Serious games for integral sustainable design: level 1

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Abstract

The use of videogames to provide engaging learning contexts known as serious games has emerged over several years and has proved effective in many contexts, but has minimal uptake in sustainable design education. We present a project that explores how serious games may be utilized to introduce Integral Sustainable Design (ISD) which proposes a holistic approach, where there is equal emphasis on quantitative performance and qualitative evaluation. A targeted review of relevant serious games precedent and theory is discussed, which informs the specification of three game levels that provide increasing degrees of challenge, choice, collaboration and context. In conclusion we document the completion of level 1, along with an outline of further work.

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1. Introduction

We provide an overview of a project that explores the use of serious games for sustainable design education and document the rationale and features of stage 1 of the project, a 3D simulation game set in a non-realistic landscape. We must emphasize from the start, that our intent is to provide a fun, abstract learning space with ‘rule of thumb’ performance feedback on design decisions and is not intended to provide the accuracy of scientific simulation or the vivacity of photo-realism. Another distinguishing principle is that the project is informed by Integral Sustainable Design Theory (ISD), which proposes a holistic approach to sustainable design, integrating qualitative as well as quantitative perspectives [1]. The target audience is first year architecture and design engineering students, with the primary learning objective being to provide an engaging introduction to ISD principles. In particular, the integration of performance measures and qualitative evaluation, viewed from individual and collective perspectives. A secondary learning objective is to introduce students to the principles of parametric design, where multiple design
iterations can be generated from associative geometry. The aim is to develop serious game environments that enable students to adjust design parameters for typical building configurations, with real-time feedback on design permutations and asynchronous qualitative feedback from their peers. Our proposal can be thought of as a scaffolding application that introduces ISD principles in an engaging way, as a precursor to designing with professional parametric design and environmental simulation software.

The project is grounded in a targeted literature review of serious games, providing a condensed overview of activity, evaluation of their effectiveness and precedent for their use for sustainable development and design education. We then articulate the learning context, introduce ISD and from this determine the learning objectives for the project. From here we introduce the basics of game design, through a discussion of serious game characteristics in relation to integral sustainable design and design pedagogy in general. This overview is complimented by our previous experience with using game engines for collaborative virtual environments and a discussion of flow theory, which is considered within the literature of serious games as an essential requirement for producing an engaging experience for learners. In the next section, we specify three game levels that become increasingly sophisticated.

Level one explores a game world that is a balance between non-realistic graphics and a quasi-realistic design scenario, based on designing simple orthogonal buildings in an evocative landscape. The emphasis is on realizing and evaluating a graphic environment, game logic and design interface that meets the essential requirement for a game to ‘flow’. Level two will extend the parametric design tools, introduce more performance measures, and differentiate environments in terms of climate and weather. The emphasis for this second level is on enhancing the range of geometry, materials and environmental feedback in a range of contexts. The ambition for the third level is to extend the single player mode to provide a collaborative learning environment for architectural and engineering students. The aspiration is to have small teams of architectural and engineering students competing against the game logic and each other, and in the process developing their discipline specific skills and ability to collaborate to achieve shared objectives, foregrounding their professional roles. The final section of this paper graphically documents the implementation of level 1. This first working game level enables the design of simple orthogonal buildings set in undulating terrain in a temperate climate; where the design parameters are location, orientation, proportions, fenestration design and material specification.

2. Serious games and precedent within sustainable design education

The original use of the term ‘serious games’ lies with US researcher Clark Abt who designed games with “an explicit and carefully thought-out educational purpose” - in his context the deadly serious simulation and role playing of the cold war scenarios of the 1960’s [2]. Since this generalist definition, there has been a range of activity that aligns ‘learning and play’, which include educational games, edutainment, instructional games, games for learning, and synthetic learning environments. The presumption behind these various takes on combining an educational agenda within a game context, is that learners will be more motivated. However early versions of edutainment and instructional computer games, have been described as combining mere practice and drill with token aspects of play [3]. Charisky argues that just as entertainment games have become more sophisticated, games with an educational agenda have developed substantially [4]. The re-emergence of the term serious games in the last several years is aligned with game environments and interfaces that deliver levels of engagement present in successful entertainment genres. Serious games are now established mechanisms for education and training in public policy, education, business, healthcare and the military. Their production is now a significant part of the games industry and game studies is a burgeoning field of research within academia. This second coming of serious games as it were, is typically based on much more engaging elements that exploit the essential characteristics of play, which include competition and goals, challenging activities, choices and an element of fantasy [5].

