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Editorial

Maria Voyatzaki

While the Anglo-Saxons would round numbers around the dozen, mathematics classifies five as a Fermat prime; therefore a regular polygon with 5 sides (a regular pentagon) is constructible with compass and unmarked straightedge, according to Wikipedia. This is the feeling we share as editors of the first five issues of our journal; after five attempts there is a sense of having found our compass and unmarked straightedge. There could be no contemporary journal addressed to doctoral students if there were no error-embraced tactics involved. After the first five volumes that are accompanied with 25 selected papers, worked and re-worked in collaboration with 50 academics from our reviewing committee, enhanced by five good-practice examples of rigorous academic writing. We keep learning to make better. This time, like in all of them, we selected, reviewed and mentored five essays.

Diversity, the current issue, includes five essays from a broad spectrum and a great geographic spread, hence its title. More specifically the first contribution is made by Ashok Ganapathy Iyer, a PhD candidate, from the Welsh School of Architecture and is entitled “Approaches to Learning in Architectural Education adopted by the Beginning Architecture Student in the Coursework of Architectural Design – A Review”. Ashok’s essay reviews selected literature on research into architectural education where the definition of approaches to learning adopted by beginning architecture students in the coursework of architectural design is compared with surface and deep approaches. The categorized approaches identified in an earlier study adopted by first and fourth year architecture students is connected to this review to how the concepts of deep and surface approaches to learning manifest themselves in architectural education. In conclusion, the study and the review points towards a more complex set of approaches to learning than just a simple deep and surface division. It also raises a further question on whether the categorized approaches from the study form different points to a continuum between deep and surface, or if there are some in a different dimension. The review on beginning architecture students’ approaches to learning seems to point towards learning approaches tending to the surface dimension and go on in the direction of deeper approaches through years of training and reflective practice in architectural education.

The second contribution, made by Aikaterini Chatzivasileiadi, is the second in this issue from Welsh School of Architecture, Cardiff University, UK. It is entitled “How can batteries ‘fuel’ the built environment?” The study presented is set out to gain a better understanding of how battery systems can contribute to the design of a future built environment where renewable energy systems will play a significant role. The essay provides suggestions that will enhance design while integrating battery storage to buildings, emphasising on their spatial requirements. An analysis is undertaken to assess the footprint, the volume, the weight as well as the investment cost of eight different battery technologies able to electrically supply a house in the UK. The house is assumed to be powered by renewable energy sources (RES), was able to operate off-grid and was electrically heated. Three scenarios are explored in order to assess the spatial requirements of each of the battery technologies in 2030. It is concluded that Li-ion, Zn-air and NaNiCl battery technologies are the most favourable options for electrical energy storage (EES) integration in buildings in all 2030 scenarios due to their small footprint, small volume and low weight. Cost-wise Li-ion batteries currently have the highest investment cost, but are expected to be a cost competitive option in 2030.

Efrosini Charalambous, from the Bartlett School of Architecture, University College of London, U.K. contributes an essay entitled “A pilot study on Spatial Cognition: Brain activity during the integration of distinct Spatial Representations”. It describes what has become a common ground amongst three distinct domains; those of spatial cognition, neuroscience and architecture. From the fact that research in cognitive neuroscience offers a deeper understanding of how we perceive and experience our environment, the essay embarks on finding how to ‘transfer’ the knowledge offered by the cognitive sciences, from lab experimental conditions into to real world dynamic and complex situations. It is proposed that by adopting a new perspective and approaching the notion of wayfinding as ‘a continuous problem solving situation under uncertainty’, a study of specific mental events in real-world scenarios and data collection using neuroscientific methods, such as EEG (electroencephalography) can be allowed. The paper departs from the exploration of the ways in which the human brain structures the information of environmental stimuli and of the ways in which we use different reference frames to represent spatial relations and store them in memory. The main focus of the study presented, is to explore the differences in brain activity when orienting in relation to locations of a small-scale indoor environment in comparison to a large-scale surrounding environment. Some initial findings of a pilot experiment on orientation that introduces the use of EEG recordings in real-world situations is presented. The fourth essay entitled “Event Platforms: Proposing a new computational design tool for integrating spatial events into the architectural design process” is authored by Panagiotis Chatzitsakyrakis, from Aristotle University of Thessaloniki, School of Architecture, Greece. The essay embarks on the premise that architectural design can be viewed as the manipulation of physical material space in relation to human events that take place inside it. As it claims, whilst architects have a multitude of computational design tools at their disposal, the vast majority of these applications focus on the manipulation of physical form. The essay proposes a new experimental design tool that enables the creation of parametric components that represent potential spatial events within three-dimensional digital models. The goal is to improve the decision-making process of architectural designers by enabling them to evaluate and iterate their design revisions based not only on the building’s form but also on the human spatial events that take place inside it.

Last but not least, the fifth essay authored by Despojna Zavraka is entitled “Shifting matters of mortality: Neo-medievalism and re-contextualisation of macabre”. The essay departs from the premise that death arises a whole new era in design, which is subject to thought, cultural responsiveness and emergent materiality. It aspires to dip into diversity of speculative projects exploring fictional scenarios on transcultural funerary conditions. This variety is aliquoted into imaginative interplays and cynical approaches on the confinement between the ‘seen’ and the ‘unseen’. Based upon extended doctoral research, this essay attempts comparatives between re-contextualization of macabre concepts and precedents of the past. The notion of neo-medievalism refers to emerging mechanisms of re-speculating one’s own death, beyond localities. Contemporary design cultures often reveal multi-layered references to the ‘darkness of death’ and present interesting cases and transformations of the ‘horrific’. These cases refer to a fragile balance between a profound fascination and simultaneous transcending of death’s obscurity and grotesque. It is within this essay’s goals to trace this fragile balance.

Our aim is now to experiment with more focused essays associated with a thematic. The forthcoming volume will be dedicated to eco, which will embrace issues of sustainability, environmental design, energy consciousness, climatic building control but also with the anthropocene and the ecology of design is a more global and systemic context as this is embraced by contemporary post-human theorists.

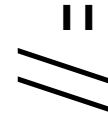
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Interdisciplinary Technology-Driven Design Processes in Architecture

Marios C. Phocas

Abstract

Architectural design operates traditionally on project based processes of development, whereas related social, cultural, visual and technological knowledge is collected, analyzed, evaluated and transformed into design. In parallel recent technological advances are paving the way to achieve 'integrated interdisciplinary design', a type of practice based on collaboration, cross-disciplinary communication, experimentation, visualization and research at all stages of the design process in order to achieve efficiency, sustainability and technological innovation in architecture. In considering the influence of technology in design, the holistic architectural design approach that enables design optimization through an integrative nonlinear development of form, functions and technical system parameters is increasingly complemented with performance based open-loop design approaches driven by means of contemporary digital technology. Respective nonlinear design developments provide through interdisciplinary experimentation and design-driven research, innovation and advances that constitute significant initial stages for further research in architecture. The paper discusses the influencing modes of technology-driven design and their implications towards a framework of related research.

Keywords

Technology-driven design, Design-driven research, Interdisciplinary integrated design.

Note

This text is an extended version of a paper "Towards an Open-Loop Architectural Design Approach", initially prepared for the Conference: ENHSA - EAAE International Conference on Trans/Inter-disciplinary Architectural Design Education, 27.08-28.08.14, Centre for Mediterranean Architecture, Chania, Crete, Greece.

Introduction

Design has undoubtedly been at the core of architectural education since its inception in the 19th Century. Especially the project based design educational model adopted at the Bauhaus workshops at the beginning of the 20th Century aimed at simulating, albeit in a simplified and directed way, the actual processes of professional action, by requiring students to apply their accumulated knowledge and skills in primarily linear and integrated way to a design problem. In the frame of this 'practice informs teaching' model, an integrated environment of theoretical and practice related artistic creativity and research was created for a comprehensive project development. Walter Gropius propagated collaborative work, aiming at the cooperation of architectural related arts at a multidisciplinary level and the search for form within an integrative environment in the studio (Lampugnani, et al., 2004).

The significance given to architectural design as the main activity for creative exploration, interaction and assimilation remains a common characteristic in architectural education. In parallel, the academic environment has been significantly altered as a result of the implementation of the European policies on higher education, mainly represented by the Bologna Process and Lisbon Strategy on one hand, and globalization and the fast growing internationalization of economies and markets on the other. In this frame, architectural education is acknowledged to be interactive and comprehensive, consisting of an equal integration of both theory and practice oriented knowledge within the core activity of architectural design. The interactive and interrelated nature of the individual components is mostly significant for a comprehensive architectural education (Spiridonides, 2005).

At the same time, contemporary design approaches gradually acknowledge the fact that architecture encompasses a number of disciplines, bringing together a number of distinct modes of research and types of knowledge. Research into architecture is becoming conscious of these interactions and of the particular need for architectural knowledge and practice to be further nonlinear and integrative across disciplinary boundaries. Design provides possibilities for interdisciplinary research, through an integrative approach to education and practice, while also crossing traditional research areas. Rationale for this change is based on widely recognized transitions from industrial societies and their linear, hierarchical thinking to the emerging post-industrial era of deeply interrelated types of knowledge and complex system thinking. Recent advances of disciplines, specialization, materials, system science and digital data driven computation have brought a radical change in the contextual frameworks in which architectural design and production are normally placed. Such advances have been paving the way to achieve 'integrated inter-, multi- or even transdisciplinary design', in all cases a type of practice that covers a mindset of collaboration and cross-disciplinary communication and experimentation, visualization and research at all or possibly at different stages of the design process. Respective modes of thematic integration may refer at areas of contents and scales of development, as well as at the design process followed on the basis of contemporary digital technology platforms of operation. Especially the latter comes into fore by considering recent technological advances and architecture as interactive processes. Along these lines the syntax of architectural design, technology and any implicated interdisciplinary developments from the conceptual design to the realization are of major significance. Such integrated activities promise to generate substantially new, innovative and transformative solutions to buildings, their designs, as well as their habitation and usage, last but not least, to the associations, the industry and methods employed in practice to realize them.

Given the interrelation and necessity for integration of architectural design and technological as-

pects, two operational modes of technology-driven architectural design processes of different and supplemental aims may be applied to associate the complexity levels of design articulation and evolution. The first operational mode follows an integrative nonlinear design development through a rather rigorous development and integration of related technological aspects concerned within the architectural design process. Such a methodology aims at holistic integrated design results that, even if following closed-loop processes of development, may be strongly influenced by the integrative development or even transfer of technology to shape the final proposal. A second approach that utilizes advances in digital technology towards interdisciplinary experimentation and research by design, follows primarily performance based open-loop processes of developments. The results obtained herefrom are representative of an architecture of homogenization of the discipline areas concerned. In this frame, complex system developments may be considered for the final design outcome, in a performance based internal and external field of influences.

Integrative Nonlinear Design

Design has undoubtedly been at the core of architectural education since its inception in the 19th Century. Especially the project based design educational model adopted at the Bauhaus workshops at the beginning of the 20th Century aimed at simulating, albeit in a simplified and directed way, the actual processes of professional action, by requiring students to apply their accumulated knowledge and skills in primarily linear and integrated way to a design problem. In the frame of this 'practice informs teaching' model, an integrated environment of theoretical and practice related artistic creativity and research was created for a comprehensive project development. Walter Gropius propagated collaborative work, aiming at the cooperation of architectural related arts at a multidisciplinary level and the search for form within an integrative environment in the studio (Lampugnani, et al., 2004).

Holistic architectural design provides possibilities for an integrated approach from early stages, facilitating merging of individual knowledge and interdisciplinary research based knowledge, while enabling new knowledge inquiry and acquisition at various design stages that form closed-loops of the development process. In this frame the term 'integration' within the holistic design process gains significance. Pedagogically the concept of integration may be applied at different levels: Integration of knowledge, skills and attitudes by emphasizing learning competencies, as opposed to their quantified and fragmented use; integration of analysis (analytical thinking) and synthesis (creative thinking), perceived as parallel processes interrogated within the design process; integration of learning and valuation with emphasis on the learning process instead of the learning result; integration of architecture as cultural phenomenon (aesthetic) and as a technical phenomenon through designing; integration of research, investigating and designing by implementing platforms of digital technology with knowledge management and valuation systems. Such integrative development objectives tend to implement respective knowledge about architecture into processes of research based design. In architectural designs that follow this approach in their pedagogy, faculty members try to give students an integrated experience in design, while also giving them the opportunity to work outside of their normal areas of knowledge and experience for applying relevant results within the actual design process. The approach has also repercussions in the way that architectural graduates are expected to influence and inform professional practice as a result of their training. Collaborations among faculty, students and corporate partners aim at exploring the potential for genuine cross-functional communication and cooperation, while highlighting strategies fundamental to the success of the integration approach (Malecha, 2008).

In terms of the design process per se, digital technology is in capacity to link conceptual design to analysis, production and fabrication. In following rather closed loops of linear design developments supported by technology transfer and material advancements, complex architectural forms become possible. Along these lines architectural design often still prioritizes predominantly form over its subsequent materialization, construction and manufacture, nevertheless leading to 'top-down' engineered, often non-optimized solutions. Kenneth Frampton among others expressed this concern in his studies in tectonic culture (Frampton, 1995). Dissociation between geometrical design and tectonics may be evident in complex surfaces of form and structure, or geometry and manufacture disintegration. In other cases, early phases of digital technology integration provide possibilities for a shift from mass-production to mass-customization, while relating the principles of the former with the advantages of individual fabrication. Related processes are based on the coupling for example of architectural computer-aided design, structural design, manufacturing and rapid prototyping.

Besides any technological advances, the design process itself can not be considered as a linear problem-solving activity, whereas sequential activities are carried out in a linear order, as for example problem definition, analysis, synthesis and evaluation, as there is no direct flow from one activity to another (Alexander, 1964). In this frame, an open structure in the synthetic process that forms the core of the design process has been proposed, in which phases are grouped in a circular arrangement, yet the process itself does not develop in a linear manner (Moggridge, 2007). Given that digital design is in capacity to provide information and complexity at every level of the design, there is no fixed scale at which design processes are essentially to be developed, while at the same time each intermediate process result may influence part or the whole of the design outcome (Picon, 2003). Along these lines, digital design may be applied throughout the different stages of the entire design process shaping individual iterative operational circles that are linearly linked to previous and subsequent ones. In this way, an integrative nonlinear design process emerges throughout the development, whereas, knowledge is employed from research and new knowledge is generated throughout the design process that develops new hypotheses and visions.

Furthermore, recent developments prove that numerically controlled devices are in position to shift architectural preoccupations beyond mono variables, such as geometry, to the integration with materiality and construction in favour of performance. Nonlinear design processes based on interdisciplinary performance optimization criteria are considered to be crucial for the future of architecture. At the same time, standardization would still mean more efficient use of raw- and new materials and energy. Such an approach shapes performance based architecture following more or less interactive, iterative closed loop research based design processes. Also in practice, given the escalating complexity of design criteria and tools to manage any implicated multi variable design criteria, new interdisciplinary and collaborative design research practices of architects and specialists consultants have become increasingly essential, while these are also collectively credited with the success of their projects.

An interrelation of technology with architecture from early design stages aims at the advancement of individual, or multiple architectural parameters within the holistic design context (Phocas and Michael, 2010). In this frame, design system components may be integrated to form the architectural design syntax, possibly by further providing design-driven technological developments. Advanced interdisciplinary research activities in individual interrelated closed-loop areas may thus be initiated through the synergy of technology with design. Alternatively, integrated design may be based on technology transfer and further influenced by new systems and materials applied within. In this way an interactive architectural design process is followed through innovative material and system based

technological applications, resulting to technological developments driven design. Any intermediate research requirements derived by design, or research results obtained from other discipline areas from outside the design field, support the integrated context of design. In both cases additional advanced research may be required for the realization of the technology-driven design proposals, that would lead to further interdisciplinary design processes and technological innovations.

Interdisciplinary Research by Design

Common backbone for architectural skills acquisition and related research processes with regard to the advancement of the field is the argument that "architecture encompasses several disciplines and uniquely brings together modes of research that are often kept apart and so provides possibilities for multi- and interdisciplinary research" (Rendell, 2004). In this frame it has often been suggested that instead of trying to conform an architectural praxis to a scientific paradigm, architecture should provide a new model for research practice in all disciplines, which carries academic and social mandates and is intellectually coherent, capacious and integrative (Wortham, 2007). Since the connection between research and design gradually becomes established, the question how to construct knowledge and understanding out of a design or a design process increases in significance (Salomon, 2011).

Several recent works suggest that we are today in the process of defining and refining the idea of architectural research as a mode of scholarship and inquiry that is special to architecture and is not adequately described in terms of the 'scientific' method. Few years ago the European Association for Architectural Education developed a framework stating "Architectural research is original investigation undertaken in order to generate knowledge, insights and understanding based on competencies, methods or tools proper to the discipline of architecture. It has its own particular knowledge base, mode, scope, tactics and strategies. Any kind of inquiry in which design is a substantial part of the research process is referred to as research by design. In research by design, the architectural design process forms a pathway through which new insights, knowledge, practices, or products come into being. It generates critical inquiry through design work that may include realized projects, proposals, possible realities, or alternatives" (EAAE, 2011). Research by design offers indeed a promising perspective for the field, requiring an instrumental and rigorous approach in the supporting and driving modes of the design process. In this sense, research by design also requires an overarching theoretical framework to ground the experimentation and to give it purpose and direction in relation to the production of a relevant architectural discourse and equally relevant improvements in practice and, by extension, the development of the built environment in terms of a performative architecture.

The interdisciplinary aspect in research by design activities constitutes in broader sense an academic and professional field of growing complexity. The following distinctions of discipline interrelations are considered in the present argumentation (Jantsch, 1970):

- Multidisciplinarity: A variety of disciplines occurring simultaneously without making explicit possible relationships or cooperation between them.
- Pluridisciplinarity: Various disciplines grouped in such a way as to enhance the cooperative relationships between them.
- Crossdisciplinarity: Various disciplines where the concepts or goals of one are imposed upon other disciplines, thereby creating a rigid control from one disciplinary goal.
- Interdisciplinarity: A group of related disciplines having a set of common purposes and coordinated from a higher purposive level.

- **Transdisciplinarity:** The coordination of disciplines and interdisciplines with a set of common goals towards a common system purpose.

Given the particular characteristics of architecture as an explorative and transformative knowledge field that inherently relates to the humanities, empirical, interdisciplinary, applied and formal sciences, it may be argued that architecture is intrinsically transdisciplinary and in extend multireferential and multidimensional (Hensel, 2012). In this context the requirement for reintegration of various types of knowledge, as stated in article 3 of the 'Charter of Transdisciplinarity', is of particular significance (CIRET, 1994): "Transdisciplinarity complements disciplinary approaches. It occasions the emergence of new data and new interactions from out of the encounter between disciplines. It offers us a new vision of nature and reality. Transdisciplinarity does not strive for mastery of several disciplines but aims to open all disciplines to that which they share and to that which lies beyond them." In parallel, transdisciplinary platforms of operation may support interdisciplinary design processes on the basis of latest advancements in digital design technology through the introduction of computing facilities and numerical methods of analysis (Hayhurst, Kedward, Soh and Turner, 2012). Digital design enables designers to collaborate, visualize, research and modify building performance with relatively high accuracy. At the same time, this mode of operation requires designers to rethink alternative strategies in order to establish a robust connective link between disciplines and specializations. Thus an aptitude for open-loop developments in multi-variable systems may be achieved from early conceptual design stages until the production phase. This implies rethinking buildings as integral systems rather than the juxtaposition of optimized and mono-functional layers.

In support of the afore mentioned, is the process of complex problem analysis and solution mechanisms within the research by design process, whereas the design domain depends on the culture of collaboration. Teams may be continually formed and reformed and new technologies employed to assemble the expertise and perspectives arising from the members and disciplines. Collective intelligence supports actions of sharing, cycling and innovation, as well as the interpretation of design into intermediate research results. Underlying such interdisciplinary mode of operation is a sense of disciplined architectural specific interactions among the diverse teams. Thus the success of the methodology rests on an integrative approach to research in architectural design, which also examines the increased complexity and quality of building systems in producing sustainable forms in physical context. In this frame integration succeeds in a double way: integrating knowledge in the design process and integrating architectural design in learning disciplinary knowledge.

Open-Loop Performance based Design

The roles of digital design and computation have played in the conceptualization and design development up to date is indicative for a new syntax of architectural design emerging. Though not new to other design industries, computational platforms of operation and real-time performance simulators provide meanwhile robust visualization and feedback features that can be associated with geometrical digital design models. Design developments at various stages encompass further parametric investigations with regard to form, material and structure. Initial examples comprise among others the stainless-steel roof over the courtyard for the Deutsche Bank in Berlin, Pariser Platz 3 by Gehry Partners and Schlaich, Bergermann and Partners, and the roof for the courtyard of the British museum in London, by Foster and Partners and Buro Happold. In this respect it may well be stated that the computer needs to redefine materiality rather than abandoning it in favor of the seduction of pure images (Menges, 2012). This means also a redefinition of design objectives and procedures.

