A COMPUTER GAME TO HELP PEOPLE UNDERSTAND
THE ENERGY PERFORMANCE OF BUILDINGS

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Abstract

The building user plays an important role in determining the energy use of a specific building; user behaviour could be one of the reasons behind the "performance gap" observed in many buildings. Moreover, informed building users can promote the sustainability agenda via their consumer choices. This, however, raises the issue of understanding building performance. This paper presents a gamification exercise which introduced players to the basic concepts of building performance. For this, a software application developed to visualise POE data in a 4D context was utilised. The theoretical framework of the exercise is discussed, and the game mechanics are presented. A pilot study used for assessing and fine-tuning the methodology is presented, followed by the main study. The main study consisted of two workshops with two different user groups: non-experts and entry-level specialists. The workshops are described, and their results presented using both quantitative and qualitative approaches. Findings suggest that the advantages and challenges of gamification described in the literature are generally confirmed by the tentative evidence of this exercise. In addition, the process highlights the potential of novel ways of presenting building data, including 4D visualisation, in enabling more stakeholders to engage with the issue of building performance.

Keywords: Post-occupancy evaluation, Visualisation, Gamification.

Introduction

Sustainability researchers can be confident that their discipline has never enjoyed such widespread attention and been assigned so much importance. The significance of the topic extends outside the Built Environment scientific and technical community, with a number of leading international policy-making bodies, most notably the United Nations, placing it at the forefront of concerns (Lukan *et al.*, 2014). This has been accompanied by a number of subsidies and other policy-making tools to support environmentally-friendly design and other pro-sustainability solutions (Kibert, 2002). In the Architectural, Engineering, and Construction (AEC) sustainability has turned into a key issue in both research and practice, encompassing all fields (Szolokay, 2014; Cruickshank and Fenner, 2007; Ortiz *et al*, 2009). In AEC education, sustainability issues have achieved prominence in many curricula (Wright, 2003; Murray & Cotgrave, 2007), while a range of post-graduate courses in sustainability are widely available in academic institutions across the globe.

However, despite the generally wide support and the amount of resources and brainpower devoted to the issue, the approach described above, which focuses on policy-making and "upskilling" the technical community has not always been able to deliver the intended outcomes. The current practice standard for achieving sustainability, typically relies on

1

satisfying the requirements of specific environmental rating systems, such as the Building Research Establishment Environmental Assessment Method (BREEAM) and the Leadership in Energy and Environmental Design (LEED). However, the adoption of those has been far from complete by the Built Environment: they can be perceived as complex, inflexible, and with issues with regard to the way they attribute scores (Ding, 2008). Even when these methods are applied in full, however, the actual performance of the building might not live up to the one originally intended. The term "credibility gap" was first used more than a decade ago to describe the difference between the design expectations and the actual energy use of a building (Bordass, 2004). Today this has been established as an accepted reality, with the term "performance gap" being the most commonly employed to describe the phenomenon (De Wilde, 2014).

This gap can be attributed to a host of reasons. Firstly, environmental design relies on digital Building Performance Simulation tools (BPS) whose effectiveness and consistency has often shown to be problematic (Schwartz and Raslan, 2013). Nonetheless, other engineering disciplines have successfully addressed similar issues in the past: the twin issue of validation and verification, where the mathematical model used in calculations (validation) and the data generated by this model (verification) meet the required criteria for acceptance appears in the vast majority of methods employed in civil and mechanical engineering (Szabo and Babuska, 2011). This is typically achieved via an iterative process, where the model is checked against existing data. There are, however, two key differences that differentiate environmental design for the built environment from other engineering endeavours.

Firstly, environmental design researchers, on whose work BPS tools are based, lack the amounts of data that are available to other researchers. Only a small percentage of completed buildings are monitored for environmental performance once put in use, usually only when there is specific research interest such as the provision of observational data to provide the basis for descriptive or stochastic methods that can be incorporated in building performance simulation applications (Yan et al, 2015). Even then, these studies are often impacted by various limitations that may limit their representativeness and applicability. For example, monitoring may often involve a limited number of case study buildings, may only take place for small periods of time which may not be representative of seasonal variations or might be subject to a range of technical problems that may impact consistency, accuracy of data collection and the robustness of the analyses, (Swan et al., 2015).

As such, the importance of Post-Occupancy Evaluation (POE) surveys and their fundamental role in closing the aforementioned loop cannot be understated. Menezes *et al* (2012) have shown how they can be used to address the performance gap, while Bordass and Leaman (2005) called for POEs to become a routine part of project delivery over a decade ago. While the benefits are obvious, a key barrier that was identified early on in environmental design research is that most clients do not see a direct benefit from a POE which creates what is referred to as 'fragmented incentives' (Zimmerman and Martin, 2001). From their perspective and in terms of a strictly business view there is no legal requirement to conduct one and, additionally, the results might reveal design flaws that a developer might prefer to remain hidden.

The Role of the Building User

The Issue of User Behaviour

2

A second challenge for sustainability conscious designers and environmental design researchers, is the issue of user behaviour. In the built environment, energy consumption is closely linked to occupant presence, interaction and behaviour. Studies have suggested that the impact of user behaviour on the energy performance of a building significantly exceeds that linked to the thermal process within the building façade and is a major contributing factor to uncertainty of building performance (Hoes et al., 2009). the assumptions made by environmental designers during the planning and design stage often differ widely from how the building is utilised once delivered and put to actual use. For example, research into uncertainty in occupant behaviour in building energy models found that the energy consumption differed by around 150% if the occupant-related inputs were maximized and minimized (Clevenger & Haymaker, 2006) and has highlighted that user behaviour significantly affects energy consumption model predictions, even if other variable such as the weather conditions, the building envelope, and the equipment were well-defined (Yan et al., 2015). The precise reasons for that are unclear and often differ from case to case. Possible reasons include unrealistic assumptions of user behaviour, inadequate building performance, a lack of understanding on how individuals make decisions or simply users lacking an incentive to conform to the design assumptions (Santos Silva and Ghisi, 2014; Gill *et al.*, 2010; de Wilde and Tian, 2009; Bourgeois *et al*, 2006).

The User as Consumer: Insights from other fields

The past two decades, and as the issue of user behaviour progressively achieved prominence, there have been many attempts to educate building users with regard to their energy use (Fink, 2011; Hui, 1999). More recent efforts have utilised digital visualisation in various forms (Boomsma *et al*, 2016; Chen *et al*, 2011). It is interesting, however, that this work has been driven by a desire to educate users as a self-evident good and as disconnected from the design stage. The idea of the building user as a consumer who, when better informed, can influence the real estate market, and thus the design options available has attracted less (if any) attention in the policy debate.