Parallel to the increasing sophistication of game production, has being the evaluation of their educational effectiveness. Boyle et al [6] have updated a previous review undertaken in 2012, to analyze the effectiveness of games for learning, which collates research outcomes for the period 2009-2014. Using a rigorous quality assessment matrix they located 71 studies that reported empirical evidence across multiple disciplines with Science, Technology, Engineering and Maths (STEM) the most numerous, closely followed by the health disciplines. Their analysis reveals a number of empirical studies that evidence serious games lead to better knowledge acquisition and positive behavioral change. The dominant types of games were found to be simulation and role playing games,
which provide “virtual activities and procedures that reflect or replicate those required in the real world, frequently using compelling environments” [6, p.187]. While the authors of the survey noted that a more comprehensive analysis of specific game features was needed, the general consensus is when they are well designed as “compelling environments”, learner engagement and educational effectiveness is significantly improved when compared to traditional knowledge and skill acquisition.

While most activity has being within STEM and health subjects, there are a number of serious games that address sustainable development. Katasaliaki and Mustafee [7] have undertaken a detailed survey of such games and associated academic articles up until 2011. They preface their survey with a discussion of the perceived advantages for education in terms of (a) simulating real world situations with minimal cost or risk (b) development of skills such as analytical, spatial and strategic thinking (c) improving problem recognition and decision making, and enhancing social and negotiation skills (particularly when play was collaborative). Their survey locates 24 serious games and 11 academic papers that specifically address sustainable development. The majority of games address climate change management and energy management, with four games on sustainable urban development. All of these urban games are versions of the ‘SIM City’ genre where the player role plays the development of a metropolis with the goal of managing growth and environmental impact through the careful allocation of resources. The survey and subsequent searches by the authors located only one game at the scale of architecture, commissioned by the Scottish government which enables material choice to build a sustainable house within budget.

3. Educational context and learning objectives

While the Katalsaliaki and Mustafee survey reveals a degree of activity within sustainable development, there would appear to be a lack of examples that consider an architectural scale and foreground design as central to the gameplay. The context in which we are interested in serious games is undergraduate education in architecture and design engineering. Like most educators we have access to commercial CAD and BIM software and a range of environmental simulation software. Typically this software is introduced in specialist second or third year subjects as the complexity requires a structured introduction. Moreover these subjects have little direct connection with the design studio, and as a result there is minimal integration of simulation software except where explicitly required by a tutor. This problem of integrating design and simulation software at the early stages of design is well known both in academia and in practice [8] [9]. More often than not, environmental performance simulation and other information analysis that is crucial to the design of sustainable building is undertaken after key design decisions on orientation, 3D massing, materials and fenestration have been decided. A second issue that is challenging for built environment education is the typical separation of disciplines and the emphasis on individual decision making. This is at odds with professional practice where the uptake of BIM and parametric design software are transforming disciplinary collaboration and design practice. BIM, if used to its full potential, requires collaboration between architecture and engineering disciplines throughout design and construction, while thinking explicitly in terms of design parameters, shifts activity from discrete design modelling to that of developing multiple design iterations from a generic model. We are interested in addressing these issues: how might we introduce the principles of sustainable design and the shift to parametric design strategies - in an environment where architectural and engineering students can collaborate?