In an open-loop performance based design, comprising a cyclical nonlinear process that moves repeatedly from 'synthesis' to 'evaluation', continuous design iterations dealing with creativity and accuracy represent respectively different phases of the design process, including a conceptual outer loop design phase and a detailed inner loop phase (Phocas, Kontovourkis and Ioannou, 2013). Throughout the development, a number of in-between loops represent the process of iterative design refinement. In this frame of operation, any design process may be repeated until a desirable solution is achieved. This implies that any development from concept to detail may be re-evaluated within a performative context in a nonlinear way, i.e. by moving from the conceptual to the detailed design phase and vice versa. In parallel to such a nonlinear design approach realized through certain cyclic interdisciplinary design steps, also interactivity within the decisions making processes may provide promising modes of operation for a bottom-up approach. Such iterative analysis steps of design verification and optimization shift the focus of the design teams to developing processes, from which specific results then come about through the definition of and emphasis on influencing values and parameters. In this frame architecture is effectively bridged with respective performance disciplines concerned (Gibson, 2013); designing thereby becomes interdisciplinary towards a form-generating process. Architectural design provides such possibilities, in terms of such an open-loop interdisciplinary approach from early stages of the design process, facilitating merging of individual knowledge and cross-disciplinary research based knowledge.

Conclusions

Architectural design implies that different types of knowledge need to be an inherent part of any related decision making process, which includes individual, rational and design driven ways of thinking and knowledge production. Within an integrated context of cross-disciplinary collaborations this mode of inquiry can address the challenges of bringing together the various aspects of the built environment on one hand and articulating a paradigm design process driven by the increasing influence of digital technology on the other. Such a holistic design approach is undoubtedly acknowledged in education and practice, due to its potential to apply a heterogeneous set of discourses, types of knowledge and disciplines, through comprehensive iterative closed-loop cyclical processes of development. In addition, it enables further interdisciplinary advancements in terms of advanced performance based research or technology transfer within architecture.

In the search for successful models of integrated interdisciplinary design, architecture benefits not only from the directive of understanding and implementing transformative design knowledge, but also from the possibility that collaboration will trigger the ability to envision, investigate, create and discover through research from a systems thinking perspective. Progressive performance based practices go beyond incremental improvements to standard responses, but instead work on fundamental questions throughout the architectural design scales, identify the forces to innovate and achieve compelling solutions. They do so by understanding key domains of architectural designs as influenced for example by the human subject, the environment and the structural and material organization complex. As the complexity and sophistication of the built environment grow, technology employed should increasingly commit to realizing an integration of considerations, coupling science, design and imagination to advance the field of architecture towards a more compelling next generation.

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Review of Approaches to Learning adopted by Architecture Students in the Coursework of Architectural Design

Ashok Ganapathy Iyer

Abstract

Students' approaches to learning in higher education has been presented in terms of surface and deep approaches (Marton and Säljö 1976). This paper reviews selected literature in architectural education where the definition of approaches to learning adopted by architecture students in the coursework of architectural design is compared with surface and deep approaches. The categorized approaches identified in an earlier study adopted by first and fourth year architecture students (Iyer and Roberts 2014) is correlated to this review to present how the concepts of deep and surface approaches to learning manifest themselves in architectural education. In conclusion, the study (Iyer and Roberts 2014) and the review points towards a more complex set of approaches to learning than just a deep and surface division. It also raises a further question on do the categorized approaches from the earlier study form different points on a continuum between deep and surface, or are some in a different dimension. The review on architecture students' approaches to learning is a reflection towards the surface dimension and going in the direction of deeper dimension through years of training and reflective practice in architectural education.

Keywords

Approaches to learning, architectural design, architectural education.

Introduction

Students' approaches to learning are directly correlative to their prior experiences of studying and understanding the key concepts of the subject matter, which is vital to the subsequent approaches to studying and learning outcomes (Prosser and Trigwell 1999). Biggs poses a case of the implicit and explicit theories of students' learning; with the latter pointing to the importance of the phenomenographic model (Biggs 1994) describing surface and deep approaches to learning (Marton and Säljö 1976). This paper reviews the literature in architectural education looking into the question of defining the approaches to learning adopted by architecture students in the coursework of architectural design and presents it in perspective of surface and deep approaches. The review is correlated to the categorized approaches to learning identified in an earlier study of comparing the approaches of first and fourth year architecture students (Iyer & Roberts, 2014) to delve into the related question of whether these approaches adopted by architecture students' in architectural education are different from the deep and surface dimension. It also raises a further question on do the categorized approaches from this earlier study form different points on a continuum between the deep and surface dimension, or are some of these identified approaches in a different dimension.

Learning Approaches of Students in Early-Stages of Architectural Education

A perspective on how are the approaches to learning in the early stages of architectural education manifested in the students during the enrollment process is reflected by the introduction of architecture as specialization after A-Level education and through aptitude tests like the National Aptitude Test for Architecture – NATA (Council of Architecture 2014). This creates a distinct student cohort within the early stages in various schools of architecture 'who have learning approaches that are streamlined due to their exposure to architectural education' (Atkinson 2010). The prior learning experiences of the students' cohort and the appeal to architectural education are, thus correlated. The architecture student's experience is explored through the terms 'creativity' and 'engagement' with research to 'tease out the relationships between engagement and creativity for student learning in design' and the complexity of 'the nature and quality of students' engagement with their learning' in the architecture profession (Reid and Solomonides 2007). The student's experience is used as the basis to understand the impact on their learning approaches within the design studio. These experiences can be tapped in the early stages of architectural education and channelized towards a deeper impact on their approaches to learning. The seminal research into 'how students learn' and 'what motivates the student' are fundamental questions posed by Biggs (Biggs 2011). Roberts emphasizes on Biggs' focus on 'the student' which he says 'we all encounter' (Roberts 2009). 'Learning is about what the students do rather than what the teachers do' and, 'if students value something, then they see it as important, and will be motivated to learn' (Roberts 2009) brings to fore; the importance of architecture students' approaches to learning after they formally enroll into the architecture program. They can be motivated through structured approaches to learning adopted in the early stages of the architectural design studio which act as the formative years of their architectural experience.

Salama explores the importance of design studio in the architectural 'curriculum to design training and teaching' elaborating that it 'is the kiln where the future architects are molded and the main forum for creative exploration and interaction and assimilation'. He argues 'that most design studio teaching continues to provide students with little understanding of the value of design as a technique, a process, or set of purposive procedures' (Salama 2005). The integration of learning history with students' learning approaches in the design studio is investigated from a historical and cultural context to learning (Stewart and Wilson 2007). Simon Unwin's stoic phrase 'nothing will come of

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nothing' (Unwin 1996) and Andrew Higgott's pointed question 'Teaching First Year: what do they need to know?' (Higgott 1996) sums up approaches and experiences seen from the students and academics perspective when dealing with architectural history within the design studio (1996). Cakin has evolved a major educational strategy developing communication skills and collaborative initiative between institutions stating 'a strong belief in the use of precedents in teaching and learning design, derived from students' need to start from a knowledge base; encouraging students to explore ideas based on metaphors and analogies resulting from the acknowledgement of the role of metaphor in conveying meaning in architecture' (Cakin 2001). The design studio is effectively presented as the fertile ground where the students' approaches to learning goes through years in its formative stage from a process, technique, language and contextual perspective.

Webster looks at project-based learning as the central pedagogic tool in architectural education 'represented by the design project at its core' with the process of students' learning where 'critical reflection; understood as a key element of project-based learning in the design studio requiring students to continually reflect on their work both alone and with others, most significantly with design tutors in the one-to-one tutorial.' The author suggests that students' experience 'three principal types of tutor behavior; the entertainer, hegemonic overlord and the liminal servant and they believed that only the liminal servant increased their motivation and supported their learning' (Webster 2004). Robinson looks at 'the tutorial system within architectural education, which aims to support the process of design in a studio environment where things can be tested without the practicalities of the real world' and concludes that mentoring using peer-assisted learning, 'seems an ideal tool in architectural education which is presently neglected' (Robinson, 2007). Thus approaches to learning of architecture students in the early stages of architectural education within the design studio have quality of students' engagement, motivation, design curriculum, historical & cultural context and the role played by the design tutor as key parameters.

The Review Process as a Learning Tool

The review process is approached by architecture students with research pointing at a revisit and a proposed guide for the design studio tutors by looking at 'the established model highlighting inherent opportunities for learning and conditions associated with a lack of learning' (Sara and Parnell 2004) reflecting the balance between challenge and support required. Chadwick and Crouch focus on 'the review, as a learning and teaching tool, is a fundamental component of architectural education' and terms it as 'educationally flawed' with the process seen as 'intimidating and unnecessarily grueling and can lead to students feeling demoralized and humiliated'. They propose a model-in-development to humanize the review process and integrating it as an important part of the students' learning process within the design studio (Chadwick and Crouch 2006). The review process as a constructive learning assessment tool in the design studio can be used by the design tutor as well as the architecture students' cohort to encourage approaches to learning towards understanding the complexities of architectural education from the early stages to the later years. In comparison, a typical surface approach; where the response of the student in early stages would generally be that the reviewers did not like the presented work; which perhaps oversimplifies the discussion and the purpose of the review and needs to be explored in further detail.

Impact of Design Studio on Approaches to Learning

This brings to the fore the impact of the design studio on the students' approaches to learning. The central role played by the design studio has been 'routinely referred to as being a core of architectural education' (Webster 2001). 'The Reflective Practitioner' by Donald Schon champions the

cause of the design studio as central; both to architectural education, the profession and the pedagogic connect of teaching design; 'the distinctive structure of reflection-in-action' and 'the future interaction of research and practice' (Schon 1983). Webster provides an outline of the ideas of Schon and related literature from disciplines outside architectural education, pointing towards the importance of 'design project, as a vehicle for project-based learning, was adopted on the assumption that the expertise needed by architects could only partially be learnt through the traditional methods of knowledge transmission, lectures, etc. used by most academic disciplines' (Webster 2001). Schon's work is described as the launch of 'an attack on the dominant technical rationality in professional education, criticizing it for being unable to respond to the complexities of the real world and of failing to account for how professionals work in practice' (Schon 1983) (Webster 2001). The design studio is reflected as the core of architectural design curriculum and the integrated design project seen as the principal teaching vehicle (Schon 1985) (Schon 1987). This clearly reflects the centrality of the design studio and its impact on the architecture students' approaches to learning.

The Design Studio in the Early Stages of Architectural Education

Platt questions 'if architectural ideas are only fully understood with the illumination of construction, what are the implications of teaching architectural design in the academic studio?' and takes us to 'design and build' design project in the design studio with the emphasis on 'do it' & 'teach it' and the required balance of full time academicians and practicing designers towards the right impact on the students' learning approaches in the design studio (Platt 2000). Roberts suggests that Schon's (1983) work on architectural education's project-based 'learning by doing' approach has been considered as a pioneering model for professional education and 'the design studio provides a venue for students to engage in conversation, dialogues and collaboration related to open-ended problems and encourages speculative exploration. Studio-based learning has been seen to be an enjoyable and effective way of learning critical design skills' (Roberts 2004). This can be seen as a pointer to the first year design studio and the approaches to learning that is required to be adopted by students of architecture.

Farivarsadri states that 'introductory design studio as a foundation of architectural design education which has a great importance' and elaborates 'on the importance to organize the body of knowledge and skills to be learned in this year properly, to find suitable methods to transferring them to students, and to achieve maximum efficiency in teaching requires an awareness of different pedagogical approaches and the implications of any chosen method of instruction on the students' (Farivarsadri 2001). The author elaborates on Bloom's Taxonomy in introductory design education and looks at the work of Lede Witz (1985) and his summarization of learning architecture as 'learning and practicing new skills such as visualization and representation; learning a new language and learning to think architecturally'. Farivarsadri states that 'still many of the design studio syllabi are derived from the 'basic design model' developed in the Bauhaus school' and the limitations of this model with a reflection on a holistic perspective concluding that the quality of introductory instructors, their knowledge about learning process and their patience and willingness to look at an array of subjects and enrich the introductory design process (Farivarsadri 2001). This need for a more holistic approach towards introductory architectural education is voiced by major architects in their seminal works including 'Lessons for Students in Architecture' (Hertzberger 2005) and 'Thinking Architecture' (Zumthor 1998); with these different ways of thinking about architecture pointing at distinctive approaches to learning.

Unwin explores the question of 'how new students in Welsh school of architecture are inducted to architecture through first semester program of design project run in parallel with supplementary exercises focusing on analysis, place and technique' (Unwin, 2001). Unwin is looking at how

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the students of architecture in early stages of their education develop an appropriate approach to learning and has structured exercises that 'run alongside the design projects' with a 'focus on three main themes, seen to build a bridge into architectural education, the core skill of which is taken to be architectural design' and based on these pointed themes including analysis, space and techniques; extrapolating on each theme with architectural examples (Unwin 1997). 'Students are encouraged to refine the framework and their own analytical themes. They are expected to translate the lessons run from the exercises creatively rather than mechanically or slavishly, into their own design work thus developing their own capacity for designing or building to build their own repertoire of architectural ideas which they will hopefully add to in similar ways through their careers as architects'. He concludes that 'students learn for themselves rather than doing what they are told but at the same time they are not left to struggle with design without sources of ideas and information' (Unwin 1997). This statement by Unwin represents two different approaches; one where they approach learning by mechanically following a demonstration or as a craft-based approach and the other; where they learn by going through the process of making architecture, which can be seen in parallel to surface and deep approaches to learning (Marton and Säljö 1976). They see the benefit of 'learning by doing' but also of 'learning by looking at the work of others' (Unwin 2001) and with this analysis, Unwin further widens the range of the approaches to learning with reference to the students of architecture. The review further explores schools of thought from the Beaux Arts-to-Bauhaus and the prevailing philosophical viewpoints; world over (Gulgonen and Laisney 1982; 1988; Bax 1991; Littmann 2000).

Approaches to Learning and Early Stages of Architectural Education

'Learning as an interactive process is an important issue in architectural design education' and the authors look at 'the role of the design studio', further considering three steps including 'learn and practice some new skills, say, visualization and representation; learn and practice a new language as Schon (1984) described design as a graphic and verbal language; and learn to think architecturally, as pointed by Lede Witz (1985)' (Demirbağ and Demirkan 2003). The design studio is portrayed as a knowledge studio defining it 'as a mental place of dialogue, where all sorts of knowledge (scientific, technological, and humanistic), skills and attitudes are integrated'. Depuydt argues that with learning knowledge and skills, the emphasis should be on the attitudinal aspects of learning (Depuydt 2001). Odgers explores 'the question of authority in teaching and learning with reference to Barthes and Gadamer' by offering 'two interpretations of authority. One is based on power, the other on the recognition of superior understanding in another' with these versions of authority in a teaching relationship within the context of the design studio at Welsh School of Architecture, Cardiff (Odgers 2001). Parnell looks at 'project-based learning, a form of which lies at the heart of the design studio' and to the surprise of architecture students in their early years of architectural education; the nature of 'students learning experiences prior to university' seems to lie within the didactic model. The students face problems in the early stages of architectural education with project-based learning, which 'requires the students to reassess their familiar mode of learning and adopt a new learner identify in relation to the tutor' (Parnell 2001). This becomes difficult to achieve for the students as, 'this transition from receiver of knowledge to critic and instructor of knowledge is complex and hence difficult for many students to achieve' and Parnell concludes that the peer discussion method has a positive effect on students' learning processes and evidence points that 'students develop higher quality cognitive strategies cited as necessary for the management of disjunction' (Parnell 2001).

Roberts has investigated 'how students with particular cognitive styles, as measured by Riding's

Roberts has investigated 'how students with particular cognitive styles, as measured by Riding's cognitive style analysis, perform in design project of work at particular stages of architectural education' concluding that 'contrary to assumptions found in the literature, those with a preference for thinking in a holistic, global manner, perform less well than their peers in the early stages of their education, but tend to improve as they progress through their education' (Roberts 2006). The design studio has been explored with reference to 'the learning styles of freshman design students in three consecutive academic years using Kolb's experiential learning model' with the conclusion that 'the bipolar perceive dimension indicated that the freshman design students are more related to the analytical skills of theory building, quantitative analysis and technology. Also, the bipolar process dimension showed that they have better behavioral skills compared to perceptual learning skills'. The research suggests that 'design education can be considered as being in line with the experiential learning model of Kolb (1984)' (Demirkan and Osman Demirbaşı 2008). In summary, this review presents the connection of the early stages of architectural education with reference to skill-based, knowledge-based, experiential and cognitive based perspective of reflecting on the students' approaches to learning.

Conclusion: Categorized Approaches to Learning in Architectural Education adopted by Architecture Students

The study on students' approaches to learning adopted in the first and fourth year of architecture based on their experiences while undertaking an architectural design project has been categorized as six learning approaches (Iyer and Roberts 2014). These categorized approaches to learning reflect on the research question & the literature review into architectural education, the latter giving a broad canvas to draw upon for a definition on approaches to learning adopted by students' of architecture; while the former points to these identified approaches falling within the spectrum of the deep and surface dimension presented in higher education research (Marton and Säljö 1976).

Table 1.

Categorized approaches to learning adopted by First & Fourth Year Architecture Students (Iyer and Roberts 2014)

Approach A	Series of steps taken from the introduction of the design problem to the completion of the final solution with emphasis on presenting a good output and preparing a good portfolio.
Approach B	Trying to understand or experience architecture using the experiences of the faculty as a scaffold or reflecting on their instructions to present the learning outcome.
Approach C	Evolving perceptions of architecture by adopting a series of steps within the process of design that is based on a product-focused outcome.
Approach D	Evolving the perceptions of architecture through the process of design that is based on a process focused outcome.
Approach E	Conceptualising the thought process and using the same in the evolution of architecture based on in-depth experiences directly correlative to the perceptual psychology within the experiences of each student.
Approach F	Looking into the conceptual and abstract foci towards design based on an innately creative and experiential level of understanding architecture; reflected by the student.

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The introduction of the architectural design coursework in the first year of the architecture program is considered as the stage where the students tread their formative learning approaches; A & B as a step-by-step approach from the design problem to its final solution (Iyer and Roberts 2014). This could be seen as learning approaches bordering to the surface dimension (Marton and Säljö 1976). Approaches F & F pursued predominantly by fourth year architecture students were learning approaches at a very conceptual and abstract level (Iyer and Roberts 2014) and dwell within the parameters of the deep dimension (Marton and Säljö 1976). The categorized approaches to learning duly form a framework parallel to the one suggested by Unwin with reference to his work with students in the early stages of architectural education at Welsh School of Architecture (Unwin 2001). This study; is a work in progress in charting the approaches to learning adopted by the architecture students' as they progress on the ladder of their rigorous years in architectural education and step into the portals of the architecture profession; thus moving from the surface to the deeper dimensions of approaches to learning.

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How can batteries 'fuel' the built environment?

Aikaterini Chatzivasileiadi

Abstract

This study has been undertaken to gain a better understanding of how battery systems can contribute to the design of a future built environment where renewable energy systems will play a significant role. This paper provides design considerations for battery storage integration in buildings, emphasising on their spatial requirements. An analysis has been undertaken to assess the footprint, the volume, the weight as well as the investment cost of eight different battery technologies able to electrically supply a house in the UK. The house is assumed to be powered by renewable energy sources (RES), is able to operate off-grid and is electrically heated. Three scenarios have been explored in order to assess the spatial requirements of each of the battery technologies in 2030. It is concluded that Li-ion, Zn-air and NaNiCl battery technologies are the most favourable options for electrical energy storage (EES) integration in buildings in all 2030 scenarios due to their small footprint, small volume and low weight. Cost-wise Li-ion batteries currently have the highest investment cost, but are expected to be a cost competitive option in 2030..

