NET ZERO GAME: A PILOT STUDY OF GAME DEVELOPMENT FOR GREEN BUILDING EDUCATION

A mini game development with parametric BIM-based simulations

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Abstract. The research investigates the design and development of a serious game to teach green building design and energy literacy in rural middle schools in the United States. The paper presents a pilot study, education mini-game development integrated with parametric BIM and energy simulations. The game scenario was built on the developed science curriculum modules in our funded research, teaching building energy technologies such as daylighting, artificial lighting, window configurations, building materials, solar panels, etc. The mini game presents a baseline science lab and a media library of typical public schools in the United States. The players have the opportunity to improve energy literacy in several ways: manipulating the building configurations and the energy options, reviewing energy cost and the emission level changes, and monitoring the performance from the dashboards. This paper presents background theory, curriculum design, the mini-game development framework, methods and tools for energy simulation and BIM visualization, and the findings and challenges.

Keywords. Serious Game; Energy Literacy; Green Building Education; Parametric BIM; Energy Simulation; SDG 4; SDG 11.

1. Context of Game-based Learning for Green Building Education

Energy literacy becomes essential in the energy workforce education to achieve zero energy and gas emission reduction. However, the teaching apparatus and curriculums of formal education in the United States still do not reflect these global demands (Kandpal & Broman 2014). Although these concepts of Green Building are simple, achieving these goals is still challenging because of complex energy mechanisms and behavior. Understanding energy flow through the built environment requires systems thinking abilities (Lacy et al. 2014). Still, it is challenging to master without high-order thinking skills and intentional learning experiences (Hmelo-Silver & Azevedo 2006).

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Serious games take the concept of video game technologies and repurpose the Game for training, education, advertising, national defense, and more (Dib, H., 2014). Serious games provide an innovative approach to computer-based modeling to support the development of systems thinking (Liarakou et al., 2012). In addition, serious games show promise for learning through informal means of creativity (Kalinauskas 2014), play (Ampatzidou et al. 2018), collaboration (Hummel et al. 2011), and role-playing (Jenkins et al. 2009). Studies described the benefit of serious games in comparison with the conventional education media, including intrinsic motivations, greater attention, enhancing the sense of engagement, lowering the threat of failure and mistakes, application of learned skills, greater intellectual intensity, and more (Klopfer et al. 2010; Coller et al. 2009; Papastergiou 2009).

During the past decades, various serious games were developed as a medium to improve energy literacy in the built environment, such as Efficient City (2001), ElectroCity (2007), Climway (2010), CityOne (2011), EnerCities (2011), EnergyVille (2011), etc. ElectroCity challenged gamers to balance energy consumption, the development revenue, and renewable energy generation in town planning and design. Climway asked users to monitor and reduce the energy consumption of the community plan during a 50-year life cycle. More recently, serious game research addressed behavior change of the specific end-user, widely accepted as the most impactful factor for energy savings. For example, Serena Supergreen (2018) was designed to motivate and educate female students between 12 and 16. Powersaver Game (2019) challenged virtual family members to save 15% on energy, electricity, and gas consumption in three weeks. Rossano (2017) claimed that these serious game developments show the advantages, including better visualization of energy consumption, increased end-user engagement, their energy behavior change, and collectible end-user feedback.

However, educational technologies are still poorly interweaved with science curriculum units despite rapid research and development. Energy data in the game does not interact with various energy options and game scenarios. Since Woodbury et al. (2001) claimed the potential of CAAD and serious game integration in architectural design education, a growing number of studies have explored BIM and game integration for visualization, design decision making, design education, professional training, etc. Our multi-disciplinary research team envisioned that the advancement of BIM, increasing graphics capabilities, accessible game developments, and multi-criteria energy simulations would boost the efforts in this field.

2. Mini game development

The section presents a pilot study, education mini-game development integrated with parametric BIM and energy simulations. The goal is to create a theoretical and empirical framework for Net Zero Game, a serious game to teach green building design and energy literacy in rural middle schools. This section describes background theory, developed curriculum, the mini-game development framework, and methods and tools for energy simulation and visualization. The target application is the rural school districts in Missouri, underserved populations for science, technology, engineering, mathematics (STEM) interventions with limited access to STEM learning opportunities.