Before addressing the above question, we introduce Integral Sustainable design (ISD), which underpins the approach and motivation for our serious game project. This alternate theory of sustainability integrates qualitative and quantitative parameters in building sustainability evaluation. Since the built environment in all its forms is probably the single biggest contributor to the increased human impact on the planet, the importance of building sustainability evaluation cannot be overemphasized. However, most of the evaluation methods e.g. GreenStar, LEED and BEEEM focus on quantitative (measurable) parameters. While the importance of qualitative parameters is usually acknowledged, a lack of qualitative methods to evaluate parameters such as aesthetics, inspiration, history and context is evident. An alternative and refreshing theory that brings a new perspective to the thinking about our built environment and one that might guide our future actions is ISD. This suggests that four simultaneous views on a problem can be represented by quadrants, which locate qualitative evaluation and quantitative performance from both singular and collective perspectives (Fig. 1).
ISD seeks to overcome the ‘art vs science’, ‘design vs technology’ and ‘analysis vs creativity’ thinking that has dominated the design disciplines for the past decades. Although it acknowledges the intention and worthiness of environmental rating schemes such as LEED, it proposes the objective-only approach requires balancing with subjective values of sustainability. While most rating schemes are based on a top down approach, which clearly defines benchmarks and assessment criteria upfront and provides the designer with a ‘tick list’ of criteria to work through, ISD represents a bottom up approach. The intention is to visualize or map the project from four different perspectives of ISD so that the designer is aware of what the project currently represents. Rather than telling the designer what should be done, and in doing so to some degree taking the responsibility off the designer, ISD emphasizes the responsibility of the designer for decision-making.

Returning to the issues that concern us in the education of the next generation of built environment professionals, we propose that serious games may provide an engaging methodology to evaluate and introduce ISD principles. As indicated above, the context is the early stages of design where the complexity of parametric design, BIM and simulation software is a barrier for students at this early stage of their education. In summary the educational objectives for our serious game project are as follows. (1) Introduce Integral Sustainable Design principles: embed real time performance measures to give feedback as design ideas are being explored; embed measures to map relationships with existing context and ecological systems; enable qualitative evaluation of individual experience; enable qualitative evaluation of social interpretation. (2) Introduce parametric design including: simple associative geometry libraries to enable real time experimentation with design permutations; sophisticated materials that embed performance measures; and intelligent physics comprising typical engineering assemblies.(3) Facilitate collaboration between architecture and design engineering students including: shared real-time networked design environment; and real-time and asynchronous communication.

4. Serious game design basics

A classic issue for serious game production is that it requires domain specific knowledge to locate and specify appropriate learning objectives, and knowledge and skill in game design. As experienced architectural design educators, we are reasonably confident the learning objectives outlined in the previous section provide a sound starting position and within our research group we have excellent graphics and programming capability. However, our knowledge of what makes a game well designed in terms of engagement and play is relatively limited. In order to address this we have undertaken an extensive literature and game review, which in the context of this short paper we can only highlight the issues most relevant to our project and discuss some of the parallels with design education.
As noted in a previous section, contemporary serious game design aspires to transcend the ‘practice and drill’ of early instructional games by incorporating many of the play elements present in successful entertainment videogame genres. All games, be they analogue or digital typically include the following characteristics: competition and goals; rules; challenging activities; choices; and fantasy elements [10]. Competition can take a variety of forms including: between the user and the game, against other players, team based competition, against the clock and may include elements of chance. In many commercial games competition expands beyond simple win-lose scenarios to provide multi-faceted pathways and many levels of achievement. These often involve setting and completing a number of sub-goals, which enables levelling up to more sophisticated environments and challenges. Charsky highlights that this approach to game design “does not solely exist with achieving victory but is coupled with negotiating difficult situations, analyzing feedback they receive, and applying this analysis to new, yet similar, situations” [4, p.182].