Keywords

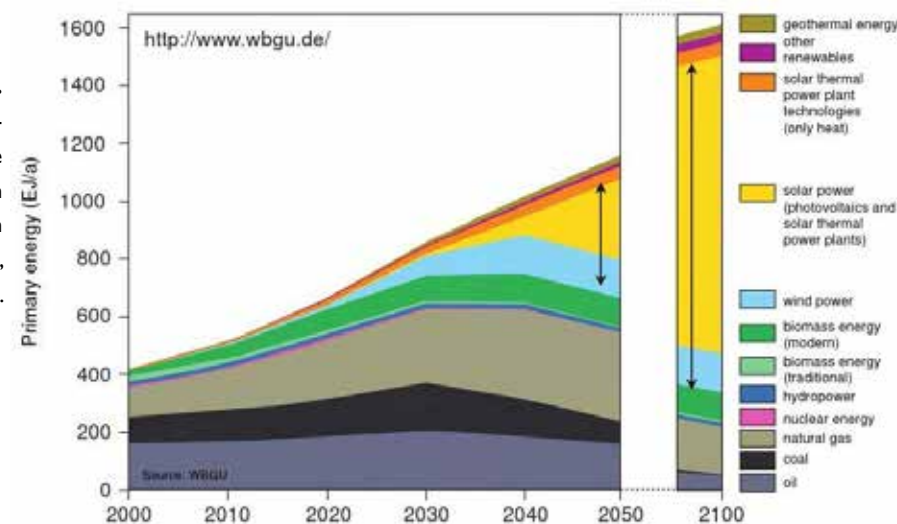
Batteries, electrical energy storage, building integration, design considerations, footprint, volume, scenario modelling

Introduction - Contribution of EES to the built environment

In the last two decades, sustainability and the irreversible depletion of natural resources has been the subject of constant debate on a global scale. Greenhouse gas emissions coming from energy-related activities accounted for 68% of the global greenhouse gas emissions in 2005 (International Energy Agency, 2012). The building sector is found to be in charge of over 40% of the total energy consumption in Europe (World Business Council for Sustainable Development, 2010). Identifying opportunities to reduce this consumption has become a priority in the global effort to deal with climate change. In addition, a very ambitious target set by the EU entails a significant CO₂ reduction by 80 to 95% by 2050 compared to 1990 levels (European Commission, 2011, European Wind Energy Association, 2011, European Commission, 2010). Hence, the establishment of eco-design requirements for buildings, services and products is central to the challenge of sustainability and the mitigation of climate change.

An **increasing demand** in the electricity sector is anticipated in the upcoming years due to the extension of the electrification of the population worldwide, the increase in energy consumption due to economic growth, the use of electrical energy for heating and cooling and the use of electricity in the transport sector (Department of Energy and Climate Change, 2011). The remaining reserves of the non-renewable energy resources currently in use, such as coal, oil and gas, are continuously decreasing and it is questionable whether their capacity will be able to meet rising demand levels. Thus, electricity generation from renewable energy sources, such as sun and wind, are already at the forefront of sustainable energy planning and are expected to play a central role in the low carbon future (International Energy Agency, 2013). Following the increasing deployment of renewable energy technologies, as shown in **Figure 1**, EES is considered to be one of the key components of the built environment in the future (Inage, 2011, Sandu-Loisel and Mercier, 2011).

Figure 1. Scenario for a world-wide energy mix in the next decades (German Advisory Council on Global Change, 2008, Droege, 2008).



Storage has always played a critical role in traditional energy markets, as the currently dominant fossil fuels—coal, oil and gas—have always been traded within commodity markets in the same way that coffee and metals have (Naish et al., 2008). Traditional primary sources of electricity generation store energy on site in the form of a stock; this can be coal, oil, gas or even water behind a dam. The key requirement for the electricity network to operate efficiently is the instantaneous match of supply and demand. If this fails to happen, blackouts and other severe consequences might occur.

The importance of EES lies in the fact that most forms of low or zero carbon energy generation that will be used in the future are fundamentally different in nature from the traditional fossil fuels currently used for electricity generation (Naish et al., 2008). Electricity in the low carbon future will primarily come from either renewable or nuclear fuels (Massoud, 2013). Nuclear generation is typically designed to operate at a constant output, but renewable generation is mostly intermittent, meaning that it has a variable output. Therefore, the instantaneous match of supply and demand will be difficult to achieve under these variable circumstances.

EES provides the possibility to store electrical energy when it is generated from the intermittent renewable sources, for example solar and wind, in order for it to be available when needed. In this way, electricity supply can match load demand on a constant basis, providing the necessary stability to the electrical grid (Electricity Advisory Committee, 2012). In addition, EES solutions can be applied at all levels of the electricity system (The Electricity Storage Network, 2014), influencing generation and consumption. Depending on their location in the system, they are capable of providing diverse benefits (Teller et al., 2013), which are summarised in **Table 1**.

Table 1. EES applications at different levels of the electrical system (Teller et al., 2013)

Generation level	Arbitrage, capacity firming, curtailment reduction
Transmission level	Frequency and voltage control, investment deferral, curtailment reduction, black starting
Distribution level	Voltage control, capacity support, curtailment reduction
Customer level	Peak shaving, time of use cost management, off-grid supply.

UK has recently started actively demonstrating, installing or planning EES applications. A capacity of 5.1 MW and 6.4 MWh was commissioned in November 2013, with an additional 7.2 MW and 13.8 MWh either under construction or being planned (Lang et al., 2013). Two recent case studies of battery integration at residential level are SoLa Bristol and Zero Carbon Homes (ZCH). SoLa Bristol project's aim is to address the technical constraints that DNOs expect to arise on Low Voltage networks as a result of the increased adoption of solar PV (Kaushik, 2014). A 4.8kWh Pb-acid (Lead-acid) battery bank along with a 2kWp solar photovoltaic (PV) installation are installed in each of thirty homes in Bristol (Kaushik, 2014). The electricity generated by the PV on the roof of the houses is stored locally in the batteries, instead of being exported to the grid. This allows customers to make the best use of their own generation. As regards the location of the battery installation, the lofts of the houses were identified as appropriate to house the equipment.

As for the ZCH project, three 25kW/25kWh Li-ion (Lithium-ion) batteries connected to the Low Voltage network have been installed by SSE to power a development of 10 homes in Slough (Steele and MacLeman, 2014). The south-facing roofs of the homes have been covered with solar PV tiles, totalling a solar installed capacity of 63kWp. This capacity provides enough renewable electricity to achieve net zero carbon emissions in each of the homes, irrespective of the heat source. The three battery units will help explore if they are capable of mitigating the effects of potential load increases, as well as the consequences from the deployment of low carbon technologies in buildings. The batteries are located outdoors in a protected area close to the housing development.

An example of an off-grid building in Wales is the three-bed farmhouse in Caerphilly, UK, which has been hailed as an exemplar of sustainable building excellence (ThermaSkirt, 2015). It is supplied with a 3.9kWp solar PV array integrated in the south facing roof and a Pb-acid battery bank located in

the basement. The panels provide power throughout the day and any surplus charges the batteries for hours of darkness. The battery bank stores 42kWh and if this dips below 40% a 10kW back-up diesel generator takes over to provide the necessary power. The battery rooms of the three case studies discussed above are shown in **Figure 2**.



Figure 2.

Battery rooms of SoLa
Bristol, ZCH and Maes

Yr Onn project

Introduction - Contribution of EES to the built environment

There are two characteristics of electricity that currently have an impact on its use and basically generate the need for the introduction of EES in the built environment.

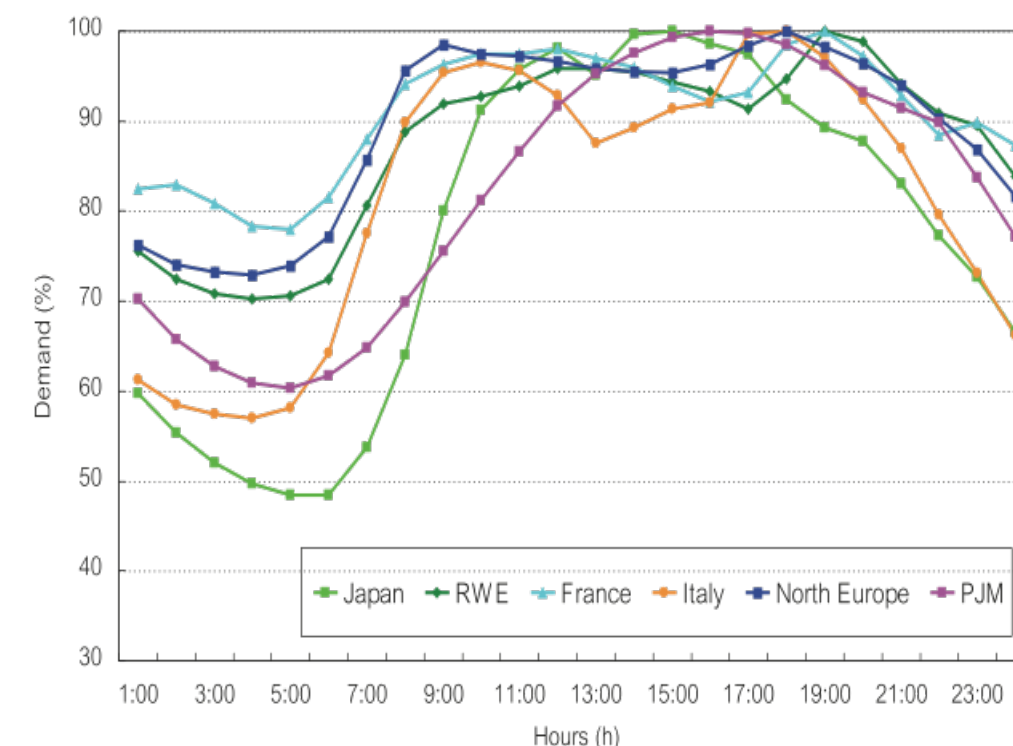
The first one is that **electricity consumption occurs at the same time as electricity generation**. The demand varies over time and electricity supply should match this varying demand (**Figure 3**). Due to the variation in demand, there is a variation in the cost of generation, too. Hence, the price of electricity is higher at peak-demand periods and lower at off-peak demand periods (Electricity Advisory Committee, 2012). Storage facilities in this case could enable the reduction of the generation costs, as they could store low-cost electricity generated during nighttime and release it to the power grid during peak periods. Consumers could also benefit financially by storing electricity generated during off-peak hours and then either using it or selling it to utilities or other consumers during peak periods (International Electrotechnical Commission, 2011).

Also, **electricity is usually generated far from the locations where it is consumed**, which forms the second fundamental characteristic. The farther the consumption and generation locations, the higher the chances of an undesirable interruption in the power supply. Wide areas could also potentially be affected by power network failures. The long distance between generation and consumption can result in power congestion, as the power transmission lines can get heavily loaded due to high demand (Electricity Advisory Committee, 2012). Moreover, powering remote areas and mobile applications can present difficulties, as the transmission of electricity always requires appropriate cabling (International Electrotechnical Commission, 2011).

Electricity storage could be helpful in all the above cases. It could, therefore, ensure the continuity of power supply to consumers, acting as emergency resource when, for example, voltage sags occur (International Electrotechnical Commission, 2011). EES facilities can also mitigate congestion by storing electricity when transmission lines hold enough capacity and by supplying it back to the grid when congestion occurs. With regard to RES powered isolated areas and mobile applications, EES systems such as batteries could be a favourable option for electricity supply, due to their mobile and charge/discharge capabilities.

There is a fundamental difference between the impact of EES when it is used to deal with RES in-

Figure 3.
Comparison of daily
load curves (International
Electrotechnical
Commission, 2011)



termittencies and the impact of EES on energy supply, as described in the two electricity characteristics above. In the first case, they might not be able to constantly match supply and demand, as the RES output might be highly unpredictable in certain locations and low at times. In the second case this limitation does not exist, as constantly available grid electricity is stored. Another limitation in the first case and particularly when RES and EES are to be integrated in buildings is a possible lack of appropriate space for the installation of solar PV panels, due to their orientation or building form.

EES technologies exhibit a range of power and energy requirements, as well as discharge times. These are presented in **Figure 4** (International Electrotechnical Commission, 2011)¹.

It is observed that the currently available types of EES technologies exhibit a large spectrum of performances and capacities to match different application environments and electricity storage scales. Not all EES systems are commercially available in the ranges shown at present, but according to the International Electrotechnical Commission (2011) all are expected to become important. The rest of the paper deals specifically with battery technologies, which are applicable at building level.

Battery storage design considerations

The estimation of the footprint, the volume and the weight of eight battery technologies when integrated in a single residential building in the UK in 2015 and in 2030 is presented in this section. For the 2030 values, consideration has been given to projections about the electricity consumption in the UK residential sector. Further design considerations as well as a cost analysis are also included

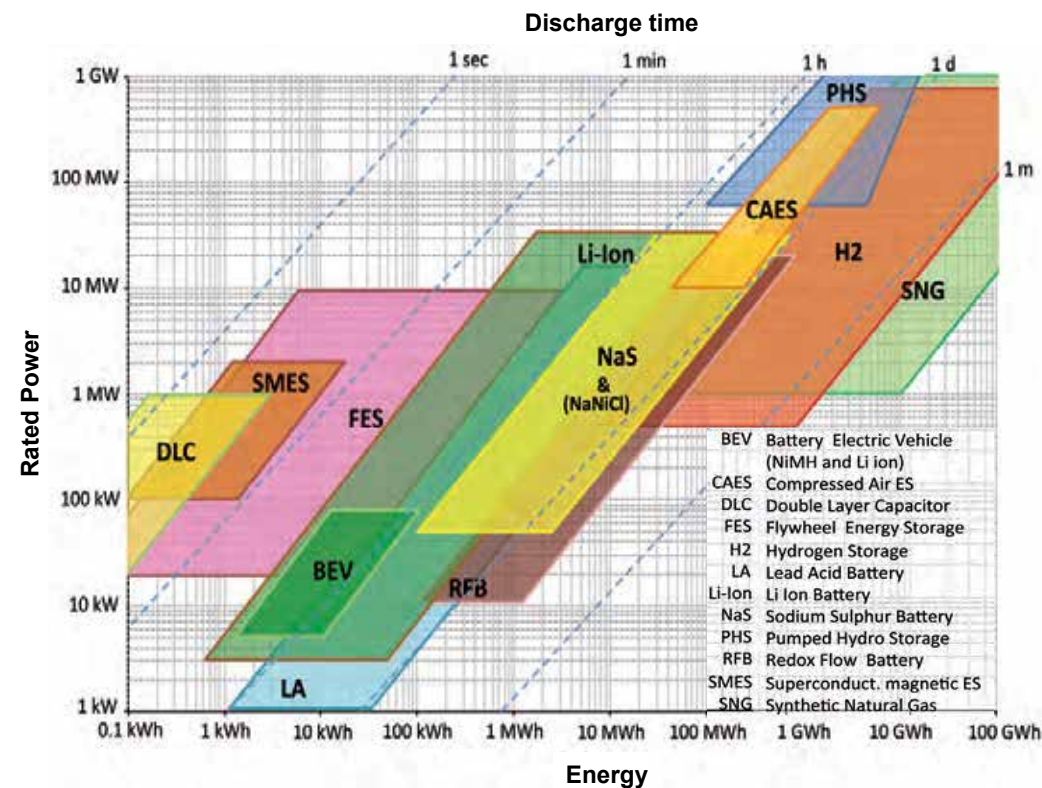
¹ The limited suggested length of this paper does not allow for a detailed discussion on the strengths and weaknesses of each technology; the reader is, therefore, advised to refer to the journal paper under the title "Characteristics of electrical energy storage technologies and their application in buildings" (Chatzivasileiadi et al., 2013).

at the end.

Daily electricity consumption

A number of electricity consumption ranges have been calculated for eight battery technologies applicable at building level in the residential sector of the UK, according to three different scenarios in 2030. Due to recent scenarios emphasizing on the likely electrification of heat in the coming years (Department of Energy and Climate Change, 2011), electric heating is assumed to take place from October to March (Department of Energy and Climate Change, 2013) in all 2030 scenarios. The investigation takes as threshold the Baseline 2015 (BS 2015) values for electricity consumption in the UK. Then the first scenario refers to Business as Usual (BAU 2030), where there are no major changes in the way electricity is used. What is taken into consideration though, is the impact from population and economic growth, as well as the historic trend towards increase in energy efficiency.

Figure 4.
Comparison of rated power, energy content and discharge time of different EES technologies (International Electrotechnical Commission, 2011, Schwunk,



The second scenario includes the implementation of energy efficiency improvements in buildings (EE 2030). The third scenario assumes the electrification of transport (Te 2030) on top of the assumptions for the previous scenario. One electric vehicle (EV) is assumed for one household. The assumptions for each scenario and the associated sources of information are presented in Table 2.

The daily electricity consumption range for a single electrically heated household in 2015 and 2030, based on the assumptions above, is shown in Table 3.

It is apparent that there is a high potential for electricity consumption reduction in 2030 through EE measures. Moreover, the EV at each home will hold a big share of the household consumption

in 2030, adding about 25-75% to the baseline values in summer and about 30-50% in winter. The electricity consumption ranges for a single electrically heated household are illustrated in Figure 4.

Table 2.
Scenarios and associated assumptions 2011)

Scenarios	Assumptions	References
BS 2015	The data have been gathered and processed for weekday/weekend values from the sources on the right.	(Kreutzer and Knight, 2006) (Department for Business Enterprise and Regulatory Reform, 2008) (Department of Energy and Climate Change, 2012a) (Department of Energy and Climate Change, 2012b) (Cambell and Cambell, 2007) (Hesmondhalgh, 2012) (SP Energy Networks, 2011)
BAU 2030	+10.4%	(Department of Energy and Climate Change, 2012a)
EE 2030	-30%	(Department of Energy and Climate Change, 2012a)
Te 2030	+6kWh	From (a) and (b)
	(a) 0.16kWh/km (b) 37km daily transport	(Element Energy Limited, 2013) (Melbourne, 2013)

Table 3.
Daily electricity consumption range for a single electrically heated household in 2015 and 2030 (Wd=weekday, We=weekend)

	Electricity consumption range (kWh)							
	Winter				Summer			
	Wd		We		Wd		We	
	min	max	min	max	min	max	min	max
BS 2015	8.2	21.2	9.3	22.0	5.0	12.1	6.0	13.0
BAU 2030	9.1	23.4	10.3	24.3	5.5	13.3	6.6	14.4
EE 2030	6.3	16.4	7.2	17.0	3.9	9.4	4.6	10.0
Te 2030	12.3	22.4	13.2	23.0	9.9	15.4	10.6	16.0

Figure 5.
Daily electricity consumption range for a single electrically heated household in each scenario (weekdays)

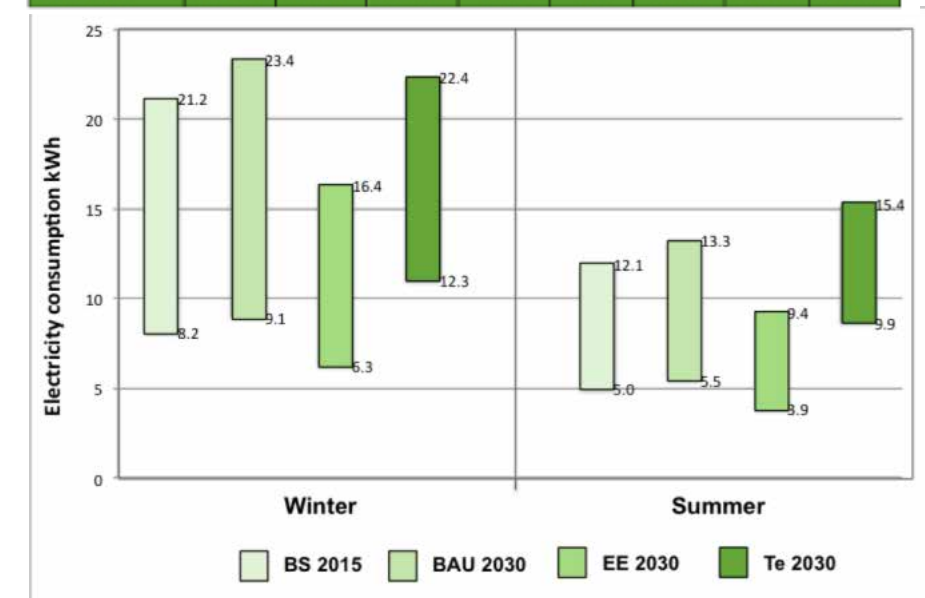


Figure 5 shows that the electricity consumption in summer is much lower than in winter due to the lack of space heating and the lower use of lights and the oven. In addition, there is a slight increase of the electricity consumption in the BAU 2030 scenario from the baseline regardless whether winter or summer. A huge consumption decrease of 30% follows in EE 2030. Finally, in Te 2030 there is a considerable load added due to the inclusion of one EV in each household. The upper bound of the electricity consumption in this scenario for winter is lower than the consumption in the BAU case. In summer, due to the lower overall baseline household consumption, the added electrical load due to EVs is considerably high.

Sizing of the battery: storage capacity, footprint, volume and weight

The sizing of the battery system is based on winter's values, so as to allow for sufficient storage capacity all year round. In order to calculate the battery capacity for the different technologies, the following assumptions have been taken into account:

1. The house is equipped with renewable energy technologies (e.g. PV panels) and is able to operate off-grid
2. Four days of autonomy² for an off-grid residential system (Little, 2013)
3. Round-trip efficiency of the battery system according to the values provided in Table 4
4. 50% depth of discharge (DOD)³

The parameters that have been used in order to estimate the storage capacity, the footprint, the volume and the mass of the battery technologies are gathered in Table 4 and illustrated in Figure 6. Colour coding (related to the characteristic described in each column) has been applied in Table 4, on a red-yellow-green scale with green being the most favourable option and red the least favourable one.

