Table 3.1 Types of information about occupants used in practice, with examples and their source, relevance to projects, and impact in practice

Type of information	*Source*	*Examples*	*Relevance to project*	*Impact in practice*
Mandatory	Building regulations, codes, and legislation	Health and safety, universal accessibility, fire evacuation, etc.	Ensure minimums are met, protect occupants' rights	Enforced in every project
Normative	Standards and handbooks	Ergonomics, predicted energy use, carbon emissions, visual and thermal comfort, effect on performance measures of occupant uncertainty, etc.	Set targets (energy, comfort, occupant satisfaction, etc.), replace missing bespoke information about occupants, reduce uncertainties	Cover for practitioners' liabilities
Business-oriented	Client	Energy demand management, client's expectations for occupant behavior, building function and activities, occupant density, etc.	Ensure client's objectives are met, control running costs	Define client's responsibilities
Lesson learned from metering and/or monitoring and/or POE	Client Practitioner	Energy use profile, indoor air quality, occupant satisfaction, preferred adaptive opportunities, etc.	Aid in fit-for-purpose sizing, reduce scope of building operation, reduce running costs	Cover for practitioners' liabilities Require risks and liabilities to be shared in contracts
Consultations with occupants	Building occupants	Bespoke layout, environmental quality, etc.	Provide bespoke information about usage and occupants' needs, requirements, and aspirations	Resolve liabilities (client/occupants) Require risks and liabilities to be shared in contracts ('speculative' client)

clients to incorporate core principles in procurement. However, little is prescribed in terms of how information should be transferred from design to operation, and no methods are yet available to record such information transfer. Currently, it is up to contracts and the client to set roles and responsibilities so that operational phase activities and performance targets can be agreed upon realistically and in consonance with design objectives and desired operational outcomes.

These changes, once fully implemented, will have a significant impact on the construction industry. They will not necessarily ensure better buildings, as their aim is to increase the client's power in decision-making and affect decisions related to project targets from inception to project delivery. Still, these changes will demand robust coordination of information throughout a project's life and form an important record for project quality control for future auditing for liability purposes, thus enabling decisions to be clearly traced back to the project team.

3.2.2 Information Flow on Occupants throughout Project Delivery Stages

Information verification, validation, and quality control methods should be established within project documentation, together with risk management (EN ISO 19650-2, 2018; EN ISO 19650-3, 2020). Project information requirements should include demand management and customer expectation policy, energy efficiency and environmental aspects, plus performance monitoring, safety, health, and environmental management. Table 3.2 illustrates where and how the different types of information identified in Table 3.1 inform the different design stages using documents from two different countries (the UK and USA) as examples. Only the stages related to design are shown and since they vary country by country as a function of when planning application and building regulation approval is needed, they are generically defined according to (EN ISO 12006-2, 2020) as pre-design and design.

As shown in Table 3.2, plans of work are fluid with regard to the granularity of information to be provided at each design stage. This fluidity is because information delivery is closely related to procurement routes and contracts, which are the legal instruments used to set roles and responsibilities and that specify project deliverables (milestones, strategies, data, etc.), information approval and authorizations, and information exchange at different design stages. Information delivery plans contained in contracts describe the breakdown of tasks, roles, and responsibilities throughout project teams in addition to where information about occupants should be provided throughout the design process.

Procurement strategies affect information requirements, high-level objectives for the project and future building operation, information exchange, how the design team will be appointed, and the technical design stage and how it overlaps with the construction stage. In this context, information

Table 3.2 Examples of different types of information about occupants deployed throughout different design stages

Documents by professional accreditation bodies	*Pre-design*		*Design*		
RIBA Plan or Works 2020	**Strategic definition** **Business-oriented** information to be checked against information from **lessons learned**	**Brief** Incorporate **lessons learned supplied by the client** into brief, targets, and POE requirements	**Concept design** Generate risk assessment report; review concept design and Facility Management (FM) plans **based on lessons learned;** run energy and other simulations	**Spatial coordination** Test performance requirements through **consultations** with design team, FM, occupants, and contractors; coordinate spatial information related to it; set plan of use protocol and develop POE for procurement	**Technical design** Use risk assessment to quality control detailed design and contractor's proposal; use plan of use to prepare tendering information
AIA Sustainability Plan 2020 and AIA BPS Guide 2019[a]	**Preliminary design** Define code compliance to be achieved (i.e., **mandatory information**) and environmental framework to be used; refer to **normative** information (e.g., LEEDS, LBC); establish vision statements to resonate with all stakeholders involved in the project; promote the use of **business-oriented** information, **lessons learned, and consultations**		**Schematic design** Establish fundamental components of the project, including preliminary systems; analyze systems through modeling if possible; design for typical operation (considering benchmarking, i.e., **normative information** from standards) and space flexibility; promote occupants' participation through **community consultations**	**Design development** Integrate technical knowledge and information to refine a design; refine the proposal involving consultants and specialists using simulations; ensure access to daylight and natural ventilation with openable windows	**Construction documentation** Refine energy model to represent final design decisions, ensuring occupant-based controls for immediate environment; develop POE plans to check targets to be achieved and **collect lessons learned**