2.1. MODEL-BASED REASONING AND EYE CURRICULUM

Prior work has focused on the numerous energy misunderstandings students have about energy systems (Duit et al., 2014). Research outcomes suggest that teaching energy systems should make energy transfer and transformation visible, observable, and manipulable (Lee et al., 2013). We content this occurs through model-based reasoning ([MBR] Duschl et al. 2016; Verhoeff et al. 2008). Within MBR, students first develop an energy system responding to a question. When students develop, they can deconstruct a complex system to focus on critical systems elements (Gouvea et al., 2017). Next, students use their models to make sense of system behavior (Zangori & Cole, 2019, Jordan et al., 2009). Finally, students evaluate and revise their models as their knowledge increases in sophistication (Ben-Zvi Assaraf & Orion 2010).

The Game was designed to be embedded within a six-lesson curriculum unit called Energy and Your Environment (EYE), funded by NSF. EYE fosters place-based education by using local school buildings to enhance systems thinking about energy consumption and flow between buildings and Earth systems. Systems thinking is taught through the MBR framework in which students have ample opportunities to break large systems into smaller components to look closely at key components, causal interactions, and inputs/outputs within systems. The research team aligned with the EYE curriculum and the mini-game scenario for better game-based learning.

2.2. PROCESS

Before creating a full-scale 3D serious game, the research explored and examined a small-scale 2.5D game. A 2.5 game uses fixed isometric views to enable 2D game play in 3D environment. Players can move throughout the game environment, but the camera view does not change until a new game scene is accessed, such as changing locations. The game scenario was built on EYE curriculum modules, teaching energy technologies such as daylighting, artificial lighting, window configurations, building materials, solar panels, etc. The Game presents a baseline science lab and a media library of the typical public schools in the United States. The players can have the opportunity to improve energy literacy in several ways: manipulating the building configurations and the energy options, reviewing energy cost and the emission level changes, receiving interactive feedback from a dashboard and virtual consultants, and iterating the changes to achieve net-zero.

The game prototype was developed from the three phases, including (i) EYE curriculum development (C1, C2), (ii) Game design and development (G1, G2, G3), and (iii) Energy modeling and simulation (S1, S2, S3) shown in Figure 1.

First, parametric BIM was used to create manipulatable virtual models, such as a ceiling height change, exterior wall configuration, a window ratio, shading device, and artificial lighting configurations. Then, the real-time visualization platform converted the parametric BIM into a series of game scenes. The research explored Unreal Engine's Twinmotion and Enscape 3D. For energy simulations, the research used BIM-based cloud simulation. The simulation results and the benchmark results were compiled to produce an energy performance matrix based on the energy options in the game interface, including Energy Use Intensity (EUI), energy cost, and CO2 emission levels. For the game development, Unity3D and the game assets were used. In addition,

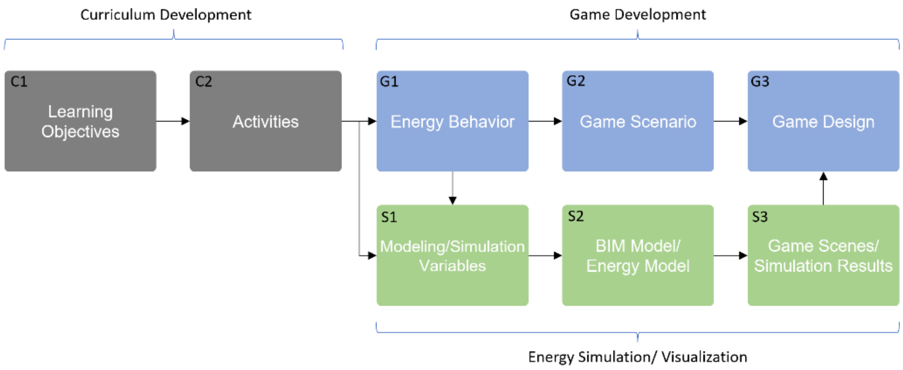

Figure 1. Research phases of mini-game development

the research created custom creature characters for better student engagement, breeding at the science lab to show the varying health conditions according to the energy performances. Although the linear process is presented sequentially, the research was built on bidirectional data exchange, frequent feedback loops, and iterative synchronizations across three domains of curriculum design, game design, and BIM-based modeling/ simulations.