		Round-trip efficiency %	Spatial requirement m ² /kWh	Energy density kWh/m ³	Specific energy (Wh/kg)
Conventional batteries	Pb-acid	80	0.06	75	30
	NiCd	70	0.03	200	45
	NiMH	70	0.02	350	60
Advanced batteries	Li-ion	90	0.01	250	100
	NaNiCl	90	0.03	150	125
Flow batteries	V-Redox	75	0.04	20	75
	ZnBr	70	0.02	20	60
	Zn-air	60	0.005	800	400

Table 4. Round-trip efficiency, spatial requirement, energy density and specific energy of the battery technologies (Chatzivasileiadi et al., 2013)

It is observed that Li-ion and NaNiCl technologies have the highest efficiencies, while Zn-air battery the lowest. Yet the Zn-air technology scores extremely high in all the rest parameters regarding spatial requirement, energy density and specific density. Li-ion performs well in terms of spatial requirement, while NiMH and NaNiCl batteries have a high energy density and specific energy respectively. It should be noted, however, that the Li-ion technology exhibits a high potential of improved energy density and specific energy values in the future. This study has taken into account the lower bound of the range for these parameters found in the literature, so as to design for the worst-case scenario. The formula used to calculate the battery capacity (C_{bank}) is given below:

$$C_{bank} = E \times 1/h \times 4 \text{ days} \times 100/50$$

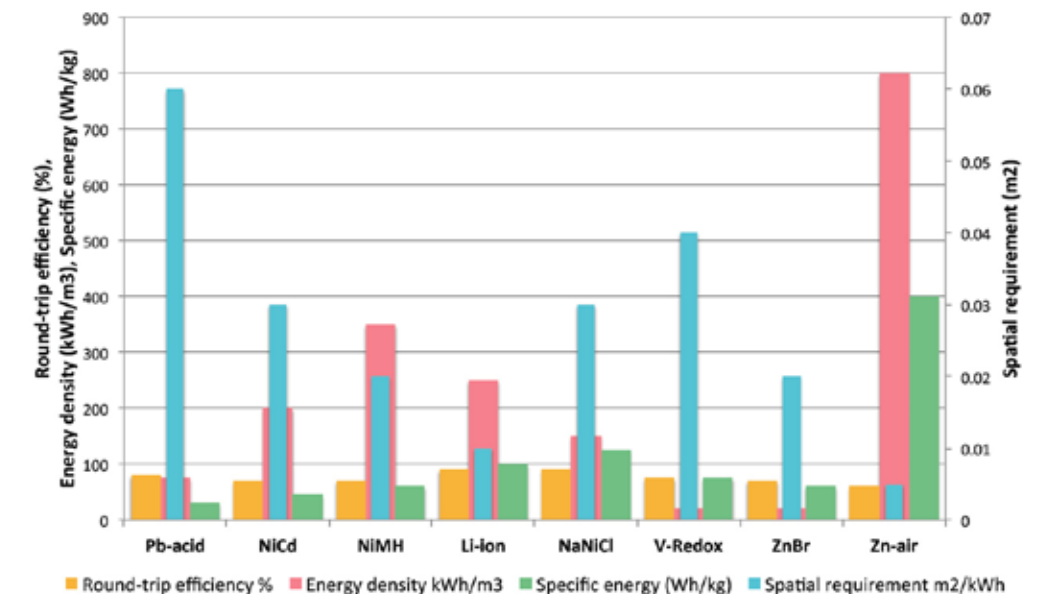
$$\text{life of batteries (MIT Electric Vehicle Team, 2008).} = (E_{we} \times 1/h \times 2 \text{ days} \times 100/50) + (E_{wd} \times 1/h \times 2 \text{ days} \times 100/50) \quad (1)$$

$$= (E_{we} + E_{wd}) \times 1/h \times 2 \text{ days} \times 100/50$$

where E is the daily electricity consumption in winter, as shown in Table 3
 h is the round-trip efficiency of the battery
 E_{we} is the electricity consumption (kWh) on a weekend day
 E_{wd} is the electricity consumption (kWh) on a weekday

After calculating the storage capacity for each technology using (1), the values in Table 4 have been used to calculate the footprint, the volume and the mass of the battery packs. The storage capacity, footprint, volume and weight for the different battery technologies are presented in Table 5. Colour coding has been applied, on a red-yellow-green scale with green being the most favourable option and red the least favourable one. The footprint, the volume and the mass of the battery packs are also illustrated in **Figure 7**.

Figure 6. Battery technologies characteristics' comparison



The yellow colour in the four graphs presented in Figure 7, which is associated with the lowest values, relates to the optimum solution as regards the characteristic described in each graph. The sky blue represents the next best option. For example, looking at the footprint requirement for an electrically heated house in all scenarios, Li-ion and Zinc-air batteries are the optimum solutions requiring very low space – up to about 2m² – and NiMH, NaNiCl and ZnBr come second with slightly higher footprints. Regarding the volume requirement, NiCd, NiMH, Li-ion, NaNiCl and Zn-air technologies score high, meaning they require very low volume up to 2m³ in all scenarios, while Pb-acid batteries may require up to 4m³ and V-redox and ZnBr up to about 14m³. In terms of weight, Li-ion, NaNiCl and Zn-air technologies are the lightest option, weighting up to 2kg depending on the scenario and the electricity consumption of the house. The rest of the technologies are heavier and can weigh up to about 8kg. All in all, Li-ion and Zn-air batteries score high in all three characteristics and NaNiCl come second. Pb-acid and flow batteries are really unfavourable options in terms of both spatial requirements and weight.

Comparing the battery footprint to the average usable floor area of dwellings in the UK, which is 91m² (Department for Communities and Local Government, 2010), batteries can generally occupy an area ranging from 1% to 12% of a dwelling's floor area depending on the scenario. Zn-air and Li-ion batteries, which are promising technologies as previously mentioned, occupy only about 1%-2% of a dwelling's floor area, while Pb-acid batteries, having a large footprint, can occupy up to 12% of it. The comparison of all technologies regarding this aspect is presented in **Figure 8**.

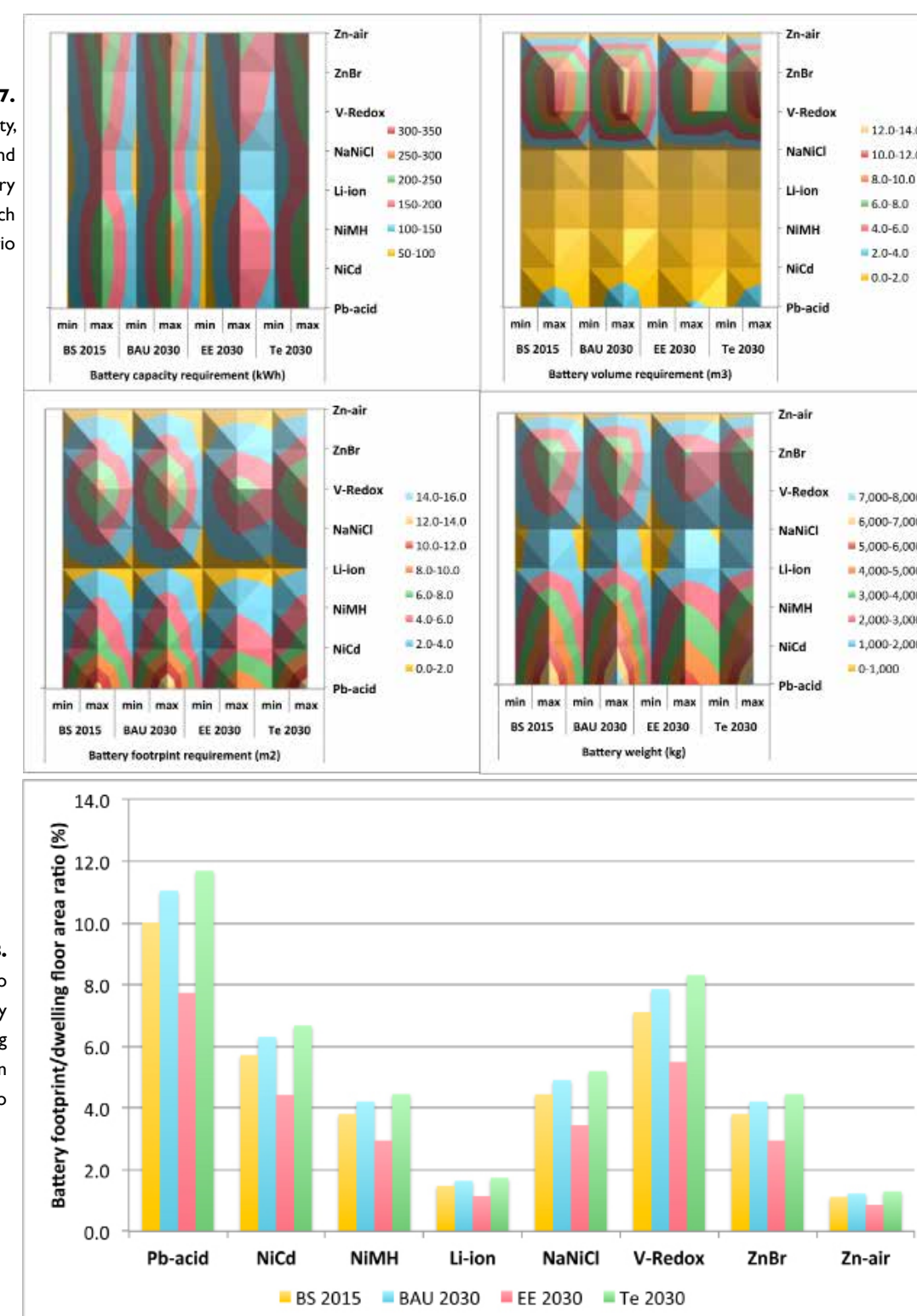
Table 5.

Electricity storage capacity, footprint, volume and weight of the battery technologies for a single electrically heated household in each scenario

	Battery capacity requirement (kWh)							
	BS 2015		BAU 2030		EE 2030		Te 2030	
	min	max	min	max	min	max	min	max
Pb-acid	88	216	97	238	68	167	128	227
NiCd	100	247	110	272	77	191	146	259
NiMH	100	247	110	272	77	191	146	259
Li-ion	78	192	86	212	60	148	113	202
NaNiCl	78	192	86	212	60	148	113	202
V-Redox	93	230	103	254	72	178	136	242
ZnBr	100	247	110	272	77	191	146	259
Zn-air	117	288	129	318	90	223	170	303
	Battery footprint requirement (m ²)							
	BS 2015		BAU 2030		EE 2030		Te 2030	
	min	max	min	max	min	max	min	max
Pb-acid	5.3	13.0	5.8	14.3	4.1	10.0	7.7	13.6
NiCd	3.0	7.4	3.3	8.2	2.3	5.7	4.4	7.8
NiMH	2.0	4.9	2.2	5.4	1.5	3.8	2.9	5.2
Li-ion	0.8	1.9	0.9	2.1	0.6	1.5	1.1	2.0
NaNiCl	2.3	5.8	2.6	6.4	1.8	4.4	3.4	6.0
V-Redox	3.7	9.2	4.1	10.2	2.9	7.1	5.4	9.7
ZnBr	2.0	4.9	2.2	5.4	1.5	3.8	2.9	5.2
Zn-air	0.6	1.4	0.6	1.6	0.5	1.1	0.9	1.5
	Battery volume requirement (m ³)							
	BS 2015		BAU 2030		EE 2030		Te 2030	
	min	max	min	max	min	max	min	max
Pb-acid	1.2	2.9	1.3	3.2	0.9	2.2	1.7	3.0
NiCd	0.5	1.2	0.6	1.4	0.4	1.0	0.7	1.3
NiMH	0.3	0.7	0.3	0.8	0.2	0.5	0.4	0.7
Li-ion	0.3	0.8	0.3	0.8	0.2	0.6	0.5	0.8
NaNiCl	0.5	1.3	0.6	1.4	0.4	1.0	0.8	1.3
V-Redox	4.7	11.5	5.1	12.7	3.6	8.9	6.8	12.1
ZnBr	5.0	12.3	5.5	13.6	3.9	9.5	7.3	13.0
Zn-air	0.1	0.4	0.2	0.4	0.1	0.3	0.2	0.4
	Battery weight (kg)							
	BS 2015		BAU 2030		EE 2030		Te 2030	
	min	max	min	max	min	max	min	max
Pb-acid	2,917	7,200	3,220	7,949	2,254	5,564	4,254	7,564
NiCd	2,221	5,482	2,451	6,052	1,716	4,236	3,239	5,759
NiMH	1,665	4,111	1,839	4,539	1,287	3,177	2,429	4,319
Li-ion	777	1,918	858	2,118	600	1,482	1,133	2,015
NaNiCl	622	1,534	686	1,694	480	1,186	907	1,612
V-Redox	1,244	3,070	1,373	3,389	961	2,373	1,814	3,225
ZnBr	1,665	4,111	1,839	4,539	1,287	3,177	2,429	4,319
Zn-air	292	720	322	795	226	557	426	757

Figure 7.

Storage capacity, footprint, volume and weight of the battery technologies in each scenario



For a better understanding of the volume required by each battery technology, a volumetric analogy is performed assuming a typical fridge. So assuming a fridge measuring 0.65m x 0.65m x 1.8m, the equivalent amount of fridges (volume-wise) required depending on the technology and scenario is presented in **Figure 9**.

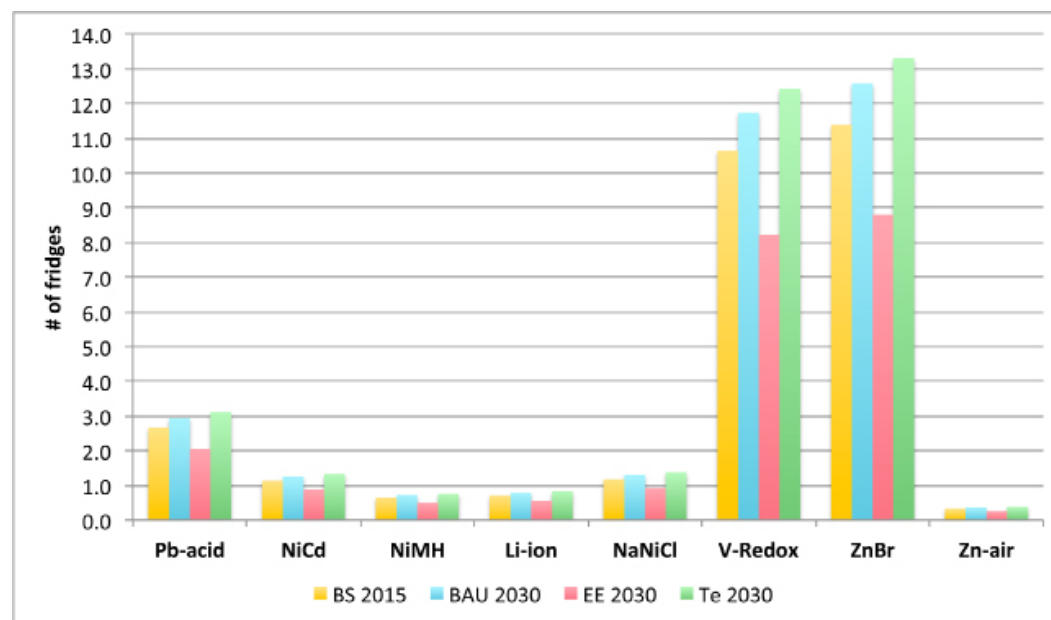


Figure 9.
Volumetric analogy demonstrating the number of typical fridges required in each battery scenario

As shown in **Figure 9**, Li-ion and NiMH batteries would require the equivalent volume of about one typical fridge in the Te scenario, while the Zn-air technology would need half this volume. NiCd and NaNiCl batteries would require slightly higher than a fridge's volume in the same scenario, and Pb-acid would need the equivalent volume of three fridges. V-Redox and ZnBr technologies are way too inefficient in that respect, requiring over four times Pb-acid's volume, which is the equivalent volume of about 12-13 typical fridges.

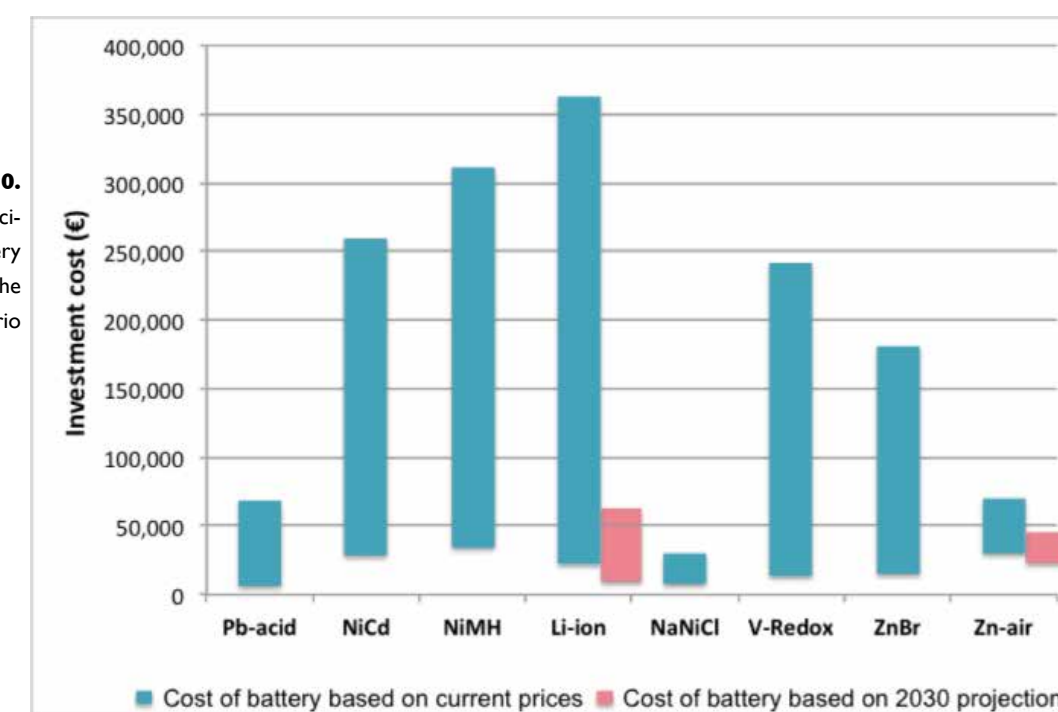
Other considerations

The batteries can be installed in various locations according to the technology used and the availability of appropriate space. They shall be housed in protected accommodation, such as cabinets or enclosures inside or outside buildings. Typical locations include a cupboard along with the rest of the electrical equipment of the building, the loft, the roof, outside in a yard or in the ground (Steele and MacLeman, 2014). They should be protected from extreme environmental influences in terms of temperature, humidity and airborne contamination (The British Standards Institution, 2001). Appropriate ventilation must also be provided. This is because during the charge of the batteries, gases such as hydrogen and oxygen are emitted into the surrounding atmosphere, which might form an explosive mixture (The British Standards Institution, 2001). Moreover, it is essential that the battery installation gains social acceptance. It is, therefore, recommended that consultation from the people using the battery or the surrounding space be sought in advance. The users would also possibly need to change their habitual daily patterns regarding their electricity consumption and this can prove indispensable for the comfort of the occupants and the efficient operation of the system.

The eight battery technologies assessed in this paper present a great variety on their investment cost. Based on the cost per kWh provided in the paper authored by Chatzivasileiadi et al. (2013),

the investment cost for a battery system able to supply an electrically heated household in the UK in Te 2030 scenario has been calculated and is presented in **Figure 10**.

Figure 10.
Battery cost associated with the battery capacity required in the Te 2030 scenario



The calculations have been performed using the current battery prices, as very few price forecasts are quoted in the literature or shared by battery manufacturers. So, according to Hoffmann (2014) and Beadsworth (2014) Li-ion battery prices are expected to decline to less than 300€/kWh in 2030. This fall will be driven by improvements in cathode/anode advanced material research coupled with mass production and industrialization of Li-ion production. Similarly, Zn-air battery cost is projected to decline from currently 180-230€/kWh to about 150€/kWh in 2030 (Parkinson, 2013).

Conclusion

There is a great potential to reduce the carbon footprint of the built environment by managing electricity through energy storage. As EES technologies exhibit a large spectrum of performances and capacities, there is at least one solution currently available for each type of application or electricity storage scale. A number of design considerations regarding the EES' footprint, location, ventilation and safety should be taken into account prior to EES integration in buildings. Through the scenario modeling, it was found that Li-ion, Zn-air and NaNiCl battery technologies are currently the most favourable options for EES integration in buildings in 2030 due to their small footprint, small volume and low weight. In terms of cost, Li-ion batteries currently have the highest investment cost, but are expected to be a cost competitive option in 2030.