[a] AIA BPS Guide (AIA, 2019) recommends the type of simulation appropriate for each design stage and AIA Sustainability Plan (AIA, 2020) refers to how sustainability information can be embedded in different types of contracts, without being specific about which design stage this information belongs to. Data from Table 3.2 are therefore inferred by combining these two documents.

management systems are defined by the market and for the market, and performance targets are a function of asset management rather than a response to environmental concerns. However, information management does bring benefits, especially in the context of integrated design process (IDP) guidelines (Sustainability Solutions Group, 2010) and integrated project delivery (IPD) roadmaps (AIA, 2007), which inform management strategies and steps to better integrate project goals related to social, ecological, economical, and sustainability performance. IDP and IPD can be connected to contractual documents to justify the implementation of shared risks and liabilities which would, in theory, facilitate and promote the use of lessons learned and consultation with occupants. There are clear opportunities to promote better design in this new reality, but uptake in practice is still very low (Piroozfar *et al.*, 2019), which potentially calls for stronger governmental intervention.

Lately, practitioners are under pressure to document their decisions, as building information management systems are increasingly framed as reflections of a true record of the design process and gradually being implemented into performance legislation and building codes. However, information management frameworks, procurement routes, project management approaches, and guidelines to practitioners do not provide methods to support the transfer of information about occupants in integration with performance management throughout building projects. Records of these decisions are normally found within project documentation, but they could be better linked with the tools used in design, particularly BPS and BIM. To the best of our knowledge, there is no recognized method for documenting information about occupants and occupant behavior that enables it to be properly inserted into BIM models and coherently transferred to BPS models. This gap increases risks in decision-making for project teams while at the same time hindering the implementation of integrated project delivery toward producing better buildings.

3.3 Methodology: A Place for Occupants in Information-Centric Frameworks

Design decisions related to occupants and occupancy must be considered within the context of information management. Documents issued by professional accreditation bodies have been revised (Table 3.2) and amended to include the deployment of information management systems throughout plans of work to bridge fundamental gaps in information exchange between the design and construction phases of a project. These revisions and amendments establish that information exchange needs to happen in a comprehensive digital model that, in theory, facilitates design for manufacturing assembly and allows for constant refinement until it becomes an asset management model. This digital model, also called a federated model (BIM), is structured to mirror the different disciplines involved in a building project.

This structure enables information exchange and design decision-making to be better controlled and coordinated by the design team. To this end, an efficient way to transfer information about occupants throughout the design team is to connect them with the objects of this federated model. Objects can contain information that is required on almost all projects (e.g., construction assemblages, room usages). Tucker and Bleil de Souza (2016) proposed that objects can also incorporate descriptions of repeatedly used simulation methods (see Chapter 8 for example), occupancy profiles, design requirements, design aims, design decisions, and so on. Often, these objects are used repeatedly on different projects and so could be recorded and held in a library to be retrieved (and possibly modified) by the design team when needed. BIM uses a specific object-oriented structure (EN ISO 12006-2, 2020) consisting of the following objects, all of which can be related to occupant considerations (see Section 3.5):

- *Construction entities* are basic units in the built environment with boundaries clearly defined by a characteristic form and spatial structure and hosting several functions and user activities; in other words, they are the building being designed.
- *Built spaces* are spaces clearly defined by the built environment to host specific user activities and/or equipment and can be classified as spaces for human activity (e.g., living, work, production), storage (e.g., materials, equipment), infrastructure (e.g., routing, transportation), or technical systems (e.g., operational technique, production equipment).
- *Construction elements* are the different components of a construction entity with distinguishable function, form, or position (e.g., wall construction system, furniture system, cooling supply system).
- *Construction properties* are attributes of a construction element, built space, or construction entity and can be classified according to functional (e.g., thermal performance, structural performance), spatial (e.g., shape, size), temporal (e.g., duration), compositional (e.g., assembly, behavior), experiential (e.g., color, comfort), symbolic (e.g., meaning), and administrative (e.g., price, style) properties.

Expanding on these four objects, the following two sections examine, generically and through examples, different types of design aims, requirements, considerations, and decisions—more specifically, how occupants affect and are affected by them when interacting within and with the construction entity as well as with the environment (natural and built) of the wider site. Two levels of information are provided: coarser information for decisions related to construction entities and built spaces, followed by more refined information related to construction elements with their respective construction properties. Section 3.6 presents a template to produce occupant-centric design information that captures decisions and objects in context and in connection with BPS tools. The rationale behind the template is that information about occupants can be deployed into practice in connection with building performance assessment methods using an object-oriented structure.