The relatively limited information on a building's post-occupation actual performance, exacerbates a situation that economists would describe as "asymmetric information" between building producer and consumer. 'Asymmetric information' refers mainly to the fact that building developers are much more knowledgeable about the characteristics of constructed buildings than consumers (Akerlof, 1970). The consequence is that 'market failure' may ensue, and mutually beneficial transactions might be lost relative to the full information benchmark (Stiglitz, 2000). The problem has been thoroughly examined in several domains: the insurance industry (Finkelstein and Poterba, 2004), the financial industry (Karlan and Zinman, 2009) and other markets. However, in the construction industry research is lacking, and thus valuable insights from theories of asymmetric information have not been sufficiently utilized (Sorrell, 2003). This neglect contributes to a very undesirable status quo, as inefficiencies stemming from asymmetric information seem to be rampant in the UK construction industry (Sorrell, 2003).

This entails serious policy implications. If asymmetric information is prevalent and consumers are not sufficiently informed about the consequences of their market behaviour, their rights will be insufficiently protected. Producers may generally not have an incentive to provide adequate information and State intervention is required (Milgrom, 2008). In terms of optimal consumer protection regulation, information requirements are preferable to 'direct regulation' (Loewenstein et al, 2013). From an economist's perspective, information is critical both to allowing for personal initiative and enable the

3

smooth operation of a free housing market. However, so far, the main focus of both research and industry has been targeting the supplier side. Considerable effort has gone into research purporting to inform engineers, designers, building developers, and government regulators with regard to the fundamentals of the environmental properties of buildings.

Technology has a large role to play in informing consumers. We posit that sustainability can be greatly enhanced by allowing the consumer to systematically evaluate the relevant aspects of the built environment (thermal comfort, energy use etc.) and to incorporate this evaluation in the purchase decision. This might ameliorate any problems of asymmetric information in the market. We are confident that this may facilitate a 'market-based approach' to the sustainability problem, in the spirit of 'nudging' (Thaler and Sunstein, 2008), rather than a strictly regulatory one. Advocating this approach is based on the principle that, in the absence of externalities, informed consumers can offer valuable insights into which sustainable options should be built, and how. In addition, consumers are more likely to provide suitable guidance for user preferences than regulators. The current state of affairs has a strong paternalistic flavour. It is well-known that excessive reliance on regulatory solutions brings the risk of rent-seeking and lobbying by special interests (Grossman and Helpman, 2001). Moreover, human attention is limited, and some modes of communicating information are more compatible with human processing than others (Loewenstein, Sunstein and Goldman, 2013). Accordingly, simplifying and conveying information in an accessible way can make a great difference to how consumers assess this product.

This implies a fundamental change of view of the user compared to existing approaches: the building user (or other non-expert stakeholder) should not aim to understand simply how his/her choices affect energy consumption for a given building; s/he should aim to understand how different buildings perform given certain conditions. These better-informed users then can, in their function as building consumers, influence the market and thus the environmental design quality of buildings.

The above ambition, however, begs the question how users can be better-trained in understanding building performance. In previous work we have demonstrated how, given certain parameters, 4d in-context visualisation can allow for a better understanding of POE data compared to existing methods, amongst both expert and non-expert users (Patlakas *et al,* 2014). Here we present the introduction of gamification elements for the same purpose.

The Role of Gamification

Gamification as an educational tool

In recent years, gamification, including serious games and ludic simulations, has attracted increasing attention. Applications of gamification have been reported by scholars in fields as diverse as marketing (Huotari and Hamari, 2012), risk management (Bajdor *et al*, 2011), health care (King *et* al, 2013; McCallum, 2012), and software engineering (Pedreira *et al*, 2015). It has received particular interest by researchers in education and training, covering practically all fields: primary (Simões *et al*, 2013), secondary (Attali and Arieli-Attali, 2015), and higher education (Barata *et al*, 2013); e-learning (Muntean, 2011); military training (Arenas and Stricker, 2013); employee training (Landers and Callan, 2011).

4

In the Built Environment, gamification has been of particular interest to researchers specialising in the different facets of architectural computing, often with emphasis on collaborative and participatory activities: Aydin *et al* (2014) employed it in the context of shape grammars for mass-housing design while more recently Savov *et al* (2016) employed it for façade design. Its importance for educating both specialised users and laypeople has also been of interest: Bertuzzi and Zreik (2011) applied mixed-reality games to raise awareness of cultural heritage issues; Chang (2004) employed design puzzles to support design learning and later on Liang and Chang (2006) expanded the concept with the *DiGame* design game. In the more specialised field of environmental design, sustainable energy use has been a focus as described by Gustafsson *et al* (2009) and Coen *et al* (2013). Yan and Liu (2007) have combined it with Building Information Modelling (BIM) elements to enhance sustainable design education.

Assessments of the impact and benefits of gamification are generally positive. Erenli (2013) finds that the gaming industry has had a "huge" impact on society and gamification can contribute effectively to teaching; Kapp (2012) states that the research consensus is largely that appropriately-designed games can be beneficial as learning tools for both games and adults. Others give generally positive, but more nuanced accounts: a comprehensive review of the literature by Hamari *et al* (2014) found that gamification generally does work, however, the gamified context and the qualities of the users were confounding factors that could affect the end result. In fields outside education, scholars have been less enthusiastic: Mollick and Rothbard (2014) found that gamification can have a positive impact on the affective experience of employees, however, it is important that consent and a sense of individual agency is maintained and the games do no stray into the paradox of management-dictated "mandatory fun". Though the authors concentrated on a workplace context, one can easily identify similarities of this caveat in the context of an educational institution, if the gamified processes are a curriculum requirement.

More critical positions exist: most famously that of Bogost (2015) who draws on Frankfurt (2005) to present gamification as a coercive strategy that is not concerned with "truth" and whose successes are largely tautological; he goes further to suggest the term "exploitationware" as a synonym for gamification, in order to highlight the fact that the game designer is trying to extract value by encouraging meaningless engagement. While Bogost's targets largely corporate and marketing gamification (besides a philosopher and academic, Bogost is an established game designer himself), aspects of his critique certainly apply on all attempts at gamification. Particularly relevant is the charge of ambiguity of the term gamification, which can impact on the framework of the game design itself.