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A pilot study on Spatial Cognition: Brain activity during the integration of distinct Spatial Representations

Efrosini Charalambous

Abstract

In recent years, there is growing interest in the common ground, between the disciplines of spatial cognition, neuroscience and architecture. Research in cognitive neuroscience offers a deeper understanding of how we perceive and experience our environment. The objective is to find a way to 'transfer' the knowledge offered by the cognitive sciences, from lab experimental conditions into to real world dynamic and complex situations. Such an attempt requires adopting a new perspective and approaching the notion of wayfinding as 'a continuous problem solving situation under uncertainty'. This will allow us to study specific mental events in real-world scenarios and collect data using neuroscientific methods, such as EEG (electroencephalography). This paper departs from exploring how the human brain structures the information of environmental stimuli and how we use different reference frames to represent spatial relations and store them in memory. The main focus of this study is to explore the differences in brain activity when orienting in relation to locations of a small-scale indoor environment in comparison to a large-scale surrounding environment. Some initial findings of a pilot experiment on orientation that introduces the use of EEG recordings in real-world situations will be presented.

Keywords

Spatial cognition; spatial representations; orientation; allocentric; egocentric; EEG; spatial reference frames;

Introduction

To orient ourselves while navigating we must be able to recognize our surroundings, use stable landmarks to make decisions and maintain our orientation while keeping track of our movement. Evidence from rat experiments shows that the sense of direction relies on an orienting mechanism based on the integration of an internal sense of movement and information from head direction cells, which are specific neural cells that fire if the heading is oriented in a certain direction (Dudchenko, 2010). The ability to update the mental representation of our current position and stay oriented within our immediate surroundings is called spatial updating. Of course, spatial updating involves an additional intuitive ability of self-localization, a 'you are here' internal sign. For Riecke and Von der Heyde (2002), 'spatial presence' can be understood as 'the consistent 'gut' feeling of being in a specific spatial context, and intuitively and spontaneously knowing where one is with respect to the immediate surround'.

The brain provides the 'you are here' information through a set of neurons called the 'place cells'. In 1971, John O'Keefe and colleagues conducted electrophysiological recordings of individual neurons, within a specific brain region called the hippocampus and reported that certain neurons fired when a rat was in a specific location in its environment while a different set of neuronal cells were activated when the rat was in a different location (Keefe and Dostrovsky, 1971). For the discovery of these cells, that constitute the brain's positioning system, John O'Keefe was recently awarded the Nobel Prize for Physiology or Medicine in 2014 (jointly with May-Britt Moser and Edvard Moser). In 1978, John O'Keefe and Lynn Nadel published an influential book called 'The Hippocampus as a Cognitive Map' where, after reviewing studies on rats with lesions in the hippocampus and along with the discovery of place cells, they concluded that these cells form the neural bases of spatial cognition (Keefe and Nadel, 1978). Furthermore, they argued that the function of hippocampus provides the substrate for the construction of a mental representation of the spatial environment, which they called a 'cognitive map', borrowing a concept that was first introduced by Edward Tolman in (1948).

On spatial problem solving

Evidence from several experimental tasks on spatial cognition illustrates the consistent distortions of our mental spatial representations. These distortions occur at the level of perception as well as during encoding and retrieving information from memory. The way we shape and distort our cognitive representations is greatly influenced on how we perceive the environmental stimuli. These mental simplification mechanisms seem to follow laws and principles that are also present in visual perception. Perceptual processes actively organize the spatial information into part-whole relations following Gestalt principles of perceptual organization (Tversky, 1981, Tversky and Schiano, 1989). According to the Gestaltists' view, the information of a stimulus is grouped together following principles such as similarity, proximity, symmetry and closure forming part-whole relations.

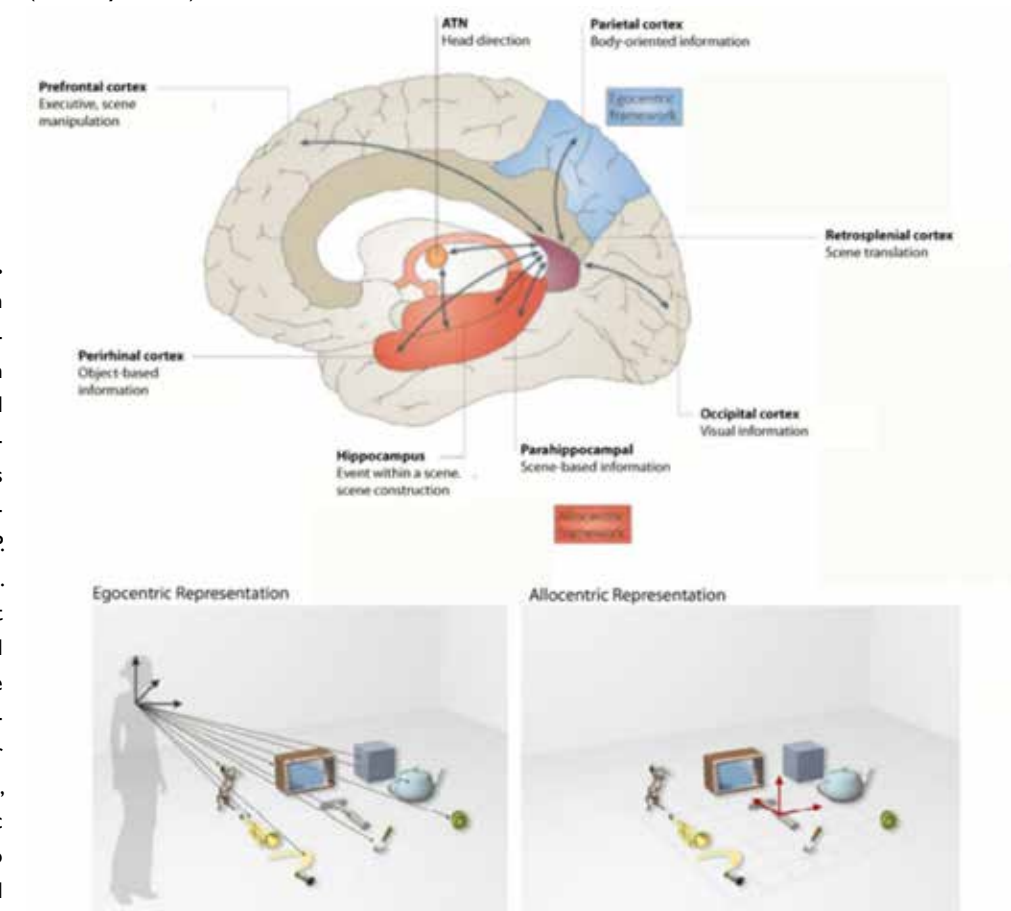
Research suggests that knowledge of spatial relations is organized hierarchically into superordinate structures and subordinate clusters (Hommel and Knuf, 2000, McNamara, 1986, Meilinger and Vosgerau, 2010). When learning target locations in a new environment, people tend to group the acquired information into clusters that share similar spatial (e.g. distance, perceptually salient features) and non-spatial properties such as functions or semantic relations (places and objects associated with same action). At the same time, these clusters are also grouped together forming higher-order structures (McNamara, 1986, Tversky, 1981). Spatial chunking or clustering into small meaningful representations "allows us to activate only the spatial information that is needed in a given

A pilot study on Spatial Cognition: Brain activity during the integration of distinct Spatial Representationsnt?

moment enabling us to operate within the capacity limits of working memory" (Avraamides et al., 2012). Chunking seems to occur where there are salient discontinuities or discrete changes (Klippel et al., 2012). For Barbara Tversky, the way the mind transforms and organizes knowledge is similar to that of solving problems; we parcel information into functionally significant components and group it into bigger categories that include other similar exemplars. Parceling and grouping information is useful when organizing knowledge and solving problems, because it 'allows inferences or predictions' (Tversky, 2005).

Figure 1.

The two-system model: The coordinate transformation of egocentric and allocentric representations (Images adapted from: Ser-alynne D.Vann, John P. Aggleton & Eleanor A. Maguire, 2009 What does the retrosplenial cortex do? Nature Reviews Neuroscience and Meilinger and Vosgerau, 2010, Putting Egocentric and Allocentric into Perspective. In Spatial Cognition VII)



Therefore, mental spatial representations are not exact maplike copies of the external environment, as the word 'cognitive maps' implies, but rather "integrated and highly organized knowledge structures processed according to cognitive principles" (Klippel et al., 2005). The human brain seems to encode spatial information using several heuristic that aim to anchor object to a certain location in space and thus minimize the information needed to be stored in memory. Shelton and McNamara (2001), among others, propose that the process of learning and remembering the structure of the environment involves an interpretation of the spatial information on the basis of a spatial reference frame. Spatial reference frames are usually divided into two categories: the *egocentric* and *allocentric* (Klatzky, 1998). The *Egocentric* is an action-related reference frame, which represents self-to-object relations and the specific orientation and location of the observer; whereas the *Allocentric* is an orientation-free reference frame and encodes object-to-object relations. Humans represent the spatial relations using both coordinate systems (figure 1). However, depending on the circumstances

However, depending on the circumstances (Mou and McNamara, 2002) or individual differences (Gramann, 2005) people seem to prefer the use of one to the other. For instance, several researchers suggest that spatial memories of small layouts are represented in terms of egocentric reference systems while the lack of influence of movement-related spatial updating in large-scale navigation, implies the use of a more stable allocentric system (Burgess, 2006).

Spatial Mental Representations and Their Coordinate Transformation

Neuroscientific studies on spatial memory suggest that the representation of spatial information occurs at two different interrelated neural networks that correspond to the two reference frames. The translation from one network, or reference frame, to the other requires information from the head direction cells which are responsible for the orientation of the observer. Neil Burgess (2006) proposes that spatial updating can be seen as a two-system model of a continuous translation between egocentric and allocentric representations. According to this model, transient egocentric representations are recruited in short-term spatial memory for immediate action and mental imagery and generated in the parietal window (posterior parietal cortex and precuneus). Coarse allocentric representations that are supported by information store in long-term memory are generated in the hippocampus and surrounding medial temporal lobe areas. Encoding and retrieval of information requires a translation between the two representational systems.

Waller and Hodgson's (2006) disorientation paradigm provides evidence for the two-system theory. In their experiment, subjects first learned the locations of objects positioned in a room. They then entered into a rectangular opaque chamber in the middle of the room and sat on a rotating stool. Participants were asked to point to different objects in the room and conduct a task called Judgment of Relative Direction ('Imagine you are at the X, facing the Y. Point to Z'). Their performance was tested with eyes-open, eyes-closed and after rotating the stool they were sitting on which caused a certain degree of disorientation. The main finding of this study is that after disorientation variability in errors increased in the egocentric pointing task and decreased in the allocentric JRD task (Judgment of Relative Direction). This suggests that disorientation causes a switch from the use of a temporary, egocentric representation of space to a more stable allocentric representation of relations between landmarks.

The two-system-model also implies that we operate on distinct representations over different timescales, for example in small and large scale environments (Burgess, 2006). Additionally, spatial representations stored in memory are viewport-dependent (Basten et al., 2012, Meilinger and Vosgerau, 2010, Avraamides et al., 2012), and when there is a misalignment with the current heading 'a differently oriented egocentric or allocentric memory requires a coordinate transformation into the current egocentric orientation' (Meilinger and Vosgerau, 2010). The Wang and Brockmole's experiment (2003) is one example that involves such transformation and integration of distinct representations. Blindfolded subjects were asked to point to objects inside the room and outside locations of the campus. When participant's heading was aligned with indoor objects they were faster at pointing to other indoor location than to campus landmarks but when they were aligned with outdoor locations they were equally fast. The main conclusion was that the representation of the campus included that of the room but not the other way around. When oriented in relation to the immediate environment (room), switching to large-scale representation of the surrounding environment is cognitively demanding because it involves transformation of allocentric information and updating of one's current egocentric representation. I have therefore used a similar experimental situation in order to investigate if differences in recorded brain activity reflect the process of updating and

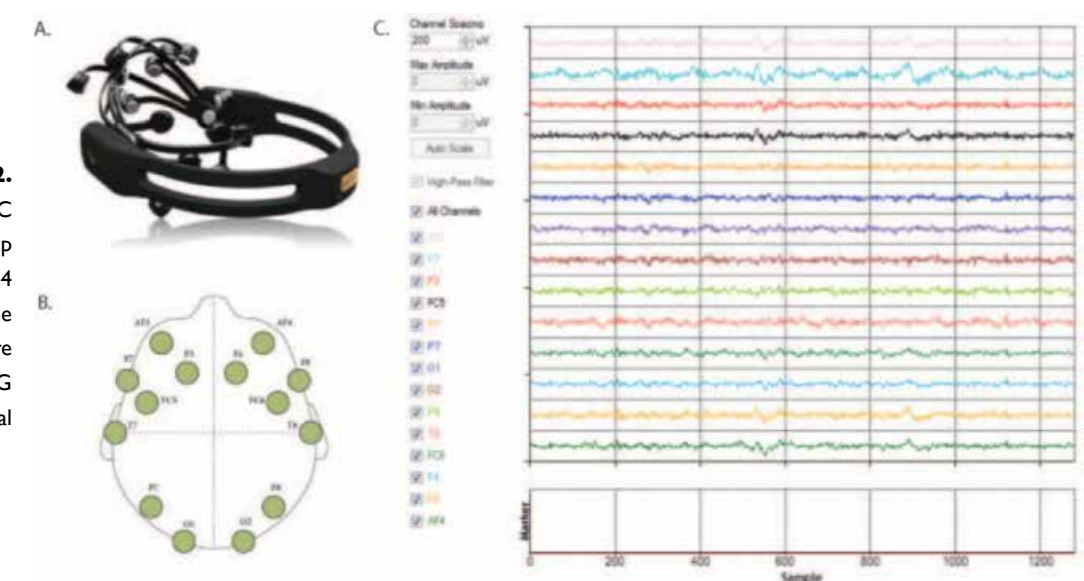
integrating information from distinct spatial representations.

Methodology

Recent developments in sensor technology and wireless communication provide a means to test scientifically derived hypotheses in real-world situations using wearable monitoring devices. A relatively inexpensive method for recording electrical signal of the human brain activity with a very high time-resolution is the electroencephalography (EEG). The Emotiv headset is a wireless EEG system with 14 electrodes arranged in specific scalp locations (figure 2). Even though, this affordable Brain Computer Interface (BCI) system is often used to enhance user's gaming experience, the device has been also reliably used for scientific explorations (Badcock et al., 2013). The Emotiv Software Development Kit includes three implemented applications (Expressiv, Affectiv and Cognitiv Suite) which process on-line information from brain activity, as well as muscle movement artifacts in some cases, using machine-learning algorithms. Even though these Suites provide the means for a good gaming experience, the exact details of the underlying algorithms are not available to the user. Thus, their ambiguous "black box" nature makes them unreliable for scientific research. However, the Research SDK package includes the Emotiv Testbench, a software tool that allows researchers to access and record the raw EEG signal, insert time-markers in the data stream and export the data for further processing. This option offers a reliable and appropriate method of data acquisition.

The EEG is a time-dependent signal and can be processed and analyzed in the time-domain or in terms of frequency bands (e.g. delta, theta, alpha, beta, gamma). When the EEG data is used to assess the neural responses associated with a specific internal (cognitive task), external (stimuli) or motor event, the focus is on the prior or post-event signal. In this case researchers analyze the Event-Related Potentials (ERP). ERPs are small changes in voltage that are triggered by an event and are described in terms of their polarity, latency and scalp distribution. Positive (P) and negative (N) deflections in the waveforms reflect the flow of information through the brain. (Luck 2005). Different conditions within an experiment may elicit distinct cognitive responses that are reflected by differences in amplitude and latency in the respective waveforms.

Figure 2.
A) The Emotiv EPOC headset B) Scalp positions of the 14 electrodes C) The Testbench software and the raw EEG signal



The continuous EEG signal is marked with event-codes and is segmented into epochs of a fixed duration that are time-locked in relation to the specific event. Random bio-signals such as eye-blinks and muscle artifacts can be detected by visual inspection or by using artifact detection algorithms. Trials contaminated with artifacts are usually either rejected or marked and excluded from further processing. However, a more effective alternative is the use of artifact correction procedures that minimize the rejection of valuable trials. ICA-based (Independent Component Analysis) artifact correction can be applied to the data in order to decompose the data into a set of underlying components, remove certain components that correspond to artifacts and then recompose the data without those artifacts (Lopez-Calderon and Luck, 2014). The event-unrelated noise is cancel out by averaging together a number of epochs that contain the event-related signal of interest. The final ERP waveforms are a result of a grand average of epochs across subjects, one for each electrode and each experimental condition.

The orientation experiment

The aim of this study is first to check the feasibility of the Emotiv Epoc and the ERP methodology in detecting differences in brain activity in real world situations and second to examine if the integration of information from distinct spatial representation is reflected in the recorded brain activity. The underlying hypothesis is that spatial locations within an indoor small-scale environment are mainly based on an egocentric coordinate system. Therefore, the mental representation of locations of the immediate environment is relatively updated with self-movement and thus more easily accessible, even if one follows a complicated route. On the other hand, as shown in the Wang and Brockmole's experiment mentioned earlier, the representation of the surrounding large scale environment requires a translation of the spatial knowledge and its integration with the current representation. Such cognitive process would be more demanding, since updating of the spatial information of the surrounding outdoor environment does not occur automatically with self-movement. In this case spatial knowledge from long-term memory requires a transformation from an allocentric coordinate system into the current egocentric coordinate system. For that reason, recorded brain activity, during tasks that require such a translation, should reflect this cognitive processes. To test this hypothesis an orientation experiment was designed and an egocentric pointing task was used in order to assess these differences.

The experiment took place in the halls of the V&A museum. The intention was to simulate the experience of maze navigation and disorient the participants by following complicated routes through the different floors of this over-stimulating environment (**figure3**). Four subjects, two male and two female, participated in the experiment. Participants were fully informed about the details of the experiment, their role in it, the kinds of data collected. The Emotiv wireless headset was then placed on their head. At four different stop points along the route, participants were asked to respond to an orientation-pointing task. Participants were first familiarized with the procedure and then instructed to sit comfortably, move and blink as little as possible in order to reduce artifacts. They were asked to take a task presented on the laptop and press the appropriate key of the keyboard as a response. While participants were conducting the tasks the Emotiv was recording their brain activity and saving this data into a file.

The orientation task was divided into two sets of four trials for each stop point (**figure 4**). In the 'outdoor' set, target locations of the large-scale surrounding environment were presented (e.g. South Kensington Station, the Marble Arch Station, Bayswater etc). Locations presented in the second set, the 'indoor' set, were closely related with the route within the museum (e.g. the en-

trance, the previous stop point, the shop) and thus based on a more easily accessible egocentric representation. In both conditions, participants were asked to rotate an image indicating these target locations in order to align it with their heading orientation. The image was rotate clockwise or anticlockwise 10 degrees by pressing respectively right and left arrows. Subjects were asked to start pressing the response keys, only when they had calculated the correct answer. Responses with a deviation up to 30 degrees from the correct orientation were considered as correct.