3.4 The Impact of Design Decisions on Occupants within Built Spaces

The overall impact of design decisions on the occupants of built spaces depends largely on how the client and the design team translate their needs and aspirations for the occupants throughout the design process. Mandatory, normative, and business-oriented information about occupants, potentially combined with lessons learned and consultations with occupants, is interpreted by designers and translated to built spaces, thereby constraining and persuading occupants to use buildings or interact with them in specific ways, but also framing affordances and opportunities for these occupants.

Designers impose ***constraints*** (either consciously or unconsciously) on occupants. Constraints can vary from, for example, the control of environmental systems to the lack of flexibility or adaptability of how occupants can use spaces. Several restrictions in controls come from mandatory and normative requirements together with business-oriented requirements and make use of lessons learned to constrain occupants' use of the building to the way clients intended it to be used. These constraints often result in removing personal control from occupants in favor of automated-only controls supported by energy efficiency standards (EN 15232, 2017).

Persuasive strategies are also starting to become part of design agendas, especially with the wider implementation of automation and smart controls that impose conditions without allowing for occupant override. These strategies, potentially heavily influenced by business-oriented information (e.g., client expectations for occupancy behavior) and supported by normative energy efficient guidelines (e.g., predicted energy use), might give designers the false impression that occupants can be persuaded or directed toward specific behaviors. They neglect the fact that occupants' adaptive needs are driven by behavioral needs (mainly motivated by internal stimuli, see Chapter 2) and change with context and time varying among different people. An iconic example is the known rebound effect in which energy efficiency measures are less effective than predicted because occupants keep energy consumption constant by increasing temperatures and/or the number of appliances in the household (Guerra Santin, 2013).

Affordances are what the building offers its occupants, including the environment the occupants inhabit as well as the way of life or actions possible within this environment (Gibson, 2015). Affordances are directly perceived by the occupants and should therefore require minimal cognitive effort and no explicit instructions, as they are dynamic and open to multiple interpretations (Kannengiesser and Gero, 2012). Affordances include the intended effects a design has on building usage as well as the unintended effects it has

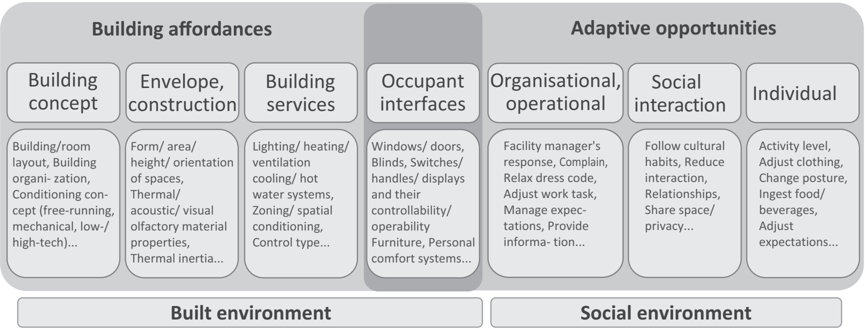

Figure 3.1 Building affordances and adaptive opportunities in the built and social environments.

on how occupants use the building. Sometimes the intended effects do not cover all areas of interpretation by occupants, and sometimes they contain misconceptions of how the occupant will interact with the building, especially when occupants are not consulted in the design process.

Therefore, designing a building that is significantly shaped by the way people live (Alexander, 2002) can only be achieved if designers put themselves in the position of the occupants (Gibson, 2015) and are able to predict expectations and adaptive needs that might occur within the spaces (e.g., feelings, perceived options). These adaptive needs trigger behavioral needs, which will be shaped by what is afforded from the built and the social environments. Consequently, when designing for the occupant, designers need to keep ***adaptive opportunities*** in mind (Figure 3.1).

The term adaptive opportunities, first coined by Baker and Standeven (1997), became a key concept in comprehensive thermal comfort (de Dear and Brager, 1998; Humphreys and Nicol, 1998) and its manifestation in practice is in line with what is defined by Alexander (1979) as the 'quality without a name'. The adaptive opportunities design process (Hellwig *et al.*, 2022) proposes to establish the occupants with their adaptive needs in the building's context (local climate, building type, human context, and local constraints) so that designers can put themselves in the occupants' position. Lessons learned and consultations with occupants can provide valuable information to design adaptive opportunities, especially in speculative buildings; still, far more is needed to increase their uptake in practice, as they require risks and liabilities to be shared in contracts.