Amongst scholars, a precise definition of gamification remains elusive: an oft-cited take describes it as the use of video game elements in non-gaming systems in order to improve user experience and engagement (Deterding *et al*, 2011). The fundamental flaw of this is, however, obvious as it simply pushes the burden of definition to the concept of "game". A highly comprehensive survey and analysis by Huotari and Hamari (2012) found no conditions that can be said to apply uniquely to games. The definition of gamification we have devised for the purposes of this work draws from both Koster (2013) and Salen and Zimmerman (2004), but expands these definitions by including the underlying aim of gamification, acknowledging Bogost's criticism. Specifically we define gamification as:

The development of a system in which players engage in a set challenge with defined rules, aiming to arrive at an identifiable outcome; the underlying aim of the system is for the developers to achieve specific results from the players' engagement, unrelated to the outcome, which might or might not affect the players.

5

Under this definition then, what is required is the development of a suitable system with an appropriate challenge, and the establishment of such rules and potential outcomes that the players' engagement with the system will produce the intended results.

Development of a Building Performance Game

Aim of the Gamification System

Drawing from the definition above, we wanted to engage in a gamification exercise that would produce a number of results that would affect both us as developers and the players. These intended results are summarised in Table 1.

Beneficiary	Intended Result	Objectives
Developers	1. Further undergoing research programme.	a) Gain insights into the respective merits of 2D, 3D, and 4D modes of communication of POE data amongst expert and non-expert users.
Developers & Players	2. Introduction of a new innovative tool into the teaching & learning process.	a) Introduction of the EnViz tool to the process b) Awareness of ongoing research programme of tutors, with possible opportunities for research topics.
Players	3. Further subject knowledge.	a) Introduction to the fundamentals of Decision Support Systems for Environmental Design. b) Better understanding of how environmental design affects performance over the building lifecycle. c) Better understanding of how Facilities Managers have to make decisions.

Table 1: Intended Results from the Gamification Exercise

The requirements for achieving these results are summarised in Table 2.

Action	Corresponds to Objective
• Use EnViz as a key part of the game	2a; 2b
• Compare POE data comprehension in EnViz with POE data comprehension in 2D charts and graphs	1a; 2b
• Use POE data to make judgements on building performance	3b
• Use POE data tools as Decision Support Systems	3a; 3c
• Provide players with a post-game questionnaire to gauge their views on the experience; supplement this	1a

with (optional) small feedback sessions	

Table 2: Action to achieve game results

The EnViz Software Application

The EnViz (Environmental Visualisation) tool mentioned above is a prototype software application developed by one of the authors as part of a research programme. It visualises temperature and relative humidity data in a 4D context of volumetric 3D models over time (Figure 1). The standard usability process consists of: input of a building model; input of data logger output; selection of timescale and time ratio; (optionally) selection of desired thermal comfort criteria. The user can then see static (3D) and dynamic (4D) visualisations of the respective data (Figure 2) based on predefined colour maps. EnViz also supports the introduction of pass-fail criteria (e.g. specific ranges of temperature and humidity) and visualizes the spaces that pass or fail these checks at any given time in the data space.
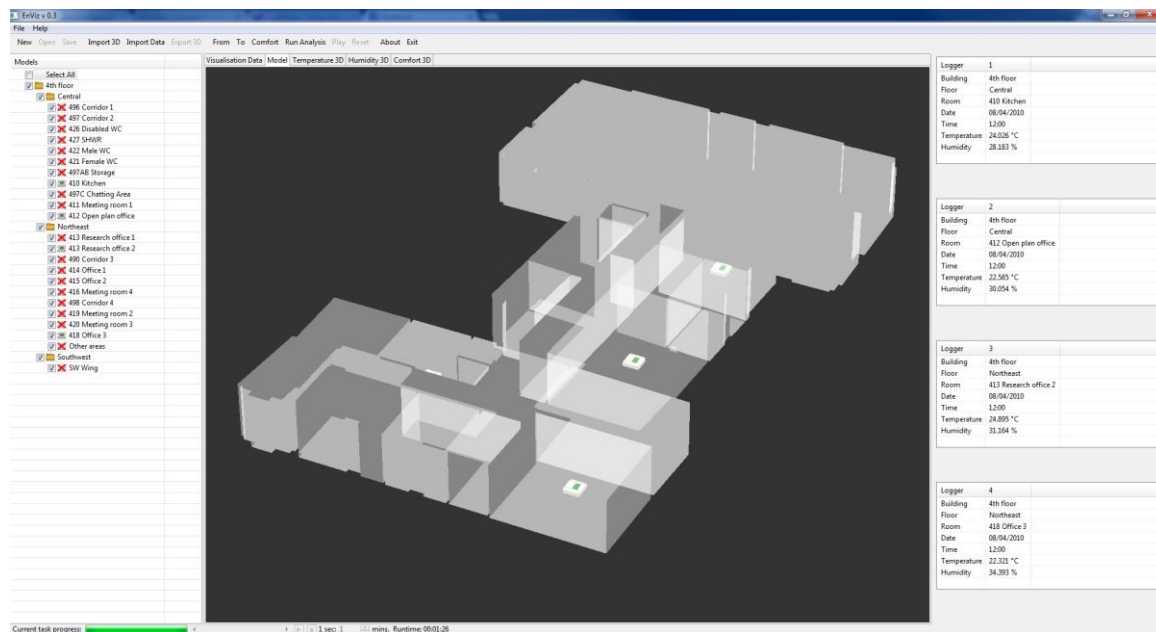