Figure 3.
Route and Stop
Points in the V&A
museum

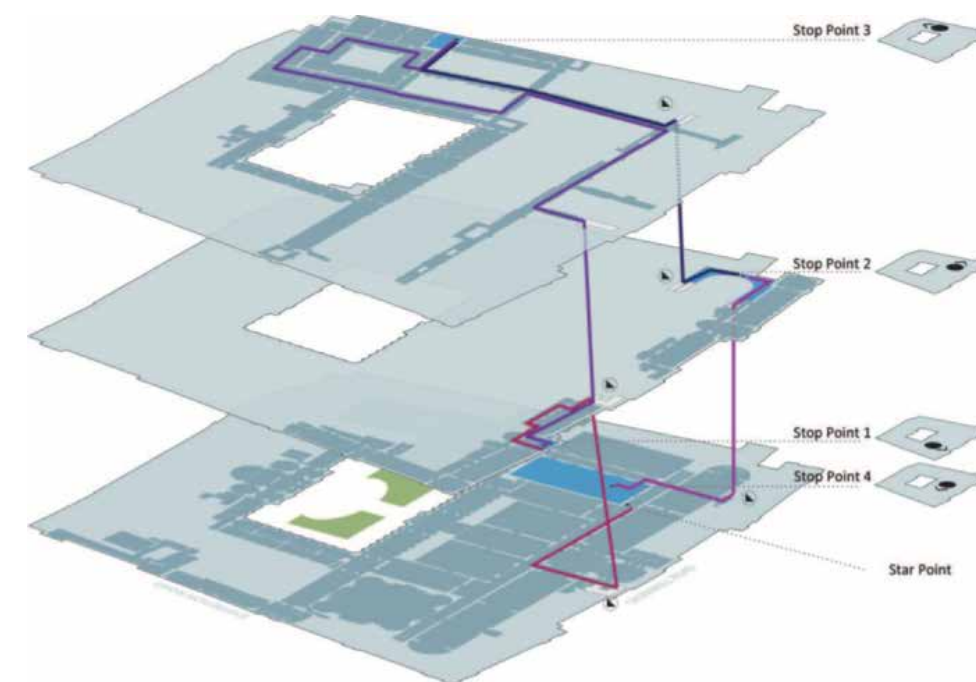
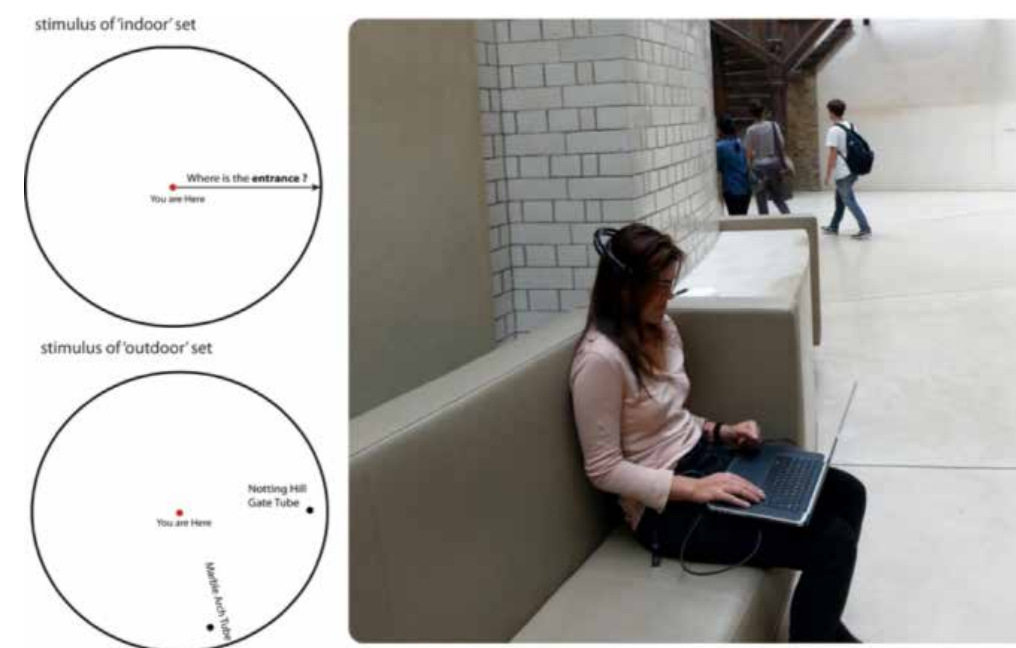


Figure 4.
Left: Experimental
stimulus Right: Subject
conducting the task in
the V&A museum



Data Acquisition and Processing

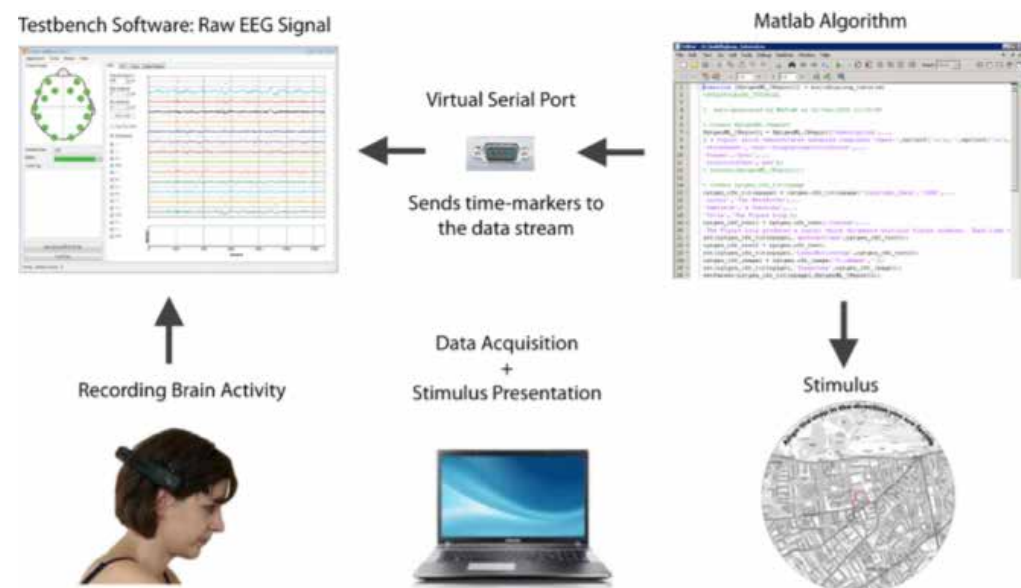
Brain activity was recorded with Emotiv Testbench software via a Bluetooth USB chip¹. The same computer was used for stimulus presentation and recordings in order to have more accurate timing of the keystrokes, as event-markers in the recorded data stream. Markers were sent from Matlab through a virtual serial port, to the raw EEG data using the Testbench software (**figure5**). Additional markers were sent for the onset and end of each new trial. A different event-code was sent to the data stream to mark subjects' responses for the two different sets, which made possible the distinction between 'indoor' and 'outdoor' responses. Event codes were differentiated offline for correct and incorrect answers.

The processing steps were carried out using EEGLAB (Delorme and Makeig, 2004), an open-source toolbox for Matlab (Mathworks, Inc., Natick, MA, USA). Data were first preprocessed as suggested in the manual², using a high-pass filter at 0.2 Hz and a low pass filter at 40Hz to remove high frequency noise. An Independent component analysis (ICA 'runica' function) was applied to the continuous data. Stereotyped artifacts such as eye-blinks and eye-movement were detected and removed by the algorithm. The corrected data were then processed using ERPLAB (Lopez-Calderon and Luck, 2014). Event codes were extracted from the EEG data, edited and stored in an Eventlist structure. With the Binlister routine, events corresponding to the different experimental conditions were assigned to different bins (categories). The EEG was then segmented based on the time-locking event. Response-locked epochs, spanning from -1000ms prior to key-press up to 200ms after and were baseline corrected³ based on the whole duration of 1200ms. Artifacts were detected using the peak-to-peak function and trials with deflections exceeding $\pm 80 \mu V$ were marked and excluded from further analysis. Epochs of the two different conditions were averaged separately. A low-pass filter with a cut-off at 30 Hz was applied to the epoched data to remove further noise, following the recommendation of the toolbox's manual. Finally a grand-averaged waveform across subject was produced for each bin and each electrode.

Figure 5.

Data Acquisition System

1. The EEG is sampled by the hardware at 2048Hz and then down-sampled to 128Hz (128 data points for one second). The device applies a pass-band filter to the signal to remove frequencies below 0.16Hz and above 85Hz and a notch filter at 50Hz and 60Hz to remove artifacts produce from the power line.



Results

2. http://erpinfo.org/erplab/erplab-documentation/tutorial_4/Filtering.html

3. Subtracting the mean value (the DC offset) of the waveform.

The different coordinate systems of the spatial representations of the two conditions, the 'indoor' and 'outdoor' sets, are reflected in a within-trial comparison of angular deviation errors. Lines representing each subject's response at each stop point have less variation for the 'outdoor' set compared to the 'indoor' set. This tendency probably reflects a more stable representation of the locations of the surrounding environment. Whereas, in the 'indoor' set, variation of errors results in more sharp peaks, suggesting that the representation of the locations presented in each trial are independent of each other and thus revealing the egocentric nature of the 'indoor' spatial model (**figure6**).

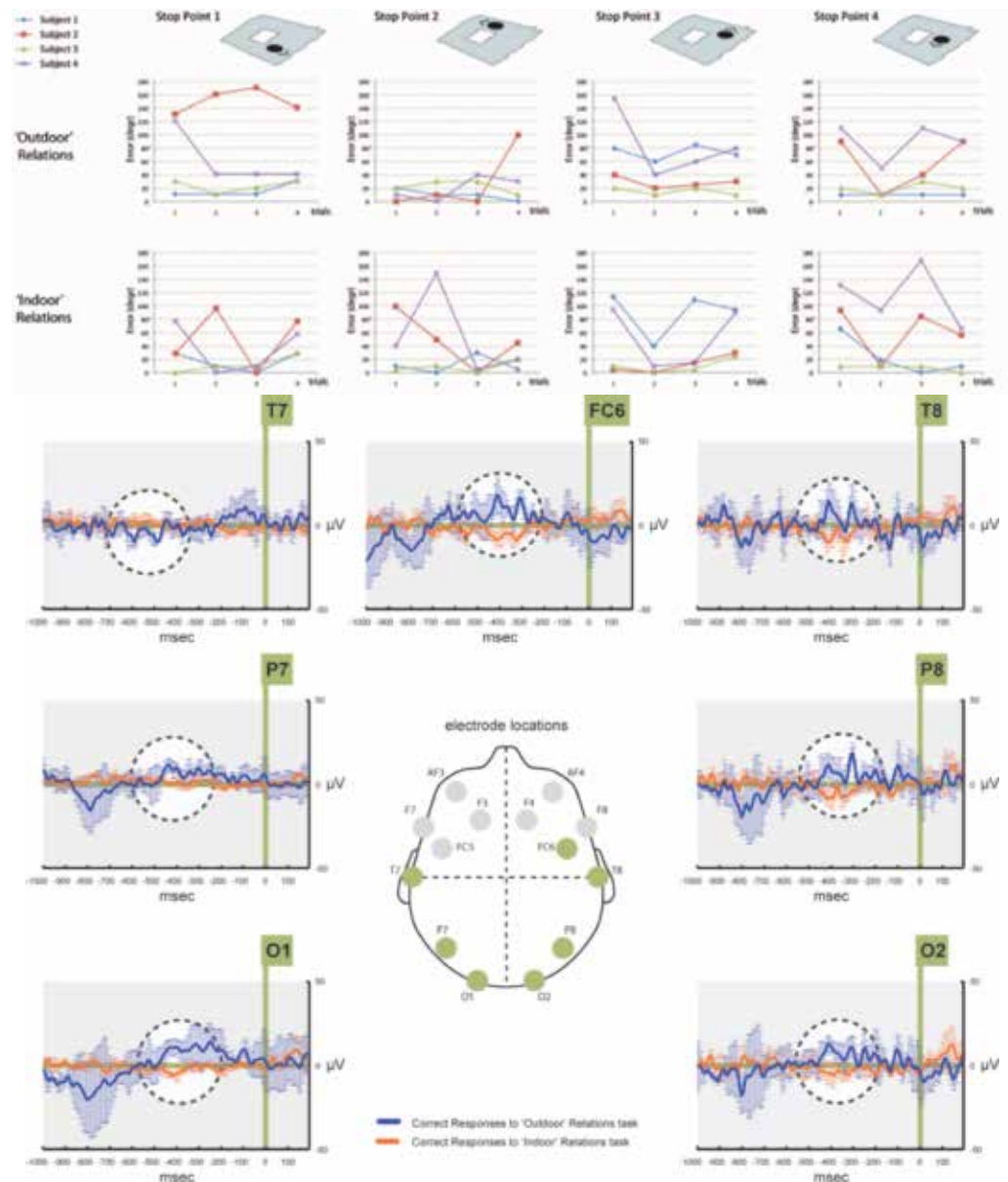
Figure 6.

Error of angular deviation of each subject at each stop point for each task: Lines representing each subject's response have less variation for the 'Outdoor' task compared to the 'Indoor'. The Y-axis represents the error of angular deviation in degrees and the X-axis the number of trials.

Figure 6.

Orientation Experiment Aha Vs NoAha.

ERP waveforms show positive amplitudes for the 'Outdoor' Relations Set condition Vs the 'Indoor' Relations Set in temporal, parietal and occipital areas in left hemisphere but right areas as well, as expected from the literature. Positive deflection occur in the time window of 500 to 200 ms before key press.



The event-related waveforms of the recorded brain activity reveal the differences between correct responses of the two conditions. In the 'outdoor' task deflections are greater than in the 'indoor' task in almost all electrodes reflecting increased cognitive load. More specifically in the right frontal (FC6), temporal (T8), parietal (P8) and occipital (O2) channels the 'outdoor' condition elicited more positive deflections in the time window of 500 to 200 ms before key press, whereas the 'indoor' set shows more negative peaks at the same time window. These differences imply the occurrence of different cognitive processes in each condition. Additionally, the recorded EEG data provide some preliminary evidence that the updating of the current mental spatial representation with information from long-term memory becomes conscious around 500 to 200ms before subjects indicated their answer (**figure7**).

Conclusions

In the present study, the aim was to explore the differences in brain activity between the mental model of an interior spatial layout and the spatial representation of the exterior surrounding environment. Behavioral results show that there is a tendency in forming allocentric spatial representation for large-scale environments with more stable relations between locations. On the other hand, route knowledge is based on transient egocentric representations that are independently related to the observer's location. Thus people tend to maintain separate spatial representation for different spatial experiences. This clustering of representations respects the capacity limits of the working memory since it permits only the activation -from long-term memory- of the necessary spatial information that is needed for immediate action.

Integration of separate spatial representations is possible but requires a translation of spatial information between the two reference frames. The EEG recordings of this study support the hypothesis that the mental model of the surrounding environment is based on a distinct spatial representation. Additionally the positive deflections in the waveforms that are elicited in this condition reflect the cognitive processes that underlie this coordinate transformation. As expected from the literature (e.g. Burgess's two-system model) greater deflections in temporal and parietal-occipital lobe are elicited in the case where transformation of the allocentric representation is needed. Increased amplitudes in the temporal lobe might be related with memory interactions underlying the updating process of the mental representation and parietal positivity might reflect the restructuring of spatial relations in the current mental representation.

The attempt to study brain activity in real-world environmental interaction is non trivial and requires an appropriate methodology. The findings from this experiment are quite promising regarding the feasibility of the EEG/ERP methodology. The EEG methodology expands the space of possible research questions that might be investigated in relation to spatial representations, environmental psychology and spatial perception and cognition. The subjective experience of the built environment might be in a certain degree objectively measurable when collecting data using such neuroscientific methods. Simple experimental laboratory conditions are not necessarily representative of what actually occurs in real complex situations. Our understanding of space, as architects, may contribute in a fruitful way in the recent attempts to investigate the neural responses that are associated with real-world spatial experience and the perception of the built environment. Research in this emerging interdisciplinary field could provide new guidelines that would also shift the architectural research towards a more mind-oriented exploration.

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Event Platforms: Proposing a new computational design tool for integrating spatial events into the architectural design process

Event Platforms: Proposing a new computational design tool for integrating spatial events into the architectural design process

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Abstract

Architectural design can be viewed as the manipulation of physical material space in relation to human events that take place inside it. Although architects have a multitude of computational design tools at their disposal, the vast majority of these applications focuses on the manipulation of physical form. This paper proposes a new experimental design tool that enables the creation of parametric components that represent potential spatial events within three-dimensional digital models. The goal is to improve the decision-making process of architectural designers by enabling them to evaluate and iterate their design revisions based not only on the building's form but also on the human spatial events that take place inside it.

Keywords

Parametric design; spatial events; design tool development; design creativity; digital modeling.

Introduction

Supported by widespread technological progress, digital design tools have been gradually becoming commonplace among architectural studios and design practitioners. Motivated by its own body of theoretical sources and promulgated by a culture of discourse, the contemporary digital design culture is mainly focused on the algorithmic control of physical form, namely the geometric surfaces and the building components that constitute what is defined as architectural space. This paper aims at enriching the current pool of available computational design tools by exploring new algorithmic techniques for manipulating and visualizing spatial events within the physical boundaries of the designed spaces. The ability to parametrically control and maneuver potential human activities alongside the presently available topological parameters within a certain three-dimensional model could prove extremely beneficial to the productivity and the effectiveness of the designer.

This research is structured around the introduction of an experimental software plugin that provides optional, additional functionality alongside the geometric modeling process of an established commercial application. This plugin is presented as a partially functional prototype and is currently tested by being utilized in three diverse design examples. The proposed application enables its users to create parametric entities that represent potential human events inside three-dimensional digital models. By translating abstract human data into malleable interactive components, these crucial architectural parameters can be productively manipulated during the design process, bilaterally linked with geometric elements and even innovatively visualized through animations and diagrams.

Spatial Events within the architectural design process

Within the framework of architectural design, there are several theories and approaches about how the design process works. In essence, these theories examine the cognitive steps and internal machinations that the architectural designer goes through in order to arrive at a final design proposal. While it is beyond the scope of this paper to analytically examine the various architectural design methodologies, it is important to acknowledge that the design process is a complex, non-linear procedure that necessitates both rational and non-rational/creative cognitive skills and involves the manipulation of various diverse parameters that contribute to the creation of the final outcome. According to Gänshirt (2007), during this process the architectural designer is obliged to seek the assistance of design tools (both visual and verbal) in order to successfully organize as well as convey and communicate his ideas, visions and thoughts. Anything from gestures, sketches, models, videos to computer simulation programs and design criticism can all be seen as tools forwarding the design in some way or another. More specifically, the subcategory of computational design tools refers to those visual design tools that are based on algorithmic processes and that require the utilization of computational resources.

Amongst the multitude of architectural design theories and a steadily expanding number of available computational design tools, this paper focuses on the notion of spatial events. For the purposes of this research, the term spatial events is defined as the physical movements and physical interactions of human users within the physical spatial entities that are the subject of architectural design. In comparison to the decisively more broad term of human events, this definition is deliberately limited in order to ensure its operational usefulness. From the perspective of the user, spatial events encapsulate the primary sense of visual perception but do not include the secondary senses of acoustic and haptic perception. Furthermore, spatial events, within the context of this paper, are taking into account only part of the visual perception of the user. The field of architectural semiotics

studies extensively the relationship between the physical geometric form (signifier) and the meaning or perception (signified) that is associated with architectural spaces. According to Eco (1980) this relationship has two distinct levels: at the denotative level architectural elements are mainly perceived based on their function while at the connotative level certain architectural objects can express certain ideologically defined values that are embedded in its function. A throne, for example, denotes that it can be used as a seating furniture but at the same time connotes or symbolizes a certain type of authority and power. It is important to clarify that spatial events are operating strictly at the denotative level of the visual perception of the users.

After establishing an exact definition of the spatial events, the next step is to delineate their relationship with the architectural design process. As a human cognitive process that targets the improvement of physical space, architectural design is inherently dependent on how the users of the physical space are moving, interacting and perceiving the designed space. Therefore, the spatial events are an integral part of the diverse mosaic of parameters that are guiding the architectural design process. Various computational design tools are specializing in organizing and manipulating algorithmic interpretations of these parameters in order to assist the architectural designer. Among others, parameters such as geometric form, materiality, illumination and structural rigidity have already been accurately represented in computational design tools. Their quantitative nature as well as their straightforward correlation with equations and laws of physics facilitated their algorithmic transition. On the contrary, it would be a much more challenging task to achieve a successful algorithmic translation of the general concept of human events. Based on the definition of the previous paragraph, spatial events constitute a simplified, striped-down version of human events that relies on physical movement and denotative visual perception and is therefore compatible with algorithmic processes. The goal of this research is to justify and produce a computational design tool that organizes and manipulates spatial events. Although it might not be possible to algorithmically represent the connotative level of visual perception, by controlling and evaluating (denotative) spatial events, the architectural designer will have the opportunity to subjectively create his own connotative interpretations. In that sense, spatial events aspire to become an algorithmic/quantitative proxy of certain non-quantifiable parameters of the architectural design process.

Computational precedents

The first instance of computational design tools that were loosely related with spatial events can be traced to practical implementations of the theoretical ideas of Christopher Alexander and Bill Hillier. Alexander's efforts had limited success due to insufficient technical resources as the architectural problems that he was attempting to quantify were too complex for the available hardware and software of the 1970s. On the contrary, during the early 1980s, Bill Hillier's team was more successful in creating computer applications based on the space syntax theory. Starting with Axman and Spatialist, there is a long list of spatial network analysis software that were based on space syntax and were utilized either as standalone programs or as extensions to other CAD products. These tools have been quite popular among urban planners and designers as they provide them with data analysis and simulation of road or path networks. However, their usability is limited in architecture since they only analyze potential movements and not spatial events in individual interior spaces.