3.5 Decisions Affecting or Affected by Occupants

Decisions affecting or affected by occupants are at the core of the design process and mainly depend on overarching strategies set up by the client and design team for the construction entity (i.e., the building). These strategies result in further decisions that define affordances, adaptive opportunities, and constraints and persuade occupants to interact within and with a building and its spaces. Thus, once the climate, site, building type, and overall conditioning strategy for the building are understood and defined, the design team must make a series of decisions related to how occupants will interact within and with the construction entity as well as with the environment (natural and built) of the wider site. These interactions are complex and context-based, but design decisions about the building can be thought of as "typical," as the design team has a finite number of construction elements and construction properties to manipulate toward achieving the project goals (Bleil de Souza and Tucker, 2015).

Table 3.3 presents a list of construction entities and built spaces about which design decisions are made by design teams. Table 3.4 refers to construction elements and their respective construction properties. Both tables are generic with regard to clients' overarching targets, constraints and requirements, procurement routes, and project management approach, and they both illustrate how design decisions related to the building, its spaces, and its elements can affect occupants. The tables are not exhaustive and contain design decisions expanded from Bleil de Souza and Tucker (2015) with the support of activities listed in BIM Forum (2019), RIBA (2020), and Yan and Hong (2018; Tables 8.2.4 and 8.5).

Some of the examples presented in Tables 3.3 and 3.4 are common across all buildings, whereas others are clearly context-based. They presuppose that designers have good information on how the building will be used, regardless of any direct involvement with its occupants, and they are non-specific in terms of what type of construction entity, built space, or construction element is being specified. They highlight the richness of the building design process and how design decisions are thoroughly interwoven with occupant interactions, thus showing that the integration of occupant behavior in design decisions is a non-trivial proposition and can be heavily context-dependent, requiring concerted decisions across different disciplines to address intangible and unquantifiable objectives.

Table 3.4 shows that once construction elements and their respective construction properties are examined in relation to the same types of interactions as explored in Table 3.3, design decisions gradually become more specific and detailed. Therefore, if consideration of occupants is to be integrated into design practice, then design teams need to be prepared to record information about occupants throughout the design process in a structured way so this information can be easily recalled as design progresses.

For example, when designing an art gallery, a designer has passive heating and cooling as the overarching strategy set up by the client, they will need to ensure that the appropriate internal conditions can be met as the design progresses. This strategy needs to be recorded as part of project information in an easily retrievable format so it can be referred to by other

Table 3.3 Examples of decisions related to construction entities and built spaces with examples of design aims/requirements/considerations/decisions that affect or are affected by occupants

Decisions undertaken in relation to construction entities and built spaces	*Examples of design aims/requirements/considerations/decisions*		
	Effects on occupants *within* the building	**Occupants' interaction *with* the building**	**Occupants' interaction *with the environment of the wider site,* through the building**
Building form and volume	Convey a sense of place; Display the status of the building owner	Create exhilarating spaces; Ensure a feeling of 'coziness'; Minimize heating/cooling costs of the building	Help shape the street; Configure outdoor courtyards; Integrate with landscape
Building footprint on site and orientation	Provide places for children to play in the sun; Shape secluded spaces for people to interact outdoors and with each other	Provide clarity of access; Create useful outdoor spaces integrated with the street	Minimize environmental impact on the site; Protect from solar overheating; Lower impact on neighbors' right to light and sun; Take advantage of cooling breezes
Program distribution and orientation	Allow for flexibility in separating or joining rooms; Consider public/private interactions	Determine the relationship of noisy/ quiet, day/night spaces (e.g., isolate the bedrooms from the living area); Orientate spaces with regard to heating and cooling needs	Provide daylight, natural ventilation, and view to the outside for the main living spaces; Enable patients to see the day go by; Enable visual contact with nature
Form and area of building spaces	Provide office workers appropriate visual/aural contact with each other (e.g., open plan cellular/ offices); Consider a mix of functions (e.g., bar, dance space, seating)	Provide an efficient and clear circulation inside the building (e.g., functionality, escape, and evacuation routes); Ensure that spaces support functions	Provide a sense of connection to the outside (e.g., shallow office spaces); Let sunlight into bedrooms in the mornings

(*Continued*)

Table 3.3 Continued

Decisions undertaken in relation to construction entities and built spaces	*Examples of design aims/requirements/considerations/decisions*		
Fire and evacuation routes	Provide for safe evacuation of building occupants	Provide safe routes to the outside; Ensure clarity on emergency access	Provide the required access to external services (e.g., emergency vehicles, hydrants)
Floor to ceiling heights	Convey status; Provide views from the top (mezzanine)	Improve sound dispersion; Manage overheating (stratification)	Improve daylighting and sky views (e.g., large glazing); Facilitate segregated natural ventilation (e.g., above the occupant)
Heating and cooling system choice	Consider running costs for the client; Charge energy bills at room level (e.g., care homes)	Position systems to minimize furniture disruption; Reduce response time on conditioning the building; Consider passive heating and cooling strategies; Shift peak demand in relation to energy tariff	Minimize greenhouse gas emissions; Consider low energy technologies (e.g., heat pumps); Consider heat release and noise affecting pedestrians or outdoor recreation areas
Heating and cooling system demand	Ensure thermal comfort for the expected range of occupants (e.g., doctors and patients in hospital)	Ensure that temperatures and humidity are suitable for building contents; Provide 'thermal delight'	Minimize demands by taking advantage of the climate
Cooking system choice	Ensure that systems are appropriate to occupant's lifestyle (e.g., food type)	Provide appropriate ventilation system and cooking facility	Consider the environmental impact of fuel
Hot water system choice	Ensure that systems are appropriate to occupant's lifestyle (e.g., run a bath and do the dishes at the same time)	Ensure correct system sizing	Consider low energy technologies (e.g., solar hot water)

