BIM to IoT: The Persistence Problem

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Abstract. This paper explores how gamification can provide the platform for integrating Building Information Modeling (BIM) together with the emergent Internet of Things (IoT). The goal of the research is to foster the creation of a testable and persistent virtual building via gaming technology that combines both BIM and IoT. The author discusses the features of each subject area in brief, and points towards the advantages and challenges of integration via gaming technology. Hospitals are the specific architectural typology discussed in the paper, as hospitals have particular properties which make them good candidates for study.

Keywords: BIM · IoT · Gamification · Buildings information model · Internet of things · AR · Augmented reality

1 Introduction

City Models have been tools of urban designers and city planners for centuries. A fine example is the Berlin Stadt Modelle museum, which maintains past and present scale models of the city of Berlin at various scales [1]. The Stadt Modelle is used for educating students about the past and present city by showing historical models, the divided city during the Cold War, and the present shaping of development along the former route Berlin Wall. Aside from the physical model, the Berlin urban authorities also maintain a CAD based 3D model, which is updated according to new development. Users of this model are limited to those who can use CAD formats, and therefore is not accessible to the general public.

Google Maps is a more accessible example, as complemented by its excellent Street View feature and 3-dimensional representations of many cities. Google Maps is complemented by GIS-powered Directions features. Many other HTTP-based information sources are available through web-links. The interiors of buildings are mostly inaccessible (with a few exception), limiting the 3-dimensional shapes of buildings and cityscape to representational rather than informational in most cases. Google Maps has even been experienced as virtual reality by using Street View via Oculus Rift [2]. The limitation, again, is that it is representational, and buildings in Street View are little more than panoramic photographs burned onto geometry as a texture.

This paper proposes, instead, an informational city model with the following features:

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1. Building Information Model imbued geometry
2. Real-Time data via the Internet of Things
3. Multiplayer Online Gaming based platform
4. Augmented Reality Interface

The paper will discuss each of these areas briefly in turn, and then summarize the advantages of an informational city model, as BIM-IoT Game is being proposed.

2 Why BIM Matters

Building Information Modelling (BIM) is a design process that is used in current architecture practice to describe, model, and publish the documentation required for constructing buildings, structures and urban design in general. There are a variety of BIM platforms, however BIM is not a single specific software. Rather it is the total information, spatial, and aesthetic design of "something" (typically a building) that can be spread across a variety of software and datatypes. The goal of BIM is always the same: create the comprehensive documentation required to build something efficiently [3].

2.1 Features of BIM

BIM models are parametric; meaning that parameters are used to control and contain the design information and spatial forms. BIM platforms are in fact advanced 3-dimensional, visual, database systems that combine aesthetics with documentation, change management, analysis, space planning, etc. etc. etc. It is difficult to describe the totality of BIM, but suffice to say that BIM is the modern practice of architecture. An entire new discipline of building professional, the BIM manager, has grown from the prevalence of BIM methodology.

BIM can be described as a top-down process. This is not particular to BIM, but architectural design has always been top-down discipline. Example: Building developers describe the requirements and intentions, Architects design and describe those requirements via BIM, and Builders construct the physical building according to the documentation and information transmitted via the BIM model. This is not to say that architecture is not inclusive of many perspectives; in fact the modern practice employs wide teams of experts, community members, sociologists, and political voices. Nevertheless, the structure is overall hierarchal and thereby can be described as top-down.

If we consider an entire city over time, then the overall built environment can be considered bottom-up, with many and varied actors creating the city. Individual buildings, however, are almost invariably top-down.

2.2 Why BIM Matters

Information has always been the essence of Architectural design. Whether an architect draws by hand or via AutoCAD or Revit, the eternal purpose has been to encode information in drawings, notations, and other documents for describing something to be built.

BIM has elevated information and data management to a central role and freed architectural data from the confines of paper. Leading BIM platform typically have a level of openness that invites further development and creativity via Accessible Programming Interfaces (API). BIM matters not only because it is the status quo among leading architectural practices, but also because the open data structure allows us to grow beyond the limitations of any particular software. The API and programming community around BIM has grown substantially and continues to accelerate. Coding has become a highly valuable skill for architecture.

The BIM model itself has become a standard deliverable for many projects, at times supplanting drawings entirely. The once all-important printer has been relegated to the status of a legal requirement and source of irritations relating to toner and paper jams. BIM has also become a mandated standard for government projects in certain countries and types of projects, notably in the UK. Various developers have also mandated BIM standards, as they perceive that it delivers a superior product and pathway to life-cycle facilities management.