Apart from software directly related with space syntax, there are various other applications that promise reliable simulation of human movements in urban contexts. Legion SpaceWorks (Figure 1)

is one such tool that allows users to simulate pedestrian movement within a defined space, such as a railway station, sports stadium, airport or any place that people assemble in or move through. Another application that operates in a similar manner is MouseHaus (Huang C-J at al., 2003). By taking into account behavioral patterns as well as real people activity data, this tool provides a vague indication of how large numbers of people will move through a certain space. These tools are usually treating people as anonymous agents without any concrete functional goals and rely on statistical estimations rather than experiential qualities. Therefore, although they are dealing with the movement of people in space, are rarely geared towards spatial events at the architectural scale.



Figure 1.

Snapshot of the application Legion Spaceworks. Source: <http://www.legion.com/stadium-evacuation-simulation>



Figure 2.

Snapshot of the application Poser Pro. Source: <http://my.smithmicro.com/poser-pro-2014.html>

Outside of the realm of architectural design, there are several applications that deal with modeling and animating human figures (Poser, Character Studio). These are specialized digital tools that are working alongside conventional modeling software in order to insert and animate detailed models of human figures (Figure 2). They are primarily targeted for character animators and offer quite complex and specialized manipulation of every aspect of the human movement. Some of them, like Mixamo offer extensive web-based interfaces that simplify the character creation process for game developers. Nevertheless, the relative independence of these avatars from the spatial model as well as the complex user interface of these tools renders them unattractive to architects.

During the last 5 years there has been a noticeable interest in tools that address the theme of spatial events within the context of architectural visualizations. There are several, recently introduced, tools that are focused on the distribution of animated avatars within a render-ready three-dimensional model. Apart from fully integrated solutions (like the Populate toolbox within 3ds Max), there are plugins such as an(i)ma (by XYZ Design) and RailClone (by iToo Software) that enable designers to enhance their models with characters before the visualization phase. Although these tools are undeniably useful, they are treating human avatars as simple geometric decorative accessories that are independent from the building components and that are inserted after the design process is finished.

Within the framework of the contemporary computational design tools, it is evident that there is an absence of tools that algorithmically address the presence of spatial events during the architectural design process. Although there are several visualization tools and techniques, it has not been possible to parametrically articulate spatial events during the design development of projects.

The significance of spatial events

In response to the relative absence of spatial events from the computational design workflow, several reasonable arguments can be made in favor of their introduction. Four of these arguments will be presented in the following paragraphs.

Spatial events are important

Although architectural design is an intuitive and complex procedure that affords multiple approaches and routines, several design paradigms embrace, either consciously or subconsciously, the significance of spatial events within architectural spaces. The potential physical movements of the inhabitants of a certain space might be intangible and invisible for the architect during the design phase, yet these interactions constitute crucial decision-making parameters for the designer. Despite the presence of some available digital visualization techniques, these are certainly not enough to establish spatial events as an effective parameter within the digital design workflow. There is room, therefore, for better tools that would manipulate and analyze spatial events in a more productive and parametric manner that would be more suitable for the creative process.

Spatial events are so complex that computers might help

In general, human activity is an extremely complicated phenomenon that constitutes the main focus of multiple scientific fields. Despite this inherent complexity, designers are required to grasp and analyze these spatial interactions utilizing only their mental capacity.

On the other hand, computational processes are extraordinarily effective in manipulating complex tasks. By breaking down complex spatial events into quantifiable elements or variables, it would be possible to employ computational systems in order to handle part of their complexity. Within that framework, the exploration of computational design tools that would enable designers to productively manipulate complicated spatial events appears to be a rational pursuit.

Spatial events are missing from the computational design workflow

It is quite evident that over the last decade the architectural design process is gradually shifting into a completely computational workflow. Architectural studios as well as individual practitioners are using computational design tools from the beginning of the design process until the final delivery of the construction drawings or the equivalent BIM model.

Within this professional landscape, the form of the building, as well as its structural and mechanical integrity, can be accurately represented with digital models. However, the spatial events of its potential users and inhabitants, appear to be missing from the digital workflow. Therefore, the creation of a computational tool that would be focused on the manipulation of spatial events could ideally provide a currently-missing digital platform for a crucial aspect of architectural design. Since the architectural design process is becoming increasingly digital, it is important to maintain a computational presence for all the potential design aspects of the workflow, including the spatial events.

Digital spatial events will mesh well with digital parametric design

The new generation of architects is becoming increasingly familiar with manipulating various algorithmic parameters during the creative process in order to reach a desirable design solution. Within this context, the potential addition of new, novel parametric options next to the existing ones could only prove beneficial to the digital workflow. The introduction of a new computational tool for representing and manipulating spatial events could add a new parametric category to the diverse network of the current algorithmic criteria.

The analysis of these four arguments leads to the realization that it is worth exploring new ways of inserting spatial events into the computational design process. Despite the failure of earlier efforts, several recent advancements and developments justify the re-examination of this research field with a fresh perspective.

The new tool

The main purpose of the proposed digital tool is to assist the designer during the architectural design process. The objective is to introduce a new design assistance mechanism that focuses on providing novel, optional digital features that could be gradually integrated to multiple and diverse architectural workflows without disrupting their routine. Within the framework of this research, these features are closely related to spatial events in architectural environments. The proposed tool attempts to complement the existing three-dimensional digital models with a mechanism of manipulating and visualizing the spatial events that might take place inside them.

At this point, it is important to clarify that the prospective tool does not simulate spatial events within digital architectural environments. A computational simulation is an accurate imitation of the operation of a real-world system over time based on a rigorous algorithmic model that describes the key characteristics, behaviors and functions of the said system. In the case of spatial events, such a task would necessitate the creation of a computational model that, given a certain space, could predict or simulate how the users will move, perceive and interact with that space. Based on the complexity of the human nature, the psychological and cultural parameters of human behavior as well as the semiotic/connotative intricacies of visual perception, it is evident that such a computational model does not exist as yet. Instead of pursuing a simulation, the proposed tool offers a mechanism for the architect to model his intentions. It does not predict what will actually happen if the designed space is realized but it enables the architect to visualize what he thinks might happen, based on his design goals and creative aspirations. The focus here is on the architect and the complicated, non-linear decision making processes that occupy his/her mind while designing spaces. Just as the three-dimensional models (physical or digital) of the building mass offer cognitive assistance in grasping and evaluating formal characteristics, the same should be possible with similar models of spatial events. Having the ability to manipulate and visualize an avatar's physical movements and inside the building structure would greatly enhance the architect's spatial understanding and would hopefully lead to better design decisions.

The Event Platform as a new component

Within the realm of architectural design, the notion of spatial events can be depicted in multiple and diverse forms. Ranging from simple functional diagrams all the way to animated avatars, all representations of spatial events seek to visualize how the end user will interact with his contextual surroundings. The crucial parameter that necessitates the existence of such a multitude of approaches is scale. A certain phenomenon requires different styles of representation depending on

the distance from which it is being observed. When designing a large building complex, the potential spatial events are simplified into functional labels attached to the various spaces (offices, reception, restrooms, etc.). In this top-down approach, these labels offer an indication of how the users will engage and interact with those spaces but they are doing it in a straightforward and simplistic fashion that is suitable for compositional editing. On the other hand, during the process of making decisions regarding the interior design of a project the architect has to mentally grasp and manipulate the approximate positioning and movements of the people that will utilize that space. This bottom-up approach operates at a smaller, more intimate scale of human activity where the simple functional labels are insufficient to capture the temporal complexity of the potential spatial events. Instead, cinematic sequences that include animated avatars are more suitable for representing human activity at this lower level.

In order to create a practical digital tool that would be suitable for manipulating human events, both ends of the fore-mentioned activity spectrum scale need to be accounted for within its inner mechanisms. The major challenge in achieving such a feature lies in the introduction of a new computational entity that would have the innate capability to seamlessly encapsulate the notion of spatial events in all scales. More specifically, this entity should capture the physical movements and physical interactions of human users within the architectural model, as this is the definition that was given to spatial events earlier in this paper. At the same time, all modeling software are object-oriented: the designer is manipulating geometric elements within the three-dimensional environment. How is it possible to combine the complexity and uncertainty of moving avatars with the clarity and specificity of an object-oriented application? This is achieved by the introduction of a distinct geometric element that represents the delimitation of the volume that is designated to a certain group of spatial events. This novel entity is called Event Platform. Within the framework of this research, the term Event Platform is used to describe a transparent, volumetric, digital representation of the intended spatial events of a certain space (Figure 3). The goal is to complement the familiar, widespread utilization of geometric building elements with a novel type of entity charged with the challenging task of depicting a geometric representation of spatial events. This representation has the following distinct characteristics:

- It is a separated entity from the actual physical elements of the building
- It is parametric
- It is top-down friendly, as it encapsulates an enhanced version of the functional diagrams
- It is also bottom-up friendly, as it incorporates corresponding activity at a lower scale

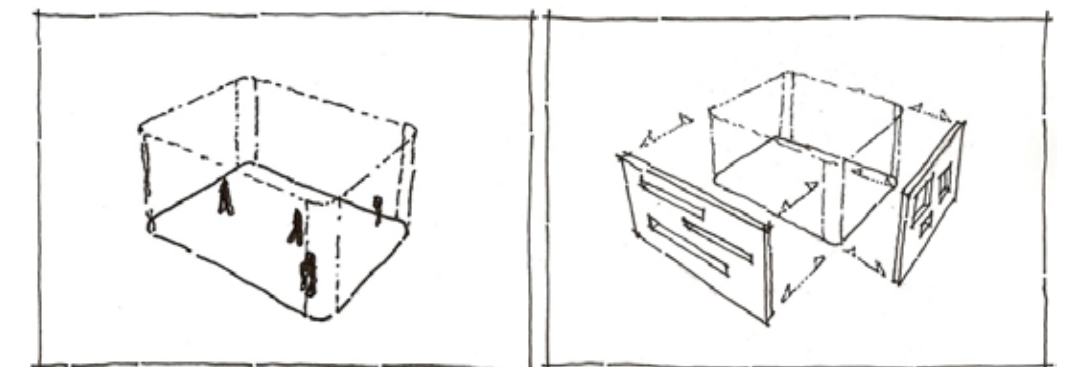


Figure 3.

A representation of an Event Platform

Figure 4.

Event Platforms are separated entities from the physical elements of the building.

Event Platforms are separated entities from the physical elements of the building

The idea behind the introduction of the Event Platforms is to provide the designer with a toolbox capable of representing information regarding spatial events inside architectural spaces. The objective is that, through the proper utilization and manipulation of these elements, the architect would be able to create a separate “activity” layer that would be overlaid on geometric elements of the model. In order for this to work properly, it is crucial to maintain a clear division between the Event Platforms and the physical building components of the structure (Figure 4). This fundamental independence of the two entity typologies (activity and geometry) does not prohibit the existence of connections and articulations between them. On the contrary, the fact that Event Platforms are inserted as autonomous objects provides them with the flexibility to interact with multiple other elements in various ways.

Event Platforms are parametric

The significance of parametric control within the framework of contemporary architecture is well documented and almost universally accepted. The gradual transition towards computational design tools has brought into focus the advantages of utilizing digital modeling software. One of their most important features is the ability to maintain parametric relationships between geometric elements and numerical values. These mechanisms enable the designer to control indirectly and interactively the designed outcome through the manipulation of data. A similar level of parametric flexibility would be extremely beneficial for the Event Platforms. These new computational entities would be customizable and adjustable through a comprehensive panel of settings and values that would be always accessible (Figure 5).

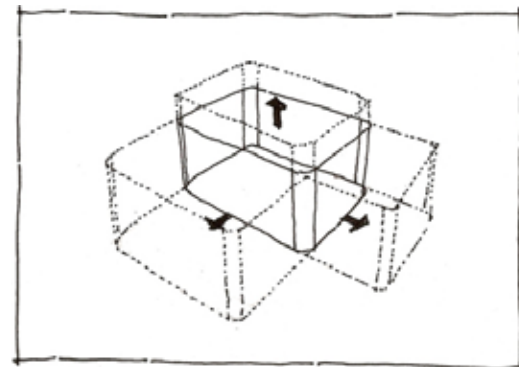


Figure 5.

Event Platforms have parametric dimensions. A three-dimensional functional diagram as a collection of Event Platforms

Event Platforms are top-down friendly as they encapsulate an enhanced version of the simplistic information of functional diagrams

Functional diagrams have always been an integral part of the design process. Whether in the form of a sketch on trace paper or as a digital bitmap, the utilization of diagrammatic hierarchical structures has assisted the designer in optimizing the building configuration. Through the usage of abstract shapes (rectangles or boxes) and simple labels (offices, reception, restrooms, etc.), the spatial events had been transformed into simple, manageable and comprehensible entities. The Event Platforms are designed as placeholders for similar data, albeit completely integrated into the digital modeling

Event Platforms: Proposing a new computational design tool for integrating spatial events into the architectural design process

environment (Figure 6). Moreover, their digital, parametric nature renders them far more suitable to cope with the uncertainty and ambiguity of the non-linear design process.

Event Platforms are bottom-down friendly as they incorporate human activity at a lower scale

In contrast to the widespread usage of the functional diagrams, lower-scale human activity has hardly ever been part of the design process. Analyzing and representing how people move and interact within a certain space has always been a highly complicated task that had minimal impact on the design outcome as the decision-making process was focused on a larger scale. However, recent advancements in the field of computation and digital media have rapidly increased their capacity of manipulating complex phenomena. The Event Platforms are taking advantage of contemporary algorithmic processes in order to visualize and manipulate the intricate machinations of the human activity. Although designers are still operating at a larger scale, the added benefit of maintaining a more circumstantial view of their project should not be ignored (Figure 7). The broadening of their understating and control over how people interact within space at a micro-scale could only lead to more educated decision-making in any design scale.

How Event Platforms are used

The Event Platforms can be utilized by architects and designers during the schematic design or the design development phase of projects. They are inserted as supplementary components within commonly used digital modeling software and appear as additional options alongside the existing tools and techniques of the programs. The most intriguing characteristic of the Event Platforms is that they are not geometric building components but parametric, transparent, volumetric placeholders for human activity. The scope of the Event Platforms is to offer a novel representation technique for capturing useful information that is currently absent from computational building models. Despite the impressive level of detail of the representation of the physical geometric elements (accurate topology, materiality, indirect illumination), modern software have not been able to capture the events that take place inside these elements. The Event Platforms attempt to bridge this gap by providing the designer with a tool for manipulating physical human activities within a spatial context. They function as a semi-autonomous parametric data layer that is developed in parallel with the actual geometric components of a project. By creating and positioning individual Event Platforms, the designer can compose an independent “event” skeleton that is separated from the building shell. Consequently, by utilizing the parametric flexibility of the software he is able to selectively link the geometric elements with the “event” skeleton. The ultimate goal is to improve the decision-making of the architect by having him successfully interact with both information structures (geometry and events) during the design process. More specifically, the Event Platforms can be used in two ways:

- As parametrically connected elements within the three-dimensional model
- As generators of innovative visual and data feedback

The Event Platforms as parametrically interconnected elements

The Event Platforms are computational components that are controlled by a diverse set of parameters (Figure 8). These options can be divided into three distinct groups: size, events and connections.

The first parametric cluster regulates the general dimensions of each entity and is quite straightforward, as it resembles commonly used settings of other components. The designer can control the width, the length as well as the area of each Event Platform by entering either absolute or flexible values within a

The first parametric cluster regulates the general dimensions of each entity and is quite straightforward, as it resembles commonly used settings of other components. The designer can control

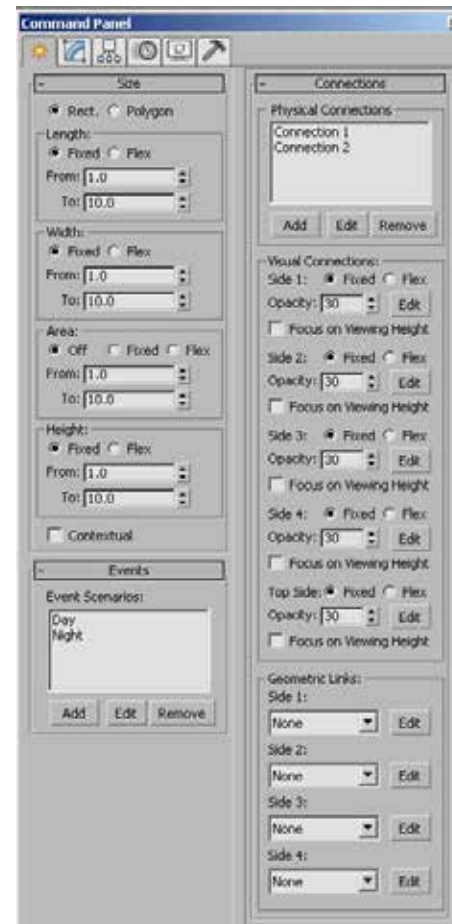


Figure 7.

Human activity is captured vividly within the Event Platforms.

Figure 8.

Part of the user interface of the plugin within 3DS Max.



the width, the length as well as the area of each Event Platform by entering either absolute or flexible values within a certain range. Therefore, the uncertainty and ambiguity that was present in analogue media (sketches on trace paper, smudges, lack of scale) can be somehow translated into value ranges within digital media environments. Although the Event Platforms are components with geometric characteristics, it should be noted that they are not physical building components. The Event Platforms are areas of activity that have a specific volume but no physical definition of their borders. They can be described as transparent bubbles that depict how much space is assigned by the architect for certain spatial events.

The second group of parameters controls the activities that take place within the platforms. The designer has the option of assigning various event scenarios to each Event Platform. By utilizing established techniques from other digital fields (character animation), the proposed tool enables the designer to create simple avatar sequences with minimal hassle. The desired event scenario can be constructed through the insertion of the participating avatars, the control of their positioning and the selection of their activities through pre-established motion capture libraries (Figure 9). These complex animated sequences might appear too complicated and inconvenient to set up for

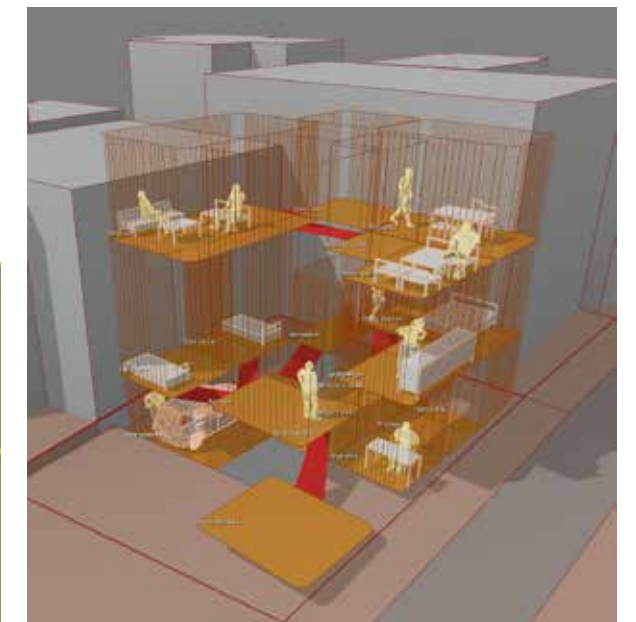
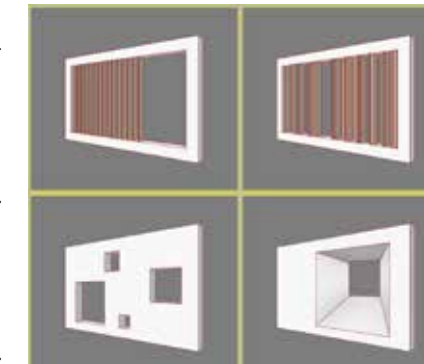
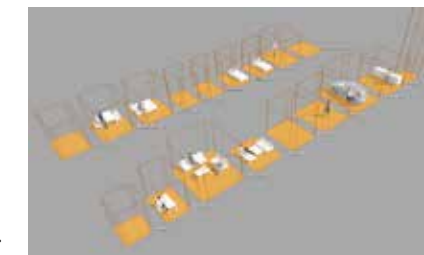
the average architect/user of digital software. Nevertheless, recent advances in the field of character animation constitute the process effortless and almost fully automated.

The last parameter group regulates the various algorithmic connections and links of each Event Platform. There are three types of connections: physical connections, visual connections and geometric links.

Figure 9.
Event Platforms after the creation of the various events.

(right) Figure 11.
A configuration of Event Platforms with physical and visual connections between them.

Figure 10.
Four types of parametric panels for a certain project.



The last parameter group regulates the various algorithmic connections and links of each Event Platform. There are three types of connections: physical connections, visual connections and geometric links. By assigning physical connections for each platform, the designer can establish how the human users can move between the platforms. Therefore, the passageways from each space to the neighboring ones can be positioned in a parametric manner.

The visual connections encapsulate parameters that define how much of the surrounding context is visible to the avatars of each Event Platform. Depending on the position, the configuration and the contained activity of each component, the architect can adjust the intended opacity of individual borders of each platform (Figure 10). Therefore, he is able to not only control the optical relationships among the different Event Platforms but also their visual connections with the environmental context. Similar to the physical connections, the presence of parametric flexibility ensures that the designer can use ranges of opacity values and selectively assign them to separate visual targets.