Table 3.3 Continued

Decisions undertaken in relation to construction entities and built spaces	*Examples of design aims/requirements/considerations/decisions*		
Ventilation system choice and demand	Consider different types of activities; Consider the number of occupants and type of occupancy	Consider occupant preferences (e.g., opening windows, HVAC, ceiling fans)	Consider natural/hybrid ventilation; Avoid outdoor noise; Filter outdoor air pollutants
Heating, cooling, and ventilation control type	Consider provision of shared and/or individual control	Consider provision of 'intelligent' controls; Ensure that controls are appropriate to occupants (e.g., elderly, children) and system type; Ensure that control are customized to activity	Provide climate responsive/ efficient controls (e.g., temperature sensors, Daylight responsive control)

members of the design team when decisions about passive heating and/or cooling are made. Since these decisions would often be made by using BPS to test potential design options (e.g., addition of shading, ventilation, insulation, thermal mass), they might be undertaken by a third party, meaning not only results and design modifications but also changes in occupancy assumptions need to be properly documented when information is handed back to the designer. This documentation is especially important when designing for adaptive opportunities, which are particularly useful in improving the performance of passive design.

Tables 3.3 and 3.4 show that occupancy-related information can potentially be linked to objects, which themselves can carry information back and forth to the design team. The level of detail embedded in each object increases as the project progresses, meaning information about occupants can be added to such objects at a number of appropriate levels and become written or read by different team members at different times. This process can be particularly useful when simultaneous decisions requiring different levels of detail are needed from different design team members; for example, when building designers are defining room internal layout and building service engineers are calculating bulk energy consumption to size equipment rooms. However, more research is needed to establish how these

Table 3.4 Examples of decisions related to construction elements and their respective construction properties with examples of design aims/requirements/considerations/decisions that affect or are affected by occupants

Decisions undertaken in relation to construction elements and construction properties	*Examples of design aims/requirements/considerations/decisions*		
	Effects on occupants *within* the building	**Occupants' interaction *with* the building**	**Occupants' interaction *with the environment of the wider site,* through the building**
Room layout/ furniture layout	Facilitate watching the children while having coffee (café); Create intimate sitting area (bar)	Create a 'sitting wall'; Increase the number of office bays; Guarantee sufficient privacy to undertake an activity	Avoid direct sunlight on sensitive artefacts (e.g., artwork, books)
Appliance layout	Provide a cooking island for people to gather around	Optimize the cooking processes	Ventilate to the outside
Interior finishes and colors	Ensure that the acoustics are appropriate to function (e.g., concert hall, call center, office)	Increase the ease and reduce the costs of cleaning; Consider the interior sound reverberation, absorption and reflection	Increase or decrease the daylight reflection
Transparent element orientation, placement/ dimensions/ properties	Facilitate sitting together in the sun; Provide a quiet space in the sun; Provide an area to watch the world go by; Display merchandise to passers-by; Display the activities of the building	Provide a reading area under a window; Enable occupant to sit close to a window without feeling cold; Ensure that the type of light does not disturb the human circadian rhythm	Frame an outdoor view; Increase the solar intake; Consider incoming light properties (e.g., spectrum, diffusion, direct/ indirect, color); Consider the inside/outside relationship

Table 3.4 Continued

Decisions undertaken in relation to construction elements and construction properties	*Examples of design aims/requirements/ considerations/decisions*		
Transparent element operation	Enable the sitting area to be part of the street; provide an opening window to talk to someone in the street	Consider window operation (fixed/openable); Provide operation appropriate to occupants (e.g., the elderly, children)	Consider the inside/ outside boundary (e.g., sliding glass wall)
Opaque elements construction and properties (floors, walls, roofs)	Segregate circulation using physical barriers to ensure on-way systems	Provide sufficient thermal mass in a room for comfort; Consider radiant temperature of surfaces to improve comfort	Protect cavities against pests; Consider required integrity of building envelope
Shading device type, dimensions, and areas	Enable sitting in shade on a sunny day	Consider possible interaction of shading with indoor climate control (e.g., internal shading devices and operability of window)	Avoid direct sunlight on sensitive artefacts (e.g., art works, books); Consider obstruction of outside views
Control of shading device	Consider individual/ group/no control; Consider combination of automatic control with override	Ensure ease of shading use; Ensure accessible control	Ensure operation is suitable for all sunlight conditions
Glare protection and control	Enable occupants to see each other (e.g., children to see the teacher and board)	Protect sensitive areas (e.g., computer workspaces; museum displays	Obstruct views prone to glare (e.g. outdoor pavement, reflective glazing/surfaces)