2.3. BUILDING MODELING AND VISUALIZATION METHODS

The mini-game development attempted to take advantage of parametric BIM for rapid model changes and expeditious synchronization between the building model, energy simulation, and game scenes. In the context of the net-zero Game, the number of building/energy models could incrementally increase when the Game allows players to manipulate building configurations and energy choices. It makes manual creation of the game scenes manually a less viable approach.

Architecture design and construction domains rigorously investigate BIM and visualization integration. The relevant technique to this research includes real-time AR/VR creation from BIM, passing BIM data to visualization interfaces, and bi-directional model synchronization between BIM and visualizations. Ideally, these features would give students various learning experiences: students can variate a wide range of energy options in BIM; they can monitor how their choices change the indoor environment; and students can access building information such as materials, dimensions, and other energy-related building parameters within BIM. In that regard, the research has investigated and benchmarked the feasibility and applicability of BIM-based real-time visualization and BIM-game integration.

2.4. ENERGY SIMULATION METHODS

Towards serious game development, the research investigated three methods for game and energy simulation integration, including (i) cloud-based pre-simulation, (ii) iterative parametric pre-simulation, (iii) and algorithm-based prediction. Three approaches vary in view of process time, feedback latency, maintainability, and dissemination capability.

Pre-simulation: Complete simulations first and pass the simulation results to the game development phase. Legacy-simulation engines provide rich validity in results, but time and effort-intensive input processing is needed. The research explored BIM-based cloud simulations to eliminate redundancies and errors in energy modeling in the legacy simulation engines. Benchmark data from Autodesk Insight 360 enabled the prediction of various energy scenarios.

Iterative parametric simulation: Automate the energy model update and simulation execution using parameter iteration. Parameters need to be fully identified before the simulation run. Also, software prototypes could automate the conversion from building models to energy models, parameter updates, simulation runs, and result aggregation. Our prior works examined the iterative parametric simulation using BIM, multi-criteria simulation interfaces, and legacy simulation engines (Kim et al., 2021). The research used Revit for energy modeling, Grasshopper simulation plus-ins such as Ladybug and Honeybee tools, TT Toolbox for the iterator, and Rhino.Inside for the crossover data communication.

Algorithm-based prediction: Identify the energy performance pattern from the iterative parametric simulation using BIM, parametric simulation iteration, legacy simulation engines, and prediction algorithm. Our current investigation examines cross-platform integrations using BIM for energy modeling, parametric training and validation data generation iterations, and machine learning algorithms to produce the prediction rules.

The mini game presents our first implementation of pre-simulation using selected curriculum modules, BIM-based cloud simulations, and BIM-based visualizations.

3. Mini game development

The mini game is developed based on Lessons 4 and 5 in the EYE curriculum, teaching energy knowledge of building materials, daylighting, artificial lighting. Sub lecture modules in EYE challenge students to conduct specific activities to test energy knowledge gain. The following sections explain the research phases illustrated in Figure 1.

3.1. EYE ACTIVITIES AND LEARNING OBJECTIVES

The first phase was critical to align the curriculum contents, game scenarios, and building/energy modeling. Table 1 shows examples of essential activities of EYE that provided a foundational framework for game scenarios and energy simulation variables (C1, C2 in Figure1). The curriculum was initially designed to use analog teaching tools for rural schools without technology access. The mini-game is an attempt to substitute these analog tools with interactive digital learning platforms. The research identified a series of energy behavior from these curriculum contents and relevant activities such as building material change, window configuration change, and lighting fixture change.