The last type of parametric connections controls the relationship between the Event Platforms and the other geometric components of a certain digital model. The geometric links enable the parametric data flow between the two distinct models in order to improve the decision making process. The designer can assign parametric geometric panels (Figure 11) to specific borders of the Event Platforms. The concept is that the embedded characteristics of the panels (type and distribution of openings, materiality, topology of their surfaces, etc.) are informed by the opacity of the visual connections and the positioning of the physical connections to algorithmically produce the final geometry. In a sense, the geometric

“armor” of a certain building will have to conform and wrap around its activity “skeleton” (**Figure 12**). Both models would remain open to parametric tweaks and adjustments throughout the non-linear design process.

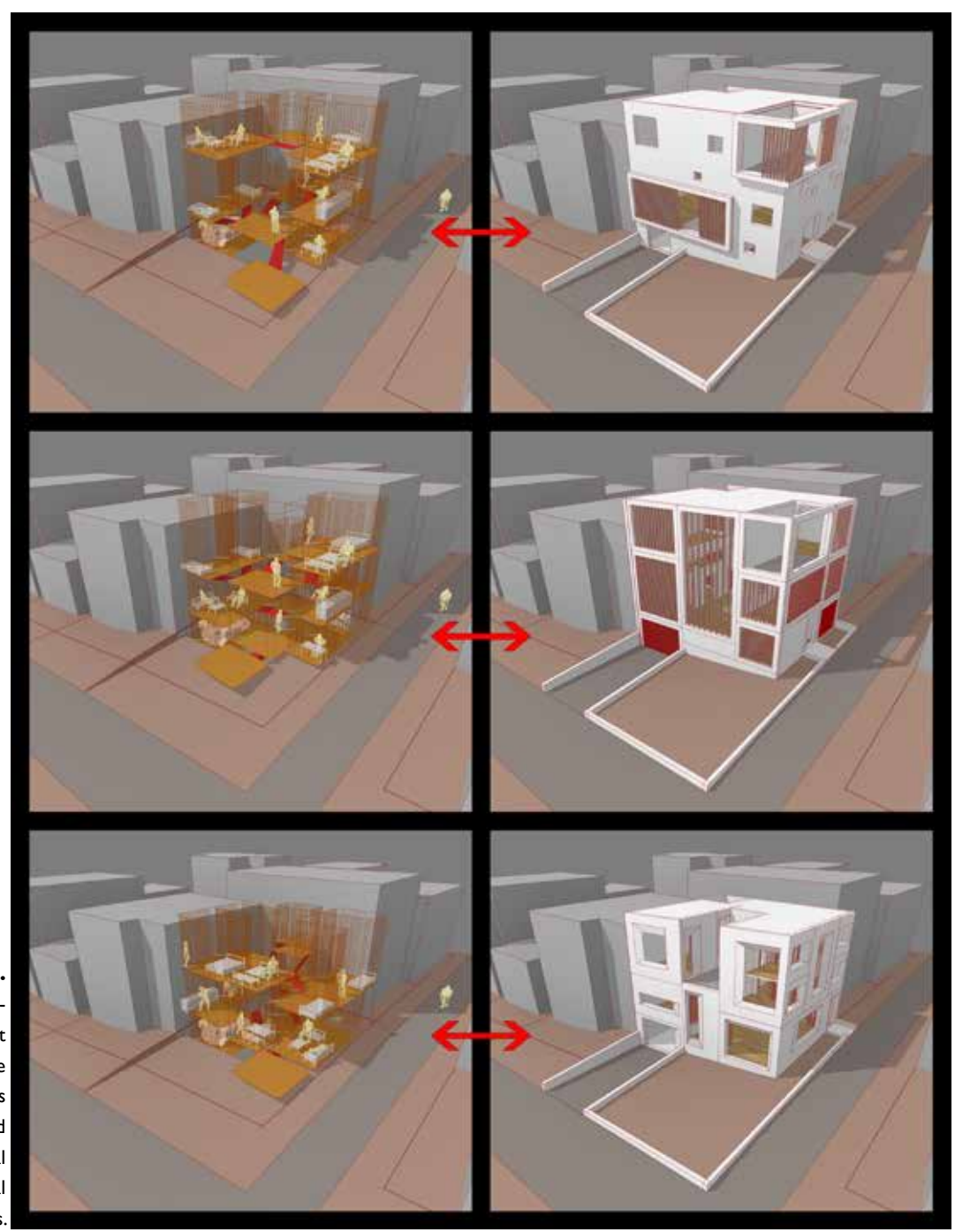


Figure 12. Three different configurations of Event Platforms with the corresponding panels that are linked based on their physical connections and visual opacities.

Event Platforms: Proposing a new computational design tool for integrating spatial events into the architectural design process

The Event Platforms as generators of innovative visual and data feedback

Apart from constituting tangible modeling components during the digital design process, the Event Platforms are also capable of functioning as generators of innovative feedback for the architect. Independent of their preferred workflow, most designers are using various representation techniques in order to properly grasp and evaluate the outcome of their efforts. The emergence of the Event Platforms provides the opportunity for a fresh perspective on the existing architectural visualization techniques. The proposed software takes advantage of the parametric nature of the Event Platforms in order to produce novel visual and data representations of the design outcome.

Visual feedback

In order to adequately encapsulate the complexity of events and human activities in space, the proposed tool utilizes the positioning of the avatars of the Event Platforms and creates various digital cameras around them by adhering to established cinematic conventions. After creating a large number of cameras, a representative sample of the best shots is algorithmically compiled into an animation matrix that shows up to 25 different frames (Figure 13). This activity animation matrix constitutes a new visualization mechanism that offers a fresh representational perspective during the design process.

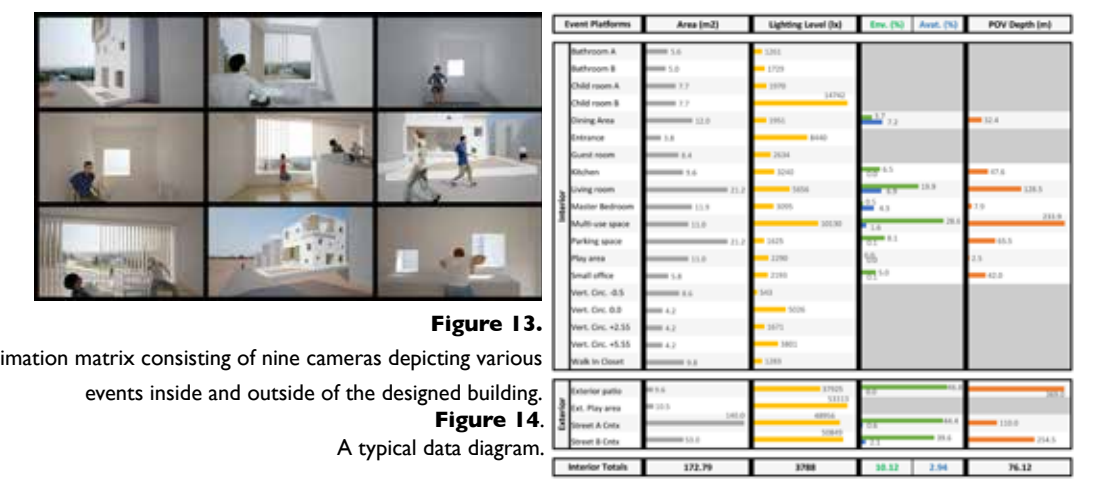


Figure 13. An animation matrix consisting of nine cameras depicting various events inside and outside of the designed building.
Figure 14. A typical data diagram.

Data feedback

In addition to the animation feedback, the Event Platforms are capable of analyzing the frames of all the point-of-view cameras and extracting useful data out of them. Apart from visual imagery that they provide, the viewpoints of the avatars can provide additional information that could be translated into useful diagrams (Figure 14). The digital tool can currently monitor data about the contextual environment (how much environment is visible to each avatar), other avatars (how many of the other avatars are visible to each avatar) and average spaciousness (the average distance of the first obstacle in front of every avatar). In addition to that, the tool can also measure the average lighting level of each platform. The currently available types of diagrams serve as a first step towards proving the effectiveness of this approach. It is quite certain that there are more aspects of architectural projects that could be partially translated into numerical quantities by utilizing the parametric nature of digital software. The challenging aspect of morphing them into productive tools is maintaining an effective balance between qualitative

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The currently available types of diagrams serve as a first step towards proving the effectiveness of this approach. It is quite certain that there are more aspects of architectural projects that could be partially translated into numerical quantities by utilizing the parametric nature of digital software. The challenging aspect of morphing them into productive tools is maintaining an effective balance between qualitative and quantitative feedback. Although architectural decision-making cannot be totally depended on data diagrams, their limited integration into the design process could be immensely valuable.

Experimentation and evaluation

During the current stage, the proposed digital tool has the form of a plug-in software that has reached the prototype phase. All the main computational threads as well as the user interface of the software have been identified and have been partially implemented. While a significant amount of the processes have already been scripted, there are some functions that are currently executed manually in order to test the usability and practicality of the tool.

In order to examine the practical usability of the tool, it has been put into use through three diverse experimental design projects. These examples (a small residence, an office building and a bank headquarters complex) differ in scale and complexity and focus on evaluating and critiquing the usefulness of the tool workflow under a diverse range of test-cases. By engaging the new plugin into the design process of these three examples the goal is to acquire a thorough and comprehensive understanding of the proposed workflow as well as the possible shortcomings of the new design tool.

Conclusion

The realm of contemporary architecture is becoming increasingly dependent on computational tools as integral parts of the design workflow. The majority of these applications appears to revolve around the parametric articulation of physical building elements and formal attributes. This paper attempted to outline the main components of a new digital tool that enables designers to visualize and manipulate human events and interactions in spatial settings. This tool aims at augmenting the architects' perspective by providing a more spherical view of the design outcome that could hopefully improve their decision-making mechanisms.

Acknowledgements

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Shifting matters of mortality: Neo-medievalism and re-contextualisation of macabre

Despoina Zavraka

Abstract

Death arises a whole new era in design, which is subject to thought, cultural responsiveness and emergent materiality. This paper aspires to dip into diversity of speculative projects exploring fictional scenarios on transcultural funerary conditions. This variety is aliquoted into imaginative interplays and cynical approaches on the confinement between the 'seen' and the 'unseen'. Based upon extended doctoral research, this paper attempts comparatives between re-contextualization of macabre concepts and precedents of the past. The notion of neo-medievalism refers to emerging mechanisms of re-speculating one's own death, beyond localities. Contemporary design cultures often reveal multi-layered references to the 'darkness of death' and present interesting cases and transformations of the 'horrific'. These cases refer to a fragile balance between a profound fascination and simultaneous transcending of death's obscurity and grotesque. It is within this paper's goals to trace this fragile balance.

Keywords

Materiality, speculative cemetery design, death, neo-medievalism

Introducing argumental comparatives: Emergent matter correlated with medieval references

Based upon mature doctoral research, this paper attempts to address a multiplicity of matters expressing mediated re-personification of mortality. The notion of multiplicity reflects variable dimensions correlated to certain diverse expressions of familiarity and matters of human decay. Within such concepts, a handful of indicative speculations trace thresholds of matter as memory and thresholds of matter as process.

A series of reasonable questions may occur to the sound of such a topic. How can materiality and materialism associate with mortality, in the rich and multifaceted context of contemporary computational architecture? How would it be possible to associate current responses to death with medieval concepts? What may possibly be the asset of computational tools to such an era? Originating from a remote relation to the general themes of computation, this paper attempts certain thematic delegations relating to emerging matters of death.

During medieval times, synthetic process had been evidently different compared to present days. Every edifice had to be identical to another and innovation did not matter at all. Gombrich states that 'our contemporary notion that an architect or an artist has to be original wouldn't be shared by artists of the past. A medieval artist of the West would have never understood why he should invent new ways when the old ones served their purpose well' (1950). For the long and blurred period of Dark ages, it is interesting to scale upon notions of 'synthetic process' and 'edifice'. Regarding western art, as following the decay of classic ancient world, Gombrich renders a continuous melting pot of different genres. These genres may often appear conflicting, both in relation to each other, as well as in relation to the so called savageness of that age. Through variable conflicts, there are certain thresholds of subtleness emerging.

Regarding medieval funerary edifice, the most important issue would be the calling to mind of the deceased person's identity and not the remembrance of the precise place where the body had been placed. Funerary edifice and religious art of the time would reflect great skill, subtle expertise and inspiring complexity. Philippe Aries traces the same general attitude towards death from Homer to Tolstoy. Though, he comments on variations of funerary objects evolving during the long medieval ages. By taming death, unprecedented familiarity with the living is celebrated, attaching almost no importance to the place of burial (1977). This variable expression transforms into sensibility currencies of the age up until medieval fascination with the macabre and beyond.

Within this introduction, a shift from vulgate of death to matters of altered attitude may be traced. Today, death arises a whole new era in design, which is subject to thought, responsiveness and unexplored materiality. This paper aspires to dip into the great variety of speculative projects exploring fictional scenarios on funerary conditions. The notion of neo-medievalism refers to emerging mechanisms of re-speculating one's own death. Therefore, it refers to shifting balance between contemporary funerary edifices and mediated emerging rituals.

Based upon extended research on evolving topological awareness of contemporary places of burial, this paper delegates to thematic comparatives between unexplored materiality of human decay and re-contextualization of past funerary concepts. Most of the cases mentioned refer to fragile balances between profound fascination and simultaneous transcending of death's obscurity. It is until the age of scientific progress, no matter how that may be defined, that human beings greatly accepted an idea of continuation, in good grace. That idea allotted a coherent response to mortality, featuring a commonplace throughout classic antiquity. Commensurability between classic ancient coherence and medieval changefulness may

arise as a correlation and potential origin for contemporary imagery.

It is tempting to correlate a 16th century pendant, featuring the double profile of a monk's head, with contemporary edifice. This piece of art is indicative of funerary objects of its time, featuring part of the monk's head with all elements of its living condition and the other part of it featuring its partly decomposed equivalent. In present days, Ulric Colette's work series on genetic portraits form an attempt of assembling similarities between relatives of different age. He is featuring common people heads, half of them featuring facial elements of their young living condition and the other half featuring their aged condition. This correlation of imagery reveals similarities in currents of mortality and established husbandry with death.

In the age of computation, a life-sized, nude self-portrait, rendered from the artist's own bodily fluid, which is fed intravenously to a CNC machine is possible. The question arising is what triggers a contemporary artist to experiment with synthetic processing, using his own blood? Ted Lawson's 'Ghost in the machine' is using technology to achieve organicness into drawing. The artist himself claims that this use of ever-expanding technology is something deeply variable, profoundly diverse and real, instated in the centerness of his work.

Distinct modes: Forming and per-forming matters of death

Extending thoughts on distinct modes of fictional agility on funerary cultures and processes, what is discussed here is emerging versions of designed and fabricated matter as well as the physical substances revealed through a new era of speculative design. A great variety of concepts and ideas are currently bringing forward two cases. These could be divided into a dual aspect of:

- non-organic matter
- organic matter

Within this paper, inorganic matters of death relate to multiple issues and expressions of memory. The second aspect would relate to variable thresholds of matter and mediative processes of interrelation to living entities. The distinction between these two aspects may be far from absolute. Such modes of transition from matter to dematerialisation reflect processes of commutation to essential elements.

Through current urge for death re-contextualisation, precedents and concrete disciplines are being transformed into eco-green care and inventive wrappings of mortality. There are numerous features relating to emerging matters of death. There is wide range of edifice featuring ashes as medium for personification of the descendants' identity. Inventive cadavers are being designed, such as artificial trees, cocoons and capsules. In most of these cases there is provocative breaking of frontiers and unprecedented expanding to a whole new field. There is also revelation of stimulating modes of interaction between postmortem care and natural processes. What we may experience in the near future is unprecedented emergence of rituals featuring vital matters related to death and its venter. Emerging matter involves mourning textiles, which are dissolving while passing time heals, transformation of digital heritage into physical and habitable surfaces, CNC mills transposing generative forms into casting moulds or visions for cadavers slowly going to light with the use of light algae or glow fungi. Someone may also observe conventional places of burial replaced by nebulae of air-travelling capsules causing rain. Such cases trigger a whole new sequence of speculative design, great potential for burial displacement and re-contextualisation of funerary edifice.

Where can the limits of *'synthetic process'*, in this design era, be traced? What is the meaning of *'edifice'*, in the age of computation? These are reasonable questions arising through a handful of examples mentioned within this paper. The distinction between matter as memory and matter as process may relate to variant thresholds of essence and layers of compound. This distinction may establish either static or performative re-personification of death and its potential for morphogenetic agency.

Fifty years after Panofsky's *'Tomb Sculpture: Four Lectures on its Changing Aspects from Ancient Egypt to Bernini'*, there are still researchers quoting that 'tomb sculpture will remain... among the basic works which determine turning points in the history of our discipline'. Both distinctive matters relate to triggering shifts in funerary edifice and cultures. In the case of Janice Wu and Gloria Ng there is a statement about ashes as *'relic of the dead'* finding place in the familiarity of every contemporary home. Their visualization of an hourglass dripping the ashes of the descendant relates to variant layers of memory. Ida Hammarlund and Alyse Sedlock suggest a new type of burial procedure, by taking on distinct earth forms different from that of the pre-existing mausoleum type. *'Fantastic repose'* is their project, under professor Hernan Diaz Alonzo, for an urban burial park evoking new understanding of the experience intended for worship and mourning. Burial repetitive space initiates deformations and transforms into new forms of edifice.

In terms of the second distinctive mode, organic matter relates to variable and differentiated processes associated with natural matter. The imagery presented by Edna Reuveni, is the product of design research on salt. The biodegradable cocoons are designed to contain human bodies and they are made from a combination of kosher salt, rice flour and water. Edna Reuveni has worked on this combination of materials, capable of being moulded for variable shaping, and aiming at certain characteristics promoting eco-design conceptions. In dry environments this cocoon acts as preservative container and in humid environments it starts decomposing together with its content. Luminescent algae memorial sarcophagi and glow fungi memorial chests are evident of emergent behavior towards death and performative rituals of mourning relating to natural matters. Mirjam van Overbeek Eindhoven states that oxygen supplying algae funeral algae can be used variously in funerals. Hollow mold pressed forms can be made of different materials, mixed with human ashes and float for several hours, or slowly wreck in a garden. A special gel with luminous algae (for the case of water environments) or natural glow fungi (for the case of ground environments) can create luminous effect for about a week, in certain environments. Infinity burial project, composed by visual artist Jae Rhim Lee, is a prototype for a body suit, embroidered with thread infused with mushroom spores. This embroidery pattern is a decomposing mechanism. Combination of two parts, one with dried mushroom spores and second with liquid culture medium, potentially activates development and growth of mushroom pattern aiming at engagement with process of decomposition. The team of studio PSK have visualized the project *'I wish to be rain'*, which is an evolution from conventional funerary edifice into types of natural spectacle. Following funeral and cremation, this project literally suggests that a vessel containing human remains and a dormant aerostat may cause rain through cloud seeding.

The nature of death: Mortality in the melting pot

Apparent shifts in expressions of mortality, through emerging concepts for deathcare, embrace advanced tools, modifications and procedures applying certain qualities to eternal edifice and natural matters, as well as engagement with process of decomposition. Michel Pacault, among others, has argued that a very important historical mutation occurred between eleventh and thirteenth century. The manner in which men applied their thoughts to their surroundings and concerns underwent a profound transformation, while mental processes evolved radically (1972). Philippe Aries grasps this important change in the *speculum mortis* (1976). Today, someone may observe computational tools emerging as medium for calling to mind the memory of the descendant, in a variety of unprec-

edented manners. Today, a triggering shift in the way humans express their mortality is becoming widely evident. This shift is both poetic and pragmatic, manifesting an emerging changing of attitudes.

Medieval macabre as correlated to the contemporary expressions of mortality, reveals a precedent for a new familiarity with death. This familiarity is expressed through both distinctive modes.

Conclusions on Dirty Futures: Beyond death ecologies and synthetic thresholds of matter

This paper argued for unprecedented matters of re-invention related to death and human decay. Such a case emerged through diverse highlights of unexplored thresholds of materiality. If our *'microbiome'* extends to our environment, leaving traces in the air and on surfaces evident of our inhabitation, the distinction between matter of decay and its relation to living entities reflects certain cultural and fictional thresholds. In terms of organic matter of death it is interesting to quote Geoff Ward and its points on biomes as reflected to eras of human mortality, blurring the boundaries of what is *'us'* and what is *'other'* (2013).

The diversity of correlations that emerges between human decay and natural processes reflects general and specific focus on differentiated qualities and assets.

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