The second game characteristic – that competition and goals operate within rules – has strong parallels with the open-ended context of design studio pedagogy. Rather than hard and fast rules, the more effective serious games provide a framework of constraints with degrees of flexibility, which “allows learners to explore the game space, test hypothesis, and fulfill goals in a variety of unique, sometimes unpredictable ways” [4, p.184]. This aspiration for serious games, aligns directly with the learning context of the design studio. Typically students will deliver multiple design solutions when presented with the same design learning context, and in the process learn a range of strategies that can be adapted for subsequent design challenges [11].

The degree of choice within a serious game is also discussed at length by Charsky, who considers how within a game choice can be expressive, strategic or tactical [4, p.185]. Expressive choice is the control given to the player over the aspects of game customization that increase player engagement. These choices, such as customizing the appearance of an avatar or selecting a geographic location to start a game, may have minimal relationship to learning objectives but can significantly enhance motivation. This increased motivation is ascribed to the building of empathy of the player-learner with elements of the game that they can personalize. By comparison, strategic choice has a direct impact on the way a game is played. A typical feature of successful entertainment games, is to allow the user to set the degree of difficulty prior to play or by ‘levelling up’ during game play. This enables the player-learner to scaffold their knowledge and skills as they increase, optimizing the degree of challenge that is central to both game play and learning. Other strategic choices that can be embedded include setting time limits or the number and frequency of unknown ‘events’ that might interrupt game play. The third aspect of choice concerns gameplay tactics, where there may be branching mechanisms such as different worlds and challenges. This allows learning objectives to be explored through multiple scenarios, each of which can emphasize different aspects or provide alternate challenges. This allows the setting of generic goals, but empowers the player-learner to choose from a range of pathways towards their achievement. In summary, this tripartite understanding of providing choices provides a useful framework that can inform the structure of a serious game for sustainable design education.

The level of learning challenge and how this is balanced with engaging play, comes into focus when considering the last characteristic of games, the element of fantasy present. Charsky distinguishes between exogenous, “reinforcement for correct behavior or response” and endogenous fantasy elements that “are just not a reward, but help develop the gamer’s knowledge” [4, p.190]. Central to both are the crucial issue of fidelity and context. As most serious games are simulations, the degree of fidelity is important, with Charsky arguing realism versus abstraction (fantasy) should be related to the domain specific need for an authentic learning context. For our project, where we are introducing the basic principles of ISD, parametric design techniques and the collaborative context of practice as a precursor to using professional design software - we would argue that the photo-realism of contemporary rendering or the complexity of a BIM interface is inappropriate. Rather, the challenge of the project is to find the balance between representations that are appealing ‘fantastic’, but have a level of correspondence to real world situations that align with the challenge of design. Other serious games theorists have reframed fantasy with the less contentious term decorum [10]. This refers to fun elements not necessarily directly related to the educational objectives, including the crucial importance of the simulation aesthetic, which enables interacting with the game world and interface to be pleasurable experience in itself.

In summary competition and goals, rules, choice and decorum provide the characteristics that separate contemporary serious games from previous instructional games. The use of a fun game context to introduce sustainable design principles, could be interpreted of trivializing the importance of hard data on building performance. Alternatively, and this is the proposition that underpins this project, real time feedback on performance alongside qualitative evaluation from peers within the context of a game, can potentially provide an engaging introduction for students who are of a generation fluent with contemporary videogames.
5. Game genre and the importance of flow

The above synopsis of the characteristics of engaging serious games provide a series of desirable attributes and considerations for the project. We also need to decide what genre would be most appropriate. As noted in the review of serious games precedent and theory, most serious games fall into the category of simulations and given our learning objectives we have decided a ‘sandbox simulation’ would be the most appropriate. A sandbox game provides an open world where users perform a task or respond to a challenge that embeds learning objectives [7, p.5]. Typically there is no explicit narrative, rather the game embeds competition and goals as the primary play elements. Central to player-learner engagement within such open worlds is the decorum of the game – the aesthetic of the world and the interface, including providing empathetic avatars and AI entities. Our previous experience with designing such open sandbox worlds for architectural design studios, albeit these were without explicit game elements, has also impacted on our approach. In a succession of design studios we located significant advantages of designing within an open video game world: the fluency of editing in real time encouraged experimentation; sound became an effective way to convey materiality and functional use; designing within a simulated world reinforced the physical context; students could evaluate spatial sequences from a sense of occupation, which challenged object based thinking where architecture is conceived as sterile geometry. There were however also significant problems: constraints on the geometry scale and complexity; the specialist technical skills required to create convincing real-time models and contexts; and when the novelty of working in ‘game space’ wore off, we found students were less engaged and hence less motivated to overcome the technical complexity [12].