Table 1. Main module's activities and learning objectives

[Module] "Activity"	*Learning Objectives*
[Sun and Building] "Light Where You Live" Use climate simulations to examine how sunlight interacts with your school building in your unique location.	Apply knowledge of the sun path and solar accessibility, considering building siting and façade configurations
[Building Operation] "How you use your building." Change building operation of HVAC, lighting, and other electric equipment. Then observe changes in overall energy use level	Recognize the impact of building occupancy and operation on energy use
[Daylighting] "Light & Your School Building" Apply what you have learned about the characteristics of light energy and light energy transfer to your school building. As you tour the building, make observations about how light travels inside.	Apply understanding of climate data to analyze how light interacts with the school building
[Artificial Lighting] "Which Lightbulb?" Students measure the heat output and illumination of different lightbulbs, making and testing their hypotheses about lighting, heat, energy use, and cost over time.	Develop an artificial lighting plan that balances the lighting quality and energy cost.

3.2. ENERGY BEHAVIOR AND SIMULATION VARIABLES

Next, we identified energy behavior and simulation variables required for scenario development and energy modeling criteria (G1 and S1 in Figure1). Table 2 shows energy behavior and simulation variables implemented in the mini game.

Table 2. Energy Behavior and Simulation Variables

Curriculum Modules	*Energy behavior in Game*	*Simulation variables*
[Sun and Building]	Reposition the buildings	Orientation
	Resize the rooms	Energy model dimension
[Building Materials]	Select roof materials	R-value, U-value
	Select wall materials	
[Building Operation]	Select occupancy schedule	Occupant heat gain
	Select equipment efficiencies	Equipment heat gain
[Daylighting]	Select window size/ numbers	Window to Wall ratio
	Select glass materials	R-value, U-value
	Select shading devices	Window transmission
	Select window opening frequency	Infiltration rate
[Artificial Lighting]	Select lighting types	Lighting efficiency

3.3. PARAMETRIC MODELING AND ENERGY SIMULATION

The energy behavior and simulation variables provided criteria of parametric modeling in BIM for game visualization, energy modeling variables, and energy simulation scenarios. In this phase, the research coincided with game design and game scenario development and had frequent feedback loops to align Game, simulation, and visualization. The mini game tested the following simulation variables in Table 3.

Table 3. Simulation category and variables

Category	Variable Types		
Wall/ Roof Materials	High performance (R38)	Moderate performance (R20 to 25)	Low performance (Uninsulated)
Window-to-wall ratio	Large window (80%)	Medium window (40%)	No window (0%)
Window shades	Large shading (1/2 window height)	Medium shading (1/4 window height)	No shading devices
Glass materials	High performance (Triple Low-E glass)	Moderate performance (Double clear glass)	Low performance (Single clear glass)
Lighting efficiency	High performance (LED)	Moderate performance (Fluorescent bulb)	Low performance (Incandescent bulb)

The research performed 243 pre-simulations in the mini game, calculated EUI, energy cost, and CO2 emission levels, and fed the simulation results into the game interface. To match the simulation set and the game scenario, we assigned simulation ids to simulation results. The simulations used Autodesk Revit and Insight 360. The visualization was based on BIM-based real-time visualization plug-ins, including Enscape and Unreal engine's Twin motion.

3.4. GAME DESIGN AND SCENARIO

The game scenario and interface design aimed to enrich engagement and motivation in learning. The Game takes place in a research facility located on an isolated island in the Galapagos, where the player can interact with other characters working at the facility. The Game places learners in the role of a scientist tasked with caring for evolving new species of creatures that are sensitive to climate change in Figure 2. The game design was informed by entertainment games popular with middle school-aged students. Games, such as Pokémon with the involvement of evolving a creature through various actions, played a role in the larger story development. The social mechanic used for decision-making to design the lab space was influenced by the popular gaming space such as Roblox.