Figure 1: Sample snapshot of the EnViz application, showing the locations of data loggers
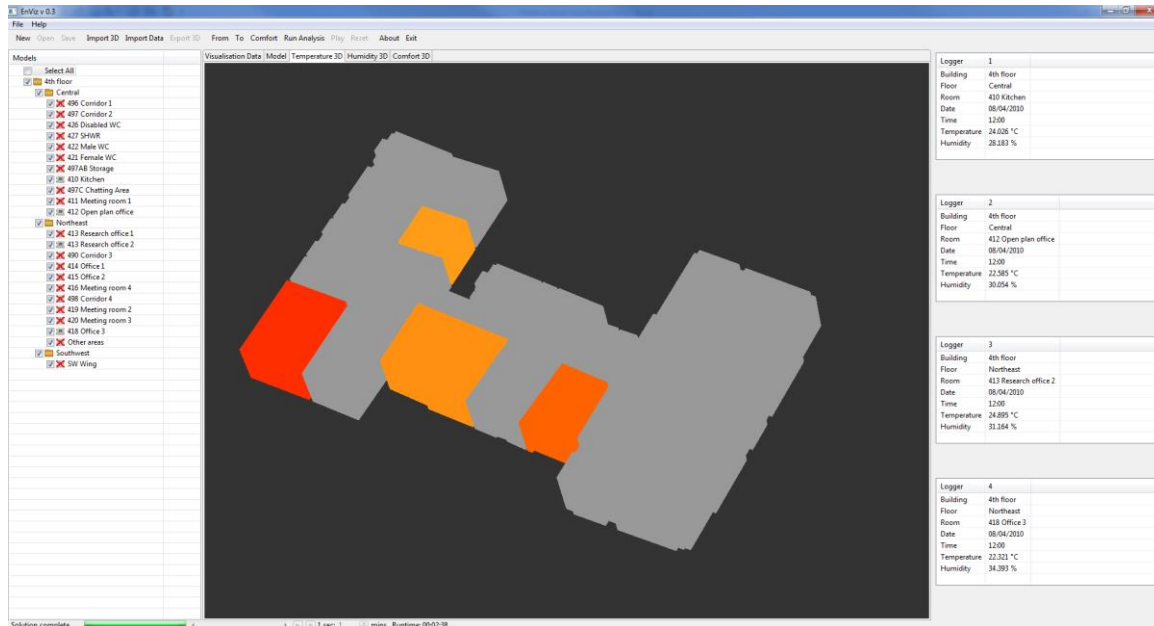
Figure 2: Sample snapshot of the EnViz application, showing temperature of spaces

The application was developed in Java SE 7, utilising the OpenGL programming interface, as implemented in the Lightweight Java Game Library (LWJGL). The model input format is COLLADA, an open-source text-based format for 3D graphics, while the data logger input can be either via XML or directly via Comma Separated Values (.csv) and Microsoft Excel (.xlsx) files.

The tool intends to provide the benefits of large dataset visualisation, including enhancing comprehension, enabling multi-scale evaluation, and facilitating hypothesis formation (Ware, 2012) for POE data analysis. In order to validate the effectiveness of EnViz, a two-year usability testing programme was undertaken. Usability testing is generally viewed as an aspect of Human-Computer Interaction (HCI). A major part involves field testing with non-expert users, ideally with controlled experiments that allow the collection of both quantitative and qualitative data (Te'eni et al., 2007). A typical approach is to measure parameters such as Response Time, Response Accuracy, and Mental Effort (Huang et al., 2009).

The EnViz testing programme involved modelling and testing three different examples of different scales and building typologies. The usability testing was in the form of eight workshops with a total of 89 participants which took place in three venues in the UK and Mexico. The Response Accuracy of the participants was measured directly while the Mental Effort was gauged indirectly via user self-reporting in questionnaires. In these experiment, participants had increased Response Accuracy when using EnViz compared to the traditional spreadsheet form (despite the users not having used the application before), while there was a clear preference in using the application to examine the data, as opposed to using Excel. The results were documented extensively in a journal paper (Patlakas et al, 2014).

Theoretical Framework

8

The theoretical framework we are employing is based on Huang and Soman (2013), who give a detailed method for the design of gamification systems in an educational setting. This method involves a five step process (Figure 3):
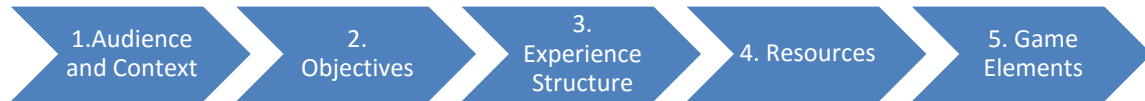

Figure 3: A Process for Effective Gamification of a Concept, adapted from Huang and Soman (2013)

Applying this process to achieve the results described in Table 1, we devised the following process:

1. Audience and Context
The target audience is split in two categories:
- non-experts, represented by first-year undergraduate students in Built Environment programmes.
- entry-level specialists, represented by post-graduate students in an MSc in Environmental Design, who have already received training in POE processes

The context would be the Higher Education (HE) courses that the players would be attending. Taking part in the game would be fully optional without any penalty to students' course assessments / grades etc.

2. Objectives
The Objectives, and the actions via which those would be achieved have been presented in detail in Tables 1 & 2.

3. Structure of the experience
Firstly, the players will be introduced to fundamental POE concepts in a 30-minute seminar, in order to understand the context. This will be followed by a demonstration of the EnViz software with a trial model, in order to be able to use a key environment of the game. The narrative and rules of the game will then be explained. The core gaming activity will then take place. Finally, the players will be asked to complete a questionnaire providing feedback on the two types of activities.

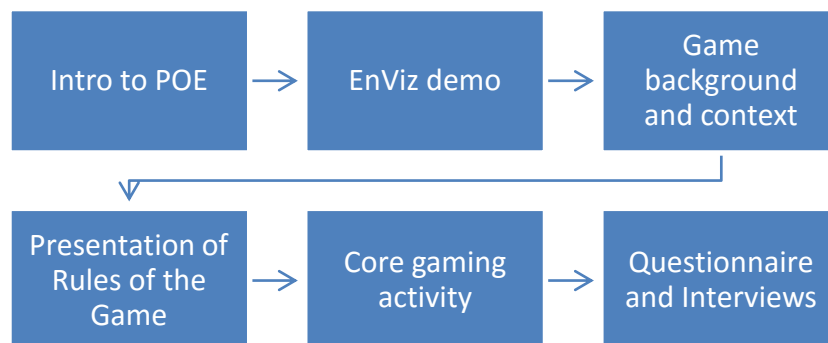The structure of the experience is summarized in Figure 4.

Figure 4: Structure of the Game Experience

4. Identifying resources

The resources available are:

- University PC laboratories with the EnViz software
- Basic programming/scripting (no dedicated budget for a fully developed game)
- Standard stationary