This previous experience, the learning objectives and our target users suggests our sandbox design simulation will need to be self-contained with all design tools and evaluation embedded in the game, and be graphically engaging. More than anything, we need to ensure that the game will ‘flow’. The concept of flow was developed by Mihaly Csikszentmihayi in the 1960’s to describe the phenomena of “intrinsically motivated activity” characterized by intense focus, distortion of time and experience of an activity that is in itself intrinsically rewarding [13]. Flow has been used extensively in game theory, and has been explored in depth in relation to serious games. Kiili et al [14] compare flow to the related concept of immersion, arguing that flow is a more appropriate for an educational context. Flow is reliant on clear goals, immediate feedback, playability and a sense of control in relation to tasks and the artifact (in our case the design and its environment). Providing the right degree of challenge such that the player can immediately have a sense of achievement, but with an increased degrees of cognitive problem solving as knowledge and skills increase. Flow state is a heightened level of engagement with the game, “not with the expectation of some future benefit, but simply because the doing itself is interesting and fun” [14, p.85]. The consequences of achieving good game flow are increased learning and more exploratory behavior, which for design should ideally lead to iterations that explore the impact of design options on ISD performance.

6. Game level specification

The logistics of producing a sandbox simulation game that approaches the degree of game flow and features of commercial games is not to be underestimated. Our approach is to break our overall objectives into three game levels where player-learners are introduced to the game with increasing degrees of challenge and choice. As illustrated in Fig. 2 these are mapped to the aspirations of ISD to encourage designers to make choices that provide a balance between an increasing number of quantitative measures and qualitative evaluation criteria. Each level also increases the breadth and depth of the research agenda: for level 1 the emphasis is on designing the world look and feel, goals, feedback, playability and the balance between challenge and sense of control that enables the player-learner to achieve an engaging flow state; level 2 provides more choice and challenge and the research will explore how effective the game flow is in realizing learning objectives; while level three will have an emphasis on developing and evaluating game features that support collaboration between teams of architecture and engineering students. Also listed are the design tools and interface functionality that progress from very basic geometry, material properties, editing and scoring to a reasonably broad set of features. Care has to be undertaken that this increasing set of design, editing and simulation features does not end up replicating CAD and BIM interfaces. While functionality will be sophisticated and reasonably accurate, this needs to be presented to the user in as an intuitive and fun interface as possible. For example, we are conceiving low level AI functions such as way finding algorithms and cellular automata as smart ‘enviro-pets’, cute creatures that will help evaluate aspects of the designs and whose presence become part of the scoring agenda, in the process helping achieve game empathy with the player-learners.
7. Level 1 Implementation

The level 1 features listed in Fig. 2 above have been implemented. The overall theme of level 1 is captured by the name – Lowpoly – where the game graphic is deliberately abstract and the design interface is minimal (as illustrated in Fig. 3). The aim is to provide a balance between abstraction and a simulation scenario that enables students to explore the implications of siting, orientation, building proportions, fenestration and materials. An interactive tutorial introduces players to the game objectives, design interface and scoring mechanisms. The game is networked to an online database that store and anonymously manages player designs and the leader board. As illustrated in Fig. 4 the goal is to design a simple orthogonal building using a parametric model that automates the placement of windows and incorporates accurate shadow projection. The user can switch between spring, summer, autumn and equinox and set animation speed to evaluate daily sun trajectories as they are designing. Quantitative feedback is updated in real time and communicated through three dials (lower middle of Fig. 4). These dials provide feedback on building efficiency (ratio of floor area to wall area), material cost (based on building size, percentage of glazing and choice of cladding), and a calculation of daylight penetration (based on shadow projection for four equinox positions at early morning and late afternoon). As illustrated in Fig 5 the intent of the sun calculations are to give ‘rule of thumb’ feedback on the impact of changes in fenestration, building siting and orientation on sunlight penetration into the building.