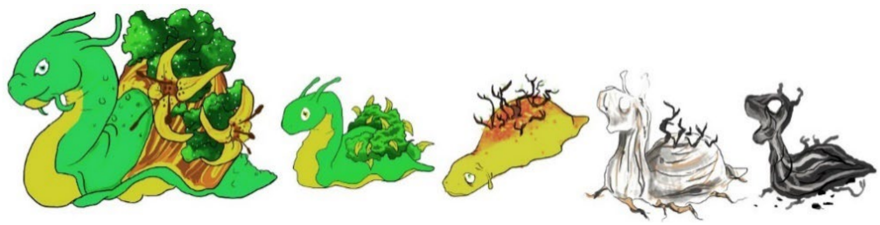

Figure 2. Creature design with five health levels

Other characters include a director of the research station, responsible for the overall energy facility and cost. A lab assistant assists the player with making decisions and finalizing results at the end of each game day. A librarian provides additional information about related energy subjects. An engineer helps the player make critical decisions about energy technology and options. The game world consists of a multi-building research facility that generates its power. The facility consists of five different spaces: main lab, library, staff lounge, research center, and observation deck.

The pilot game was developed using Unity3d with purchased assets to enable us to focus on how to connect the simulation data into the Game that would be meaningful. We created a 2.5d game that uses a 2.5d Toolkit to facilitate player movement around isometric environments. Combined with the 2.5d Toolkit, we utilized a dialogue tool to form the core gameplay and dialogue selection to make choices (Figure 3)

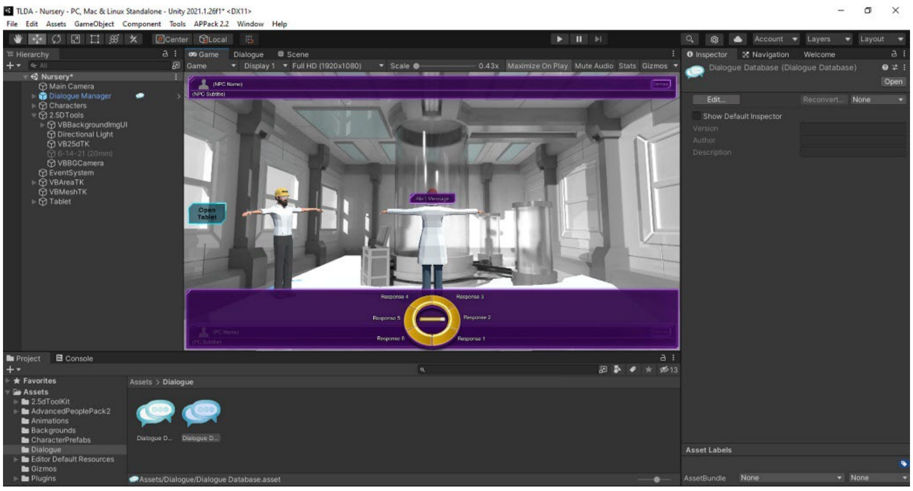

Figure 3. The lab scene development in Unity3D

4. Results

The research investigated game development based on our energy curriculum, including game scenarios, characters, dialogues, and game interfaces. The research also explored BIM-based parametric modeling and interactive visualizations to expedite game scene creation, energy modeling, and simulation result creation. To feed performance data into Game, the research examined BIM-based cloud-based simulation.

Figure 4 shows the resulting Game, a mini version of the larger NetZero game. To evolve the creature, the player must first power the lab to be energy efficient based on energy simulation variables listed in Table 3. The Game starts off in the main lab where the player is introduced to the creature and the lab assistants. The main goal is to evolve and release the creature found on the island. Within 30 game days, the player will be prompted to engage with the other characters in the research facility. The player

Figure 4 The game interface (left) and the dashboard (right)

observes the evolved creatures to determine the best decision to improve the creature's health. Players would also maintain information on the dashboard that would track decisions made as the game progressed. Based on the pre-simulation results and unique ids, the dashboard displays updated energy performances of EUI, energy cost, and CO2 emissions. The game interface swaps the background scenes created from the Revit models and visualization tools. Players monitor how their energy choices affect the environmental conditions from the creatures' status.