2.3 The Value of the BIM

The BIM model is encoded with valuable information, but that value may be perceived differently by different stakeholders. For example, regional healthcare authorities want to know the number of trauma wards for regional emergency planning, while waste disposal contractors want to know the number and location of waste containers for estimating disposal costs and logistics for removal. An artist wants to understand the spatial qualities of the space where he/she has been awarded a commissioned. Herein lies the problem; different actors could benefit from the BIM data in different ways, and most likely in ways that are unpredictable. Only one actor, however, owns the data directly and thereby acts as a gatekeeper.

Ownership of the BIM data is often quite clear: The building owner usually has sole ownership over the totality of the BIM model and the information contained therein as it pertains to that specific building or thing. Some BIM-derived information would be extracted as legal documents at various points in the design and approval process (permit drawings, traffic approvals), but ongoing access to the BIM model is typically controlled solely by the ownership organization or its proxies.

We don't treat our buildings BIM data in the same way that we treat GIS data, which, in western democracies, is generally much more open to creative analysis. BIM data, as with the physical buildings themselves, are private. More often than not, the BIM data is largely discarded at the conclusion of production.

2.4 What BIM Can Offer to IoT

We have all by now heard about the Internet of Things (IoT), and we are all mostly confused by what the fuss is all about. What we can say is that internet connected devices can create an ambient flow of information via internet protocols, which can be made useful by thoughtful applications. IoT nodes includes things like traffic lights, which when internet connected can provide both instant traffic feedback as well as histories of data to be analyzed later. Other nodes are less obvious, such as sensors embedded in waste receptacles that can signal when they become full. The single instances are mostly insignificant, but the sum of IoT enabled devices provides a powerful source of information that can be harnessed to provide efficiency and intelligence.

As opposed to the top down implementation of BIM, the Internet of Things is a bottom up, emergent phenomenon. Individual nodes can be added or subtracted, and assuming the protocols are all standard, the IoT cluster expands or contracts automatically. It is comparable to a group of huddling penguins on a frozen beach somewhere; individual penguins can wander off or return from a swim, but the Internet of Penguin ™ remains as long as two of the odd birds remain to continue clucking at each other.

The internet of things is built on the foundation of *horizontal information silos* that carry information across and between the individual islands of data. Currently BIM is a vertical information silo that can offer very specific information about the built environment, that which is visible as well as the invisible. Again we can think of all the parts of a building as nodes within a system, in much the same way that IoT devices can be considered as nodes of the IoT ecosystem. Examples of visible nodes includes things like the structure of a wall, the manufacturer of a floor covering, or the system capacity of a cooling tower. Invisible nodes are more conceptual, like a room or a space, which has no physical presence, but nevertheless carries a large amount of information. It is the marriage of visible and invisible nodes that makes the BIM model such a useful tool and source of information.

2.4.1 Context

"Where am I?" is a common question that we answer every day with applications like Google Maps. GPS systems like TomTom help us find our location when we drive in unfamiliar places. When we arrive at a building, however, we tend to leave that concept behind us. The owner of the building may provide signs to aid in way-finding, and rooms may have signs that say where they are. The interior arrangement of a building is generally considered to be private and in many cases secure. Government buildings are careful that the location of offices for important officials are not accessible to the general public, for example.

There are many buildings that are considered more public, and could benefit from more open and connected forms of way-finding. For example a shopping mall benefits from having the stores discoverable for visitors. A visitor to a hospital complex is sometimes mystified by the layout. This is compounded when a visitor is wanting to find a sick or injured loved-one, which can understandably create anxiety when the visitor is confused by the building layout. This is a great example of where the BIM model can be paired with IoT to answer the question of where is the patient's room (BIM), and where is the specific patient right now (IoT).

2.4.2 Requirements

Rooms have specific requirements related to their function. For example, a recording studio has specific acoustic requirements, a datacenter server hall has specific humidity levels, and an operating theatre has required hygienic levels. Room requirements are managed via Room Objects in a BIM model, the rooms as objects are otherwise invisible conceptual spaces in a building, but are the centers of information flow in a BIM model.

A BIM model can therefore answer questions of the intentions of rooms as according to the design of the room. A radio-medical technician can thereby know instantly if the room has the correct radiation shielding for a new piece of equipment if the BIM data is accessible in real time via IoT.

2.4.3 Spatial Awareness

BIM models describe spaces and the things that define the spaces, like walls, ceilings, floors etc. At a very basic level, BIM-IoT can deliver information like area or volume, but it can also deliver 3-dimensional visualization, and the relationship or connections between spaces. Spatial information in a BIM-IoT deployment can be visualized either in the building or remotely. Training scenarios can be much more immersive for planning evacuation, security, logistics, or orientation.