Once a design has been tuned to balance efficiency, material cost and sunlight the design is saved and in the process the player frames the best view of the design in relation to external appearance. This makes the design available to other players from a design review interface that ‘teleports’ the reviewer to the saved view where they evaluate external appearance of the design. Once this is recorded, the reviewer is then teleported inside the design where, as illustrated in Fig 6, they evaluate how well windows frame external views and the spatial quality of the design. The graphics of the rating interface are similar to social media interfaces that capture the collective view of anonymous users (players are not able to rate their own designs). These qualitative evaluations of the ‘crowd’ are combined with the measures of building efficiency, material cost and sunlight penetration to give an overall score and ranking on a leaderboard (Fig. 7). For a player to improve the ranking of a design typically there needs to be a balance between quantitative performance measures and the qualitative aspects of the design as evaluated by the collective, mirroring the approach of integral sustainable design.
Fig. 3. Level 1: Overview of game world and interface

Fig. 4. Level 1: (a) Parametric window interface (left) (b) sun position and animation settings interface (right).
Fig. 5. Level 1: (a) Matrix showing impact of orientation on daylight score (left) and impact of siting (right).

Fig. 6. Level 1: (a) Qualitative scoring interface for framing of views (left) (b) spatial quality (right).

Fig. 7. Leaderboard based on combination of qualitative and quantitative scores.
8. Conclusion and further work

Integral Sustainable Design provides a holistic framework for architectural design education, aligning well with the open ended agenda of design studio pedagogy where the emphasis is on iterative explorations and the weighing up of a range of performance criteria. In a parallel field of research, serious games have developed a similar aspiration to provide open, explorative learning contexts that leverage from proven approaches to learner engagement. Our project uses this precedent from serious games to inform a networked 3D game world intended to provide an engaging introduction to ISD for undergraduate architecture and engineering students. After a review of serious games literature, we have developed a three stage implementation plan that will produce multiple game levels that offer increasing levels of challenges. The first stage has been implemented and the outcome is a playable game called ‘Low Poly’, which provides rule of thumb measures of performance alongside a review mechanism that capture the qualitative views of the player collective. The game is currently out for beta testing and we are receiving both informal feedback and in-game activity tracking that collates data on player behaviour. Initial feedback is positive, in particular in relation to the decorum of the game and the production quality.

The beta testing is informing some refinement of the modelling interface in preparation for use of the game as part of a sustainable design studio involving 140 architecture students and an engineering design foundation class of 200 students. Data from these user trials will be collected via two anonymous methods: (a) in-application tracking of time, type of activity and user scores against quantitative and qualitative criteria, which individual participants generate in the course of the game session will be stored; (b) survey information based on Likert scale questions related to game flow (as discussed in section 5) and learning objectives (as outlined in section 3). The survey also captures data in relation to previous experience with 3D CAD software and 1st person 3D videogames. The data from the questions will be statistically analysed and compared with a number of other published studies that use flow theory to evaluate engagement. This will be cross referenced against the in-application tracking of activity. A third analysis will be undertaken to examine any patterns in relation to course of study (architecture or engineering) and previous experience with 3D CAD and 1st person 3D videogames. After the completion of this user trial, we will review the development plan in preparation for implementation of level 2 as documented in Fig. 2. Given the resources required to develop a serious game to commercial production levels, we are exploring collaboration opportunities and welcome queries from potential academic or industry partners.

References