(*Continued*)

Table 3.4 Continued

Decisions undertaken in relation to construction elements and construction properties	*Examples of design aims/requirements/ considerations/decisions*		
Artificial lighting type and layout	Enhance jewelry shining; Use best daylight spectrum to display food (e.g., enhance the yellow in the cheese (pizzeria) and the red in the meat (butcher))	Spotlight a work of art; Reinforce the circulation path; Provide task lighting; Ensure visual comfort	Complement daylight illuminance; Replace daylight when needed; Mimic daylight at night
Artificial lighting system control	Enable individual lighting control (task lighting)	Use presence detector sensors	Provide dimming according to daylighting
Ventilation system equipment zoning and layout	Remove food smells; Remove excessive sweat from the gym	Remove chlorine from the swimming area; Remove VOCs; Avoid discomfort (e.g., in sitting areas)	Coordinate perimeter ventilation (natural) with mechanical ventilation
Heating and cooling system equipment zoning and layout	Reconcile gender and cultural requirements (e.g., in offices); Reconcile age requirements (e.g., in nursery, care homes)	Ensure thermal comfort; Consider internal gains	Consider perimeter heating (e.g., if windows can open)

links can happen, especially considering BIM and BPS have different ontologies. In any case, if decisions affecting or affected by occupants are recorded and manipulated in an object-oriented environment, information about occupants and their behavior can be documented through links between these objects. Pathways with these links can therefore be traceable and provide evidence-based information to clients and design teams in future projects.

3.6 Occupant-Centric Decisions in Context

This section presents a template for producing occupant-centric design information that captures decisions and objects in their design contexts. The purpose of the information is to demonstrate to designers how a design problem (and its solution) can affect or be affected by occupants. This information could be attached to or associated with the relevant construction entity or built space, but it could also be linked to relevant construction elements and construction properties. The information is presented to the designer in the form of a design pattern, following the initial concept developed by Alexander, Ishikawa, and Silverstein (1977) and Alexander (1979) and further adapted by Bleil de Souza and Tucker (2016) and Tucker and Bleil de Souza (2016). When the template is instantiated with information relevant to a particular design problem and context, it becomes a design pattern.

Occupant-centric design patterns (OCDPs) describe common situations where design decisions will affect occupants and describe design solutions that will take occupants' needs into account. Alexander and colleagues' original set of patterns (Alexander *et al.*, 1977) described abstract solutions to common abstract problems that designers encounter in the built environment. These problem-solution pairs are a powerful way to transfer and share knowledge as well as provide quality control for design solutions. They enable expert knowledge that is normally deployed in a tacit form to be formalized, stored, and accessed by novice designers or non-experts.

This way of recording information has been highly influential in computer science, where proven solutions have been developed for common coding problems, and there is a need to make these solutions available to novice programmers to reduce coding time and maintain quality. Design patterns have also inspired developments in object-oriented programming by treating programs as a number of self-contained objects that are linked to other objects (Gamma *et al.*, 1994; Buschmann *et al.*, 1996; Fowler, 2002), and they continue to be used in computer science (e.g., Lakshmanan, 2020) to capture best practice. We propose that design patterns are used to better integrate consideration of occupants' needs into design processes.

Each design pattern describes one problem-solution pair with instructions for how to use it, examples of its use, descriptions of the contexts in which it is used, and links to other related patterns. For any particular building project, a number of appropriate patterns are selected. They can be adapted into an object-oriented model, as the pair problem-solution is structured in a consistent and reproducible way and can be linked through the BIM system to a building model.

The structure of patterns was developed by Bleil de Souza and Tucker (2015) to encapsulate expert knowledge for BPS. This structure is further developed to integrate relevant occupant-related information (e.g., models to be used, analytical processes) and make them available to building designers in a user-friendly way. There are already strong connections between simulation and occupant profiling; for instance, Hong *et al.* (2016) recorded occupants' interactions with buildings and considered the types of action undertaken with the potential drivers behind them. They propose an

Table 3.5 Template adapted from Tucker and Bleil de Souza (2016) for the content specification of an OCDP