5. Applying Gamification Elements

The game is point-based, devised around a hypothetical scenario, of a simplified real-life problem. Players are provided with sketches of floor plans of a real-world building (Figure 5). They are also provided with POE data in two formats: in the first half of the game, they are given Excel files with the source data, as exported from data loggers. In the second half, they are provided with the EnViz software with appropriate source files.
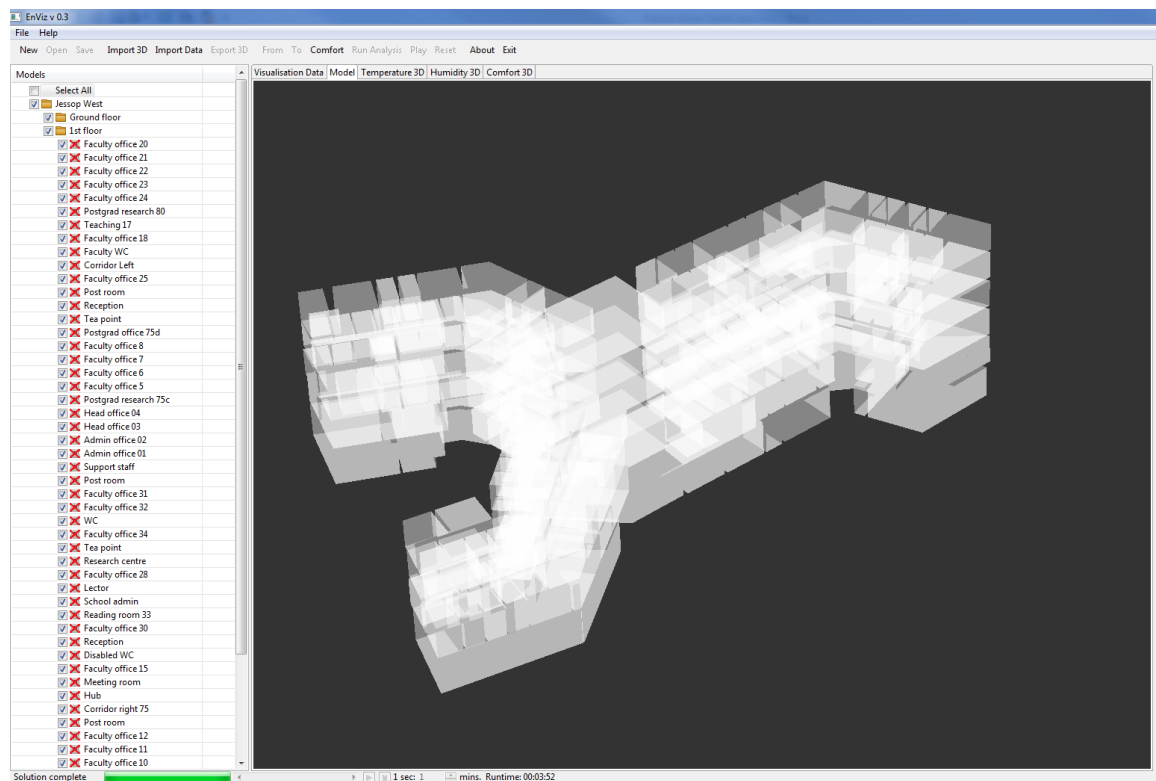

Figure 5: Visualisation of the building used in the game.

Our approach was further informed by the work of Dubbels (2013), who defines three dimensions for gamification analysis. There are Process (story vs narrative); Interpretation (diegesis vs mimesis); Purpose (coherence vs ambiguity). As our targets where highly specific and the gamified domain highly specialised, our game needed to emphasize coherence and guide the player through a structures process. Our choices within Dubbels matrix are summarized in Table 3. The specifics of Dubbels's process are outside the scope of this paper and interested readers are advised to refer to the original work.

DIMENSION	ACTION	
	Story	Narrative
X = PROCESS		✓

Y = INTERPRETATION	Diegesis	Mimesis
	✓	
Z = PURPOSE	Coherence	Ambiguity
	✓	

Table 4: Game analysis using the Dubbels matrix

Further recommendations from Dubbels (2013) which were of interest to us during the design stage involved social interdependence, aesthetics, and the utilisation of Reward-Action Contingencies (RACs). We addressed interdependence via the introduction of a "Hall of Fame" element: top-performing players would have their names and scores publicised in the whole group. Moreover, when applicable, top performing players would receive a very small bonus in their overall course grade for that semester. This would be of a positive nature only (i.e. students who chose not to play the game would not be penalised in their grade and could still achieve 100%), and it would not decide if a student passes or fails a module (i.e. it would be applicable only for a student that would pass the module without it). We were limited in our capacity of enhancing the aesthetics of the basic game environment, due to limited resources, and thus had to rely on what we could build ourselves; however, in this we found support in Kapp (2012) who suggests that the real power of games like in non-superficial elements such as engagement and problem-solving.

Engagement remained a key issue. It is a truism that most players won't finish most games; one estimate has 90% of players not finishing video games due to short-attention spans and a small amount of leisure time in a world with a wide range of leisure options (Snow, 2011). This engagement-driving characteristic, sometimes referred to as "good gameplay" amongst video game designers, however, is usually elusive. RACs appear as a potentially very useful feature, but they increase significantly the need for resources in terms of programming time and cost. As such, in the first iteration of the game we used practically no RAC.

Narrative and Game Mechanics

The scenario given to the players assumed that the given building was found to be problematic in a number of areas. A POE survey was commissioned, in all the areas that were supposed to fail in achieving the standard temperature and/or relative humidity criteria for thermal comfort identified by the Chartered Institute of Building Services Engineers (CIBSE). The players were given the role of a facilities manager whose aim is to "fix" different areas of the building in the best possible way, within the constraints of an allocated budget.

The main rules of the game were:

1. The budget was approximately 25% of what would be required to fix the entire building, and hence the players were required to prioritise the areas with the greatest percentage of failure. Points were awarded based on the percentage of actual failure of an area. For example, if a player decided to fix an area that failed to reach the required temperature 75% of the time, s/he would be awarded 75 points.
2. The cost to fix each area was proportional to its surface (based on area categorisations), and the points awarded were also similarly proportional (if an area was four times as large as the base area category, and it failed 75% of the time,

11

the student would be awarded 75 x 4 = 300 points). Effectively, the requirement of the game was for player to identify which areas performed worse, and prioritise them accordingly.

In the first iteration of the game, areas were also given "importance" coefficients based on their use. As such, corridors were awarded a multiplier of 0.1 (10% of points), secondary spaces a multiplier of 0.5 (50% points) and office spaces and classrooms a multiplier of 0.5. Penalty points were applied to players who went over budget that negated any benefit from breaking the rule; this intended to add an additional puzzle element, requiring the players to focus on optimising their budget use, as well as provide an insight into the choices faced by facilities managers.

The total sum of the points followed the equation below:

$$P = i \times a \times F$$

where:

P is the points awarded
i is the importance of the area (0.0 to 1.0)
α is the area factor (1 to 8)
F is the failure rate of the space (0 to 100)

Pilot Study

A pilot workshop was run at a UK University with 8 first-year students enrolled on a BA in Architectural Technology programme. The students executed both parts of the game and completed a questionnaire recording their views. The results of the pilot workshop were, however, inconclusive. When using EnViz, students performed generally better, however, in both cases most students were heavily penalised for going over budget. Also, some students appeared to ignore completely the importance factor of a space and concentrated on circulation spaces. Thus it was difficult to gauge how effective each method was with regard to response time.