5. Conclusion

The mini-game development produced a theoretical and empirical foundation for the full net-zero Game. The research attempted to facilitate seamless communication and data flow across three domains of curriculum development, energy modeling/ simulation, and game development. We observed that the linear and top-down process could deteriorate flexibility in revisions, content alignment, and data exchange across three domains. However, the game designed here fits within the curriculum structure as it was specifically designed to work within the EYE unit. This is a novel educational intervention that is new to the field of science education.

Within the U.S., rural school districts are underserved populations for STEM education. They do not have ready access to green buildings in their communities. This challenge presents crucial equity issues as rural student expectations towards energy workforces increase, such as the gas, oil, wind, water, and solar energy industries. The described game is expected to bring knowledge about energy flow, human energy use, and green buildings to the rural students.

BIM adoption in serious games still faces several challenges. For instance, real-time communication between BIM and games is available when the classroom has access to full software licenses. Data exchange between BIM and games is still limited. The game development platforms have limited access to BIM data, and BIM tools have insufficient features for game developments vice versa. In addition, mini game relied on prerendered images and the image swapping function to update game scenes.

When considering the broad curriculum scopes, various energy options in the Game can exponentially increase the cost of energy simulations. Pre-simulations based on the predefined game scenario can prevent flexible game scenario and curriculum revisions. Reversely, it can cause complex changes in game design after the energy simulation runs. We anticipate that algorithm-based prediction may mediate the limitation of top-down and pre-simulation. We envision that it can eliminate the potential software license issues when distributing the serious Game to the classrooms. The full net-zero Game will further investigate this simulation method. The game development is still in early stage and needs feedback from the teachers and students. The under-developing research phase is the usability test of the mini game, planned to be performed at rural middle school districts in Southern Missouri.

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References

Ampatzidou, C., Constantinescu, T., Berger, M., Jauschneg, M., Gugerell, K., & Devisch, O. (2018). All work and no play? Facilitating serious games and gamified applications in participatory urban planning and governance. *Urban Planning*, 3(1), 34-46.

Dib, H., & Adamo-Villani, N. (2014). Serious Sustainability Challenge Game to Promote Teaching and Learning of Building Sustainability. *Journal of Computing in Civil Engineering*, 28(5). https://doi.org/10.1061/(ASCE)CP.1943-5487.0000357

Hummel, H. G., Van Houcke, J., Nadolski, R. J., Van der Hiele, T., Kurvers, H., & Löhr, A. (2011). Scripted collaboration in serious gaming for complex learning: Effects of multiple perspectives when acquiring water management skills. *British Journal of Educational Technology*, 42(6), 1029-1041.

Jenkins, H., Camper, B., Chisholm, A., Grigsby, N., Klopfer, E., Osterweil, S., ... & Guan, T. C. (2009). From serious games to serious gaming. *Serious games: Mechanisms and effects*, 448-468.

Kandpal, T. C. & Broman, L. (2014). Renewable energy education: A global status review. *Renewable and Sustainable Energy Reviews*, 34, 300-324.

Kim, J. B., Aman, J., and Balakrishnan, B. (2021). Forecasting performance of Smart Growth development with parametric BIM-based microclimate simulation. Projection, *Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021*, March 29-April 1, Hong Kong.

Liarakou, G., Sakka, E., Gavrilakis, C., & Tsolakidis, C. (2012). Evaluation of serious games, as a tool for education for sustainable development. *European Journal of Open, Distance and E-learning*, 15(2).

Rossano, V., Roselli, T., & Calvano, G. (2017). A serious game to promote environmental attitude. In V. L. Uskov, R. J. Howlett, & L. C. Jain (Eds.) *International Conference on Smart Education and Smart E-Learning* (pp. 48-55). Switzerland: Sprinter International.

Zangori, L., & Cole, L. (2019). Assessing the contributions of green building practices to ecological literacy in the elementary classroom: an exploratory study. *Environmental Education Research*, 25(11), 1674-1696.