2.4.4 The Promise of Persistence

Persistence is defined as the continued or prolonged existence of something. A persistent online game is where the game world continues after the local game user has ended their session. Other players are still using the persistent online game world, and significant actions can occur which will alter the local users game after the session is continued again.

A persistent BIM-IoT keeps the BIM model alive after local users have ceased to access it. A persistent BIM imbued with IoT promises the ability for multiple users at different times to access both the device ecosystem pulsing through the built environment as well as access to the design intentions, design data (what is that wall made of?), and spatial qualities. Myriad other aspects of the BIM model can give deep context to the real-time IoT nodes.

If the top-down BIM model is to be synthesized with the bottom-up IoT ecosystem, then the building owner has to solve the problem of persistence. Simply put, how is the BIM-IoT hybrid kept alive? What is the format the effectively represents the potential of these two technologies? What skills are required to create and maintain the BIM-IoT hybrid? What is the revenue model that maintains BIM-IoT? What is the payback period?

3 Why Games Matter

3.1 Persistence

The Multiuser Online Game (MOG) has become a dominant paradigm for many big-budget games. Almost all AAA games released from major games studios in recent times have an online component that allows players from across the globe to compete in a virtual world. More often than not these are first-person shooter type games (Call of Duty). There are several subgenres under the rubric MOG, but the common thread is an internet based game through which multiple (sometimes thousands) of players can interact in a highly detailed world simultaneously. MOG games persist after single players have left, as other players continue to compete, cooperate, or explore the online world.

3.2 Immersion

Games take a wide variety of forms, but for this discussion I will focus on the first-person shooter variety (minus the shooter). First-Person Games take the point-of-view of the player themselves. By employing mouse, keyboard or controller manipulation, the player navigates a 3-d world and often completes tasks or defeats enemies. The point-of-view is the key to creating a sense of immersion and presence in the 3D world. A player that feels immersion can achieve a higher level of motivation to compete, explore, and play the game to its conclusion.

3.3 Fun

Games, on some level, are designed to be fun. To paraphrase (from something entirely different), "I don't know what fun is, but I know it when I am having it". Fun is difficult to define, but in the context of games it can be attempting to solve a difficult puzzle, battling across an arena, exploring a vast world, or any number of different variations that someone, somewhere thinks is fun. A key feature of being fun is that the game mechanics, that is the controls, the rules, the interface, are not so cumbersome or ergonomically difficult as to interfere with the actual game play. For a game to be fun, the user interface and user experience should probably be intuitive, stable, and perhaps even beautiful on some level. Further delving into the idea of fun can lead to very complicated philosophical abstractions, and I don't think this paper needs to go there. I will leave it this way: There is a thing called fun, people know when they are having fun, and generally people want to keep having more fun. That last component, the desire to have more fun, is the most important aspect. Fun is enticing, inviting, and approachable. Fun turns work into a game. Fun is motivating.

3.4 Complexity

Scientific research has already made the jump to gamification in some examples. The Wellcome Trust Sanger Institute in 2013 teamed up with Epic Games, the makers of Unreal Engine, to sponsor a competition to create games around the theme of "Mendelian inheritance: genetics and genomics". "There's something about genetics that seems to lend itself to computer games," said Carl Anderson, a researcher at the Wellcome Trust Sanger Institute [4].

4 A New Approach: Gamification of BIM-IoT

A variety of services has been delivering BIM to gaming platforms. Some notable examples are Revizto, Lumion3d, and Twinmotion. Revizto aims to aid in project collaboration during the design and construction process, while Lumion3d and Twinmotion are high-end rendering platforms that leverage gaming technology.

Apart from the services and others on the market already, architects are able to export BIM models directly into gaming platforms themselves. Popular and powerful game engines such as Unity or Unreal Engine are being used in current architectural practice to create game-like environments for client walkthroughs, prototyping, and virtual reality experiments. Visualization specialists in architecture are increasingly offering to translate architectural and real estate proposals into high-end gaming platforms.

More importantly, it is possible with available technique to retain the BIM data when published in the game environment. I have a large healthcare project being designed currently, where BIM Gaming is being applied to the design review and visualization process via Revizto. This is been received very enthusiastically by our clients. Gamification of BIM has allowed architectural clients to interact with the BIM design in a very approachable, immersive, fun format.

The Gaming industry has solved many of the most challenging aspects of presenting complex environments in a first-person game. Think of any of the more recent AAA games released by major studios, with an eye towards the complexity of the game. Furthermore, gaming technology via Multiplayer Online Games has solved the persistence problem of online environments. Richly detailed MOGs like World of Warcraft or EVE are persistent and accessed concurrently by millions of players. BIM-IoT Gaming can shed many of the complex game mechanics of MOGs, and retain the persistent world aspect and level loading technologies.