Qualitative feed provided via questionnaires and informal chats after the experiment generally suggested that the students preferred to work with the 3D model than with spreadsheets (despite the students reporting a greater familiarity with Excel than 3D tools before the experiment).

Game Mechanics Redesign

The pilot workshop highlighted weaknesses in the game, corresponding to aspects 1 (Audience and Context) and 5 (Game Elements) of the design process:

   W1. the rules were too complex for the players to understand in a short introduction session, and apply successfully the first time
   W2. the complexity of the point system meant that players spent too much cognitive effort on tasks unrelated to the outcome, and thus the objectives were largely not achieved. The players were "missing the forest for the trees".
   W3. the lack of interactivity (lack of RACs) meant that some players quickly disengaged from the game
   W4. the lack of information about the current budget and the requirement for calculations led to further disengagement; the puzzle element that was introduced as part of the budget did not work for the particular audience

W5. the context meant that the audience still treated this as a type of "university work"; the complexity in the rules and process was treated more as an exercise than a game element

W6. the lack of a "game-like" environment meant that the context was taken further as "work" as opposed to a "game"

Table 5 shows the key modifications that were made to the game mechanics and presentation, and the weaknesses these intended to address.

Modification	Details	Corresponds to Weakness
• Improve presentation	The rules would be discussed more clearly, highlighting to the students that this exercise is unrelated to marks and school-work (positive outcomes only).	W1, W5
• Rules Simplification	The space coefficient was removed. All spaces would have equal importance. The "budget penalty" was also removed (see below) thus significantly reducing the cognitive load for players.	W1, W2, W4
• Game Environment	An interactive game environment was built for logging the points (Figure 4). With this, the players see immediately the area factor of a space, and the cost effects the space has. Thus players could not be over budget. Simultaneously, this introduces a RAC element, as well an allusion to game aesthetics (though both at a rather rudimentary stage).	W2, W3, W4, W6

Main Study

First Workshop

Two workshops were run with the new design. The first took place with a cohort of 12 students enrolled on an Environmental Design and Engineering Masters programme at a UK University. All the members of this group had already taken a semester-long module covering POE, and thus represented the "entry-level specialists" segment of the target audience. The workshop was fully voluntary and took place outside taught modules; as such no extra marks could be awarded for top performers and the incentives for committing to the game were lower. The top three students would have their scores published on the virtual learning environment of the related module. Potentially due to the low incentives to commit to the game, some students did not complete one of the components, did not engage fully, or broke the core rules (e.g. collaborated on one or more activities). All students were nevertheless allowed to remain for the entire duration as the educational benefits for the students were considered more important than strict enforcement of the rules (priority of Intended Results 2 and 3 over 1).
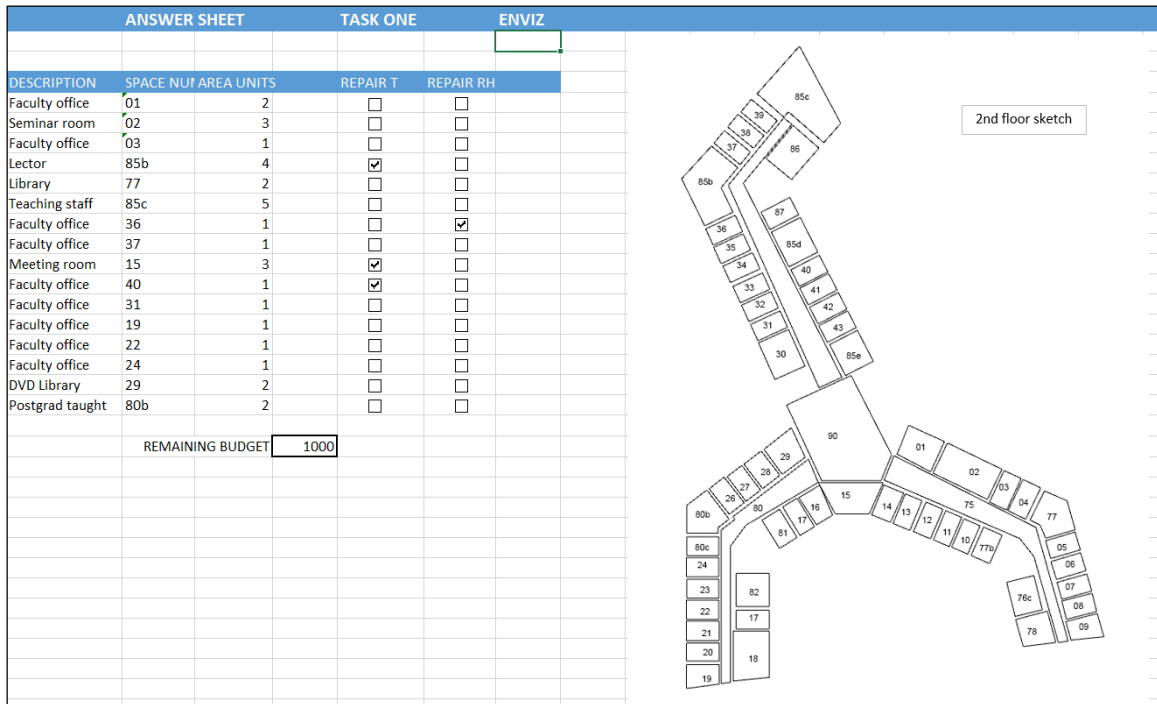
	ANSWER SHEET		TASK ONE		ENVIZ
DESCRIPTION	SPACE NUM	AREA UNITS	REPAIR T	REPAIR RH	
Faculty office	01	2	☐	☐	
Seminar room	02	3	☐	☐	
Faculty office	03	1	☐	☐	
Lector	85b	4	☑	☐	
Library	77	2	☐	☐	
Teaching staff	85c	5	☐	☐	
Faculty office	36	1	☐	☑	
Faculty office	37	1	☐	☐	
Meeting room	15	3	☑	☐	
Faculty office	40	1	☑	☐	
Faculty office	31	1	☐	☐	
Faculty office	19	1	☐	☐	
Faculty office	22	1	☐	☐	
Faculty office	24	1	☐	☐	
DVD Library	29	2	☐	☐	
Postgrad taught	80b	2	☐	☐	
	REMAINING BUDGET	1000			

Figure 6: Snapshot of the interactive game environment given to the students

Among those who completed both components according to the rules, there was a marginally better performance when using EnViz, of approximately 7.5% when comparing averages (Figure 7). Qualitatively, players rated EnViz as a preferred method of work in most categories (Figures 8 and 9). The players were asked to rate the two approaches in the following categories:

- Easy to learn
- Easy to use
- Allows me to identify the required data easily
- Allows me to combine different information easily
- Allows me to evaluate the change over time easily
- Helps me understand how the data is connected to the space
- Helps me appreciate what is actually going on in the building

Finally there was a separate entry indicated as "Satisfied Overall".