Index	Index or code to store the proposed pattern in a database for retrieval into a BIM environment. Index could refer to building type, design actions, analytical methods, climate, type of human/building/environment relationship, etc.
OCDP name	Name should clearly reflect the abstract problem-solution pair and can refer to building typology, specific design actions, design goals to be addressed, analytical methods, outputs required, type of human/building/environment relationship, etc.
Introduction	Situates the pattern in its design context and describes how it is related to occupants. The introduction is written in non-technical language and describes how the OCDP is intended to be used. It also describes how it is related to other OCDP's.
Problem	A brief outline of the problem addressed by the pattern, including the aims of the design decision(s) to be undertaken.
Context and examples	Situates the use of the pattern in relation to occupancy, simulation, and design practice and explains the context of the decision(s) to be undertaken by designers and provides examples. Information (e.g., on theory or practice) is provided to justify the advice given by the pattern.
Solution	A description of the occupancy models and simulation methods that will produce the information required by the designers with an indication of what BIM objects can affect or be affected by it.
Pattern elements	Describes the simulation details (e.g., aim of simulation, model settings (simulation and occupancy), processing and analysis methods, simulation outputs, required user interaction with outputs).
Further modeling details	Further notes on modeling.
Interpretation and quality assurance	Instructs the designers on how to interpret results, what to expect from results and why, and which quality assurance patterns to use.
Further patterns	Information on other patterns that may potentially be relevant.
Comments and further development	Further comments and observations for pattern development.

obXML[3] schema connected to simulation software environments to provide highly detailed schedules and data-based models of occupants' interactions with a building's systems, including probabilistic functions—for instance, statistical schedules for window operation in specific building types and climates to be used in thermal comfort and energy simulations (Haldi and Robinson, 2009).

Capturing the correct and meaningful use of successful occupant-related analytic models together with the context in which they work enables the construction of a library of OCDPs that better connect design decisions with different types of performance to be simulated and assessed. Each problem-solution pair contains on its problem side the context in which the decision is made (e.g., the aims of the decision to be made and type of problem at hand). On the solution side, each pair contains a list of relevant and useful information for BPS tools and occupant behavior models to be used in a specific context. The template includes a description of model and simulation settings, types of analysis to be made, recommended output post-processing, and quality assurance procedures. Table 3.5 shows the template for the information contained in an OCDP (adapted from Tucker and Bleil de Souza 2016).

OCDPs focused on performance would help to better provide comfortable conditions and healthy environments, test effects of uncertainty on equipment and system sizing, and achieve economical operation of the building and its systems (see examples in Tables 3.3 and 3.4). The example OCDP given in Section 3.7 below concerns the use of BPS to provide performance information, therefore linking occupant information to building performance assessment.

3.7 Example of an OCDP

Table 3.6 shows an example OCDP that depicts information from the Eco-Housing case study in Chapter 11 in which consultations with occupants were undertaken to build occupancy schedules and test their impact on energy use. This OCDP contains a combination of technical details, notes, hyperlinks to other patterns, and engineering details. It focuses on the energy performance aspects of building occupancy, as these relate clearly to the use of simulation. That is not to say that an OCDP cannot be more broadly related to non-simulation design aspects of occupants; Tables 3.3 and 3.4—particularly the interactions within the construction entity column—suggest many examples that could be developed into patterns.

Further examples of how patterns can be presented to the designer and linked to design stages are discussed in Tucker and Bleil de Souza (2015), including hierarchies or classification of patterns (e.g., based on RIBA work stage, climate, building type), automatic linking between patterns based on their outputs to create a network, and the possibility of simply selecting patterns from a list. The development of an OCDP involves a process of consensus among experts and can also be done through using combinations of different information types described in Table 3.1, which vary from recording mandatory information about occupants to information coming from consultation with occupants. The activity of generating patterns leads to ideas for new ones, improvements to existing ones, or indeed the deletion of those not found to be useful, so that information on how design can affect

Table 3.6 Example OCDP for testing building energy use following consultation with occupants to develop custom-build schedules as described in Chapter 11

Index	#
OCDP name	***Effect on building energy use of occupants in low energy co-housing apartment building***
Introduction	Low energy co-housing can provide a sustainable solution for affordable housing for low-income occupants. The requirements of this building type are low running costs and some shared rooms and facilities. A participatory design process is used to inform details of occupancy schedules for the project at hand as well as obtaining feedback on the design from its future occupants. This OCDP is used to reduce energy demand and energy costs to occupants. It is used to test the effects on the thermal performance of a range of building occupation schedules that can result from the variety of employment conditions that typical inhabitants may expect to encounter. It provides simulation output information that should more accurately reflect actual heating, cooling, and ancillary energy use and therefore help address the performance gap between simulation results and buildings in use, which in turn can support decision-making on heating, cooling, and renewable energy system sizing. This OCDP also affords custom inputs to schedules based on the availability of survey data. Such data can also be used to inform design decisions on shared building facilities. This OCDP is intended to be used at a detailed design stage when the construction and form of the building are known.
Problem	The problem is to provide a range of occupancy schedules that describe the effect on thermal loads of differing occupancy patterns, represent levels of uncertainty in the results, and to allow data input of survey results where available.
Context and examples	Example 1: Apartment building in Budapest, Hungary. This research examined the effect of different occupancy profiles on heating and cooling loads (details in Chapter 11).
Solution	ASHRAE, UK NMC, and French Th-BCE 2012 schedules plus co-design informed (active, passive, and weighted average) schedules are used in the simulations to provide information on magnitude and variance of heating, cooling, and plug loads in each apartment or zone. Model variants are simulated using the appropriate full hourly weather file.
Pattern elements	Aims – To inform the designer of the effect on performance metrics of uncertainty in occupancy schedules. This information contributes to a robust design. – To be able to compare performance metrics for heating and cooling energy use for different occupancy schedules that are automatically run and/or defined by the designer.