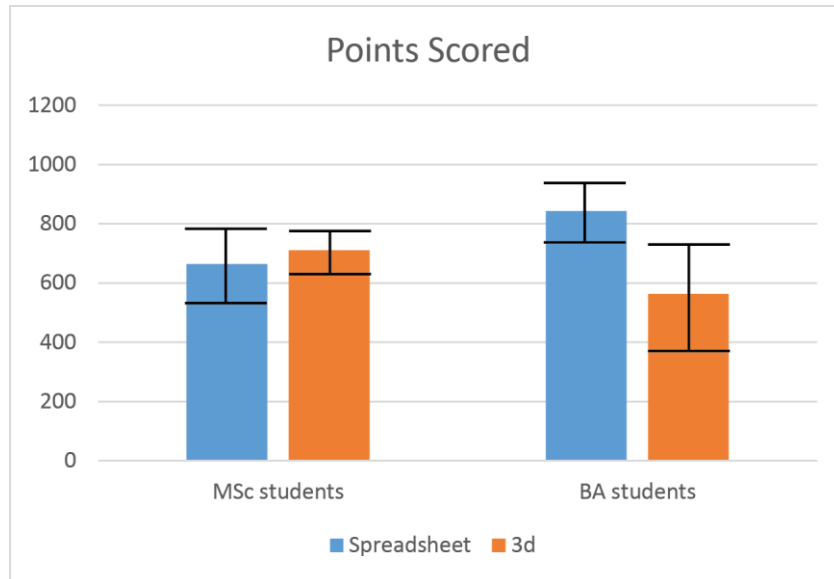The scale was 1 to 5, with 1 being the most negative and 5 the most positive.

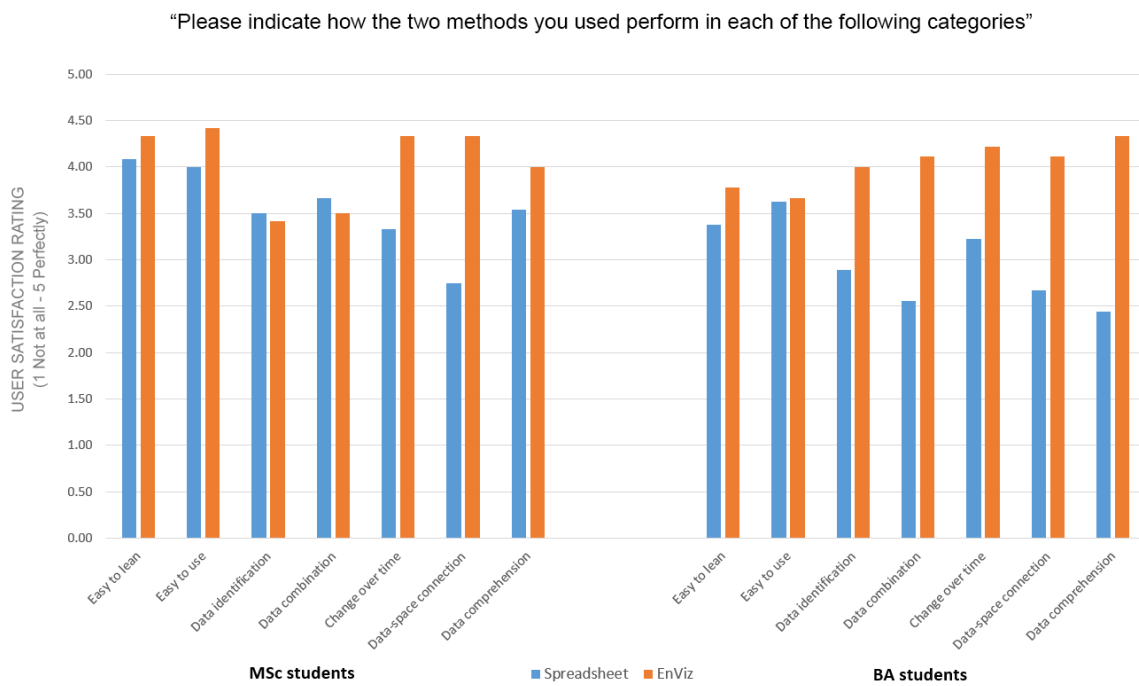**Figure 7: Points scored by each student group (Average with Standard Deviation)**

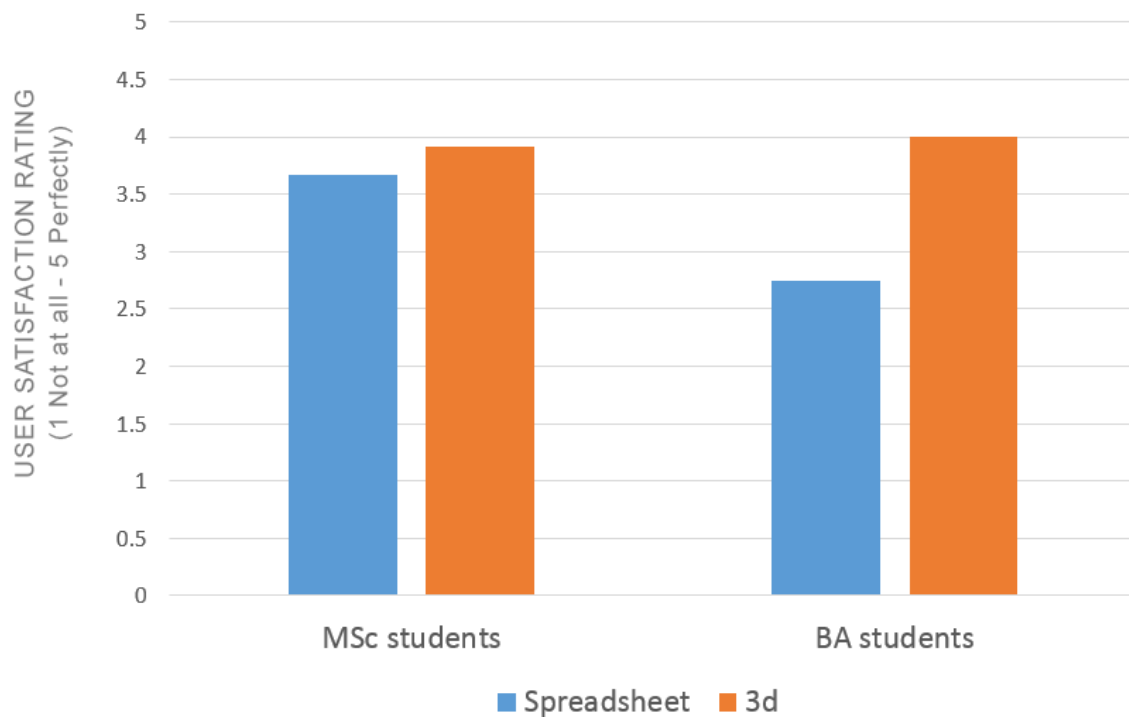**Figure 8: Ratings players gave on the two types of systems on different categories.**

Figure 9: Overall rating the players gave to the two approaches.

Second Workshop

A second workshop was run with a cohort of nine BA students (first year Architectural Technology), who represented the "non-experts" segment of the target audience. The brief rules, and game environment were the same as in the first workshop. Issues of engagement with learning the software were reflected on the results, with two students not completing one or both tasks, while three more scored very low when using EnViz suggesting that they did not engage with learning the software (something visible during the workshop). As a result the average scores of the students when using EnViz were significantly lower (33%) (Figure 7). All students were more familiar with Excel than 3D modelling, which could thus influence the results. However, when it came to evaluating the two applications, all students rated EnViz more highly than the spreadsheet-based method, while they found that it allowed them to work better in all aspects (Figures 8 and 9). It should be noted that these opinions were expressed anonymously, in order to allow students to express their views candidly.

From a teaching perspective, while there were issues with engagement in learning the software, which affected performance, as discussed above, it is important to note that most students appeared to enjoy the activity. The undergraduate students that completed these workshops as part of a taught module appeared to have a better grasp of POE compared to students from previous years, as evidenced in end-of-year assessments. They have also talked favourably about the activity in informal discussions during the year. As the sample is very small, and the results of the POE segment fall within a greater report, a quantitative study was judged to be of little importance and benefit. Accordingly, the results should be viewed as tentative, and replications with larger sample sizes and stronger financial incentives (Smith, 1982) are needed to establish their robustness and validity.

16

This is especially so, given current research indicating that new empirical results should be viewed as tentative (Open Science Collaboration, 2015; Maniadis et al., 2014).

Discussion, Conclusions, and Directions for Further Research

This paper presented the development of a simple building performance game. The results from the gamification of this process were intended to affect both the players and the developers. The players were intended to understand better issues relating to building performance, POE surveys, and facilities management, as well as be introduced to the research agenda of the developers. For the developers, the objectives covered both the above teaching & learning aspects, as well as collecting evidence with regard to gamified processes.

The experience demonstrated both the advantages and challenges of gamification, in agreement with the experiences reported in the literature. The development of the game, informed by Huang and Soman's (2013) system allowed for a straightforward transfer of building performance concepts to a gaming experience.

The main advantage of the game approach appeared to be a generally greater interest from the students in the topic. It is characteristic that most students engaged for a 90' period in a topic which, when delivered in seminar form in previous years, did not appear to hold equal interest. The event also appeared to be more memorable to the students, probably due to the difference in format from the more standardised teaching & learning activities they covered in the rest of the year.

However, gamification should not be viewed as a panacea. The pitfalls identified by Kapp (2012) appeared to apply in this case as well. The game needs to be carefully structured to avoid overloading the students with information (as in the pilot study), and be entertaining and intuitive while still enabling students to achieve the learning objectives. The use of RACs, as highlighted by Dubbels (2013) is fundamental in order to keep players engaged. It is telling that the introduction of even a rudimentary RAC element in the main study considerably improved the players' engagement and capacity to complete the work compared to the pilot study. It is, however, important to highlight the game development overheads this places on the party that wants to set up the gamified process. No individual researcher or HE teacher is likely to have the resources required to design a game that approaches the state-of-the-art in other industries, especially the entertainment one. One way to address this could be the pooling of resources amongst researchers and/or institutions to develop one game, applicable to all. This, however, runs contrary to the approach typically adopted by the research and HE communities and, as such, might not be feasible in the near future.

Player engagement is a key topic in all types of games, but more so for gamified process. In our exercise, while gamification did appear to lead to greater engagement, some students still appeared to need appropriate incentives to commit fully. In pedagogical parlance, students are often "strategic" in their choice of engagement with a topic, and thus at least some will not engage with something not tied to assessment. The financial incentives suggested by Smith (1982) which have been widely adopted by Social Sciences researchers could be a good first start. This, however, could create a controversy with regard to this still being a game and not simply a ludic simulation. However, technical topics with a teaching purpose might by necessity fall in the grey area between ludic simulations and "true" games.

17

A different intended result of the gamified process was to allow comparison between the spreadsheet-based and the 4d visualisation methods; in this case it was only partially achieved. The small sample, the different student profiles, and the different levels of engagement meant that the results were different and with significant standard deviation. Thus, the Pilot Study and the First Workshop seemed to largely follow the results of the more rigorous surveys reported above. The Second Workshop, however, showed that most students did not engage with the visualisation software sufficiently to enable direct comparison. This is to be expected to an extent; despite the conversation of the so-called "digital natives" in recent years in the pedagogic community, software fatigue appears to be a phenomenon across almost all age brackets.

It is interesting, however, that all students preferred working with the 4d visualisation method, irrespective of their degree of attainment, which also agrees with previous studies. This tentatively suggests that there are potentially significant benefits in visualising large datasets from buildings in creative and innovative ways, enabling non-specialists to engage with them more easily. If the aspiration of POE studies becoming a standard part of the building process is going to be realised, its outputs should be easily communicable and comprehensible by all stakeholders, and not just the domain of specialist practitioners.

The overarching objective of the EnViz project is to examine whether 4d visualization improves the quality of decisions that influence environmental properties of buildings. One line of enquiry we're considering is to examine the effects of gamification when some methodologies from behavioural disciplines such as experimental economics are introduced (Smith, 1982). In particular, offering financial incentives for good performance could increase cognitive effort and improve commitment to the game. Furthermore, ensuring a sufficient power of the experimental design by increasing the sample sizes will allow for formal statistical analysis and thus produce more robust results.

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18

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20

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