Table 3.6 Continued

Index	#	
	Model settings	– Construction entity = Whole building. – Construction elements and Construction properties (discrete) = combination of designer defined and defaults for built spaces and their respective services (e.g., plant ideal load in early stages with detailed plant in later stages). – Climate file: full year (hourly). – Operation parameters = designer defined + defaults. – Occupancy schedules: ASHRAE, UK NMC, French Th-BCE 2012, and custom co-design.
	Processing and analysis	– Full-year simulation. – Comparative assessment of each metric across models. – Metric 1: heating loads (kW). – Metric 2: cooling loads (kW). – Metric 3: heating energy (kWh). – Metric 4: cooling energy (kWh).
	Outputs	*Overview:* – Time series: occupant heat loads all profiles (W/person). – Bar chart: annual heat energy all profiles (kWh). – Bar chart: annual cooling energy all profiles (kWh). – Time series: typical summer day occupant heat loads (all profiles), cooling loads (all profiles).
	Interaction with model and outputs	*Interaction afforded:* Zoom in location and time. *Designer can select*: Individual space, occupant profile. *Outputs afforded:* As for Overview (see above).
Further modeling details	– Surrounding buildings should be modeled.	
Interpretation and quality assurance	– Advice on heating and cooling load interpretation. – Record of operational model settings (ventilation rates, internal gains, occupancy profiles).	
Further patterns	Follow-up patterns include detailed design patterns for HVAC design and/or specific obXML model of occupant interaction with the building or its systems.	
Comments and further development	An early design stage version of this pattern could use a massing model and small range of default building constructions and parameters to give indicative figures on heating and cooling load variance.	

building occupants can be constantly revised, updated, and integrated into the various stages of a building project.

In sum, the proposed template and OCDPs are an attempt to develop a way to record and trace design decisions related to occupants in a single environment that is compatible with BIM federated models and BPS tools so that multiple assessment points can be scheduled throughout the design process and design decision-making can be evidence-based and better integrated with performance in use. The advantage of supporting design decisions using an object-oriented information system is that the discussion is not tied to project stages, but rather to a network of generic objects detached from country-specific systems or contracts. Different levels of detail can be set to a single object and recalled as design progresses, which would make it possible to develop and record context-specific entities in a centralized environment, which would open the door for future work to implement this structure within common BIM tools to facilitate agility and distributivity in decision-making. In addition, this framework can be used to record best practice and therefore clearly connect information management with performance targets needed to design better buildings that benefit occupants and the environment, thus filling a current gap in practice.

3.8 Closing Remarks

In this chapter, we argued that information about occupants should be properly documented throughout the design process such that it is linked not only with BPS but also with BIM in order to fit within the information exchange between team members of different disciplinary backgrounds and thus support collaborative initiatives from a technical perspective.

The framework we proposed in Sections 3.6 and illustrated in 3.7 would enable practitioners to record and store sequences of problem-solutions for future retrieval and develop blueprints for how occupant information flows through design projects. The framework would also enable practitioners to identify how similar problems and issues concerning occupants reappear across projects, which would promote the creation of corporate object libraries that link BIM, BPS, and occupant behavior modeling tools to inform performance assessment. In this library, decisions could be recorded in context by the agreement of all involved stakeholders to avoid misalignment between design goals and intentions and occupant expectations throughout all stages of the design process. The process would be transparent and traceable, thus making information on potential solutions and best practice easily accessible to design teams, promoting a shared understanding by combining pattern recognition with context knowledge developed through consensus among practitioners. The following chapters of this book discuss different components of this framework.

Notes

1 EN ISO 12006-3 (2016), EN ISO 19650-1 (2018), EN ISO 19650-2 (2018), EN ISO 55002 (2018), EN ISO 19650-3 (2020).
2 AIA (2019, 2020), RIBA (2020).
3 obXML is an occupant behavior XML data exchange format developed by Lawrence Berkeley National Laboratory. https://behavior.lbl.gov/?q=obXML download.

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