4.1 Overlaying the Real with the Unreal

In the paper "A Multiplayer Learning Game based on Mixed Reality to Enhance Awareness on Archaeology" researchers used a multiplayer online game to increase immersion, motivation, and effectiveness of archaeology education [5]. Mixed reality scenarios took students out of the game to investigate real life artefacts. This example uses is very close to the scenario I am proposing, however BIM-IoT Gaming uses the real buildings and the real city complemented with real-time IoT data.

The concept of overlaying the real and unreal has been defined as *Pervasive Games* [6], where "Pervasive Gaming implies the construction and enacting of augmented and/or embedded game worlds that reside on the threshold between tangible and immaterial space, which may further include adaptronics, embedded software, and information systems in order to facilitate a 'natural' environment for game play that ensures the explicitness of computational procedures in a post-screen setting" [7].

4.2 Augmented Reality

Augmented Reality interfaces are the most promising candidates for experiencing the merged BIM and IoT game system. In previous literature this has been dubbed Mixed Reality [8], and it refers to a merging of virtual and actual worlds. Recent examples have included Google Glass, and promising prototypes like Microsoft HoloLens technology. Hypothetical examples are Magic Leap, which has not yet disclosed the hardware, software, or indeed much else of their AR applications beyond a few videos. Other very successful AR solutions are the Osterhout Group, who have been making sophisticated AR glasses for the American military, and plan to release consumer AR glasses in 2015. Some might question why we would overlay a virtual building onto a real building. What's the point, when I can just tap on a real wall to know that, yes, it is a concrete wall?

The pervasive overlay, accessed via AR allows the ability to know the structure of the wall. Does this wall have sufficient radiation shielding? What is behind this wall? Where are the heating ducts located behind the wall? Microsoft showed an excellent example of this, where the Hololens allowed the ability to blast a virtual hole in a real wall and view a Minecraft world beyond. With AR a maintenance worker could dematerialize a wall to find the mechanical or plumbing systems inside.

The ideal BIM-IoT Game would be accessible in a variety of ways, including via mobile phones, laptops and desktops. Different access formats invariably requires a different range of capabilities. Desktop and laptops could have very advanced analytical capabilities through APIs that are not generally possible in a mobile or AR deployment.

4.3 The Hypothetical Hospital

Hospitals are a great test-case for this technology because they are typically complex spatially, extremely information dense, and having very high concentrations of equipment which could be IoT enabled. Healthcare equipment manufacturers like Siemens are amongst the leaders in IoT technology, as is an indication of the coming integration of IoT sensors in hospital equipment. Furthermore, hospitals have a wide cross section of users who all experience the buildings very differently.

Let's take a stroll through the Hypothetical Hospital to illustrate how BIM-IoT Gaming might be experienced: A visitor comes to the hospital to visit a patient. She has received an email with her relative's room number, and she registers herself as a visitor. When she arrives at the hospital she is presented with turn-by-turn directions in her AR glasses to find her relative's room. This is also complemented by virtual and physical way-finding signs. Her relative, the patient, is being taken for a test in another part of the hospital, and an update alert is sent. The Visitor can either follow a new set of turn-by-turn or continue following directions to a waiting area. A logistics worker receives an alert from an IoT enabled sensor in Just-In-Time cabinet outside a surgery. New surgical gowns need to be delivered. He checks out the goods from Sterilization Central and delivers them to the exact cabinet, which can be identified further via AR highlighting. A maintenance worker receives an alert from an IoT enabled ventilation fan that a part is failing. He gets the replacement part and goes to the room. He dematerializes the wall in his AR vision, and overlays the equipment in his view. He calls the ventilation specialist for detailed instructions on replacing the part. The ventilation specialist shares the camera view. An A/V technician is hanging a new monitor on a wall. He checks the wall's structure via the BIM overlay to ensure that there is plywood where she wants to install the new monitor. There is no need to tear open the wall to check. A hospital administrator sees the need for more intensive care rooms. She logs into the BIM-IoT game on her laptop and analyzes the hygienic class of the existing nearby rooms to plan the possible changes. A patient is going to undergo emergency surgery. An expert surgeon in another country is assisting remotely. The Surgeon in the operating room can see an avatar of the existing surgeon who is giving detailed instructions. The assisting surgeon can see and access the equipment in the room and feel immersed in the room spatially. An artist is invited to create an installation for the children's ward. He uses the 3-d BIM model to understand the space and creates a virtual representation in the actual space. The hospital arts director visits the children's ward, and sees via AR the proposed installation layered over on the actual space, and shows the AR model to children and staff in the ward for feedback.

5 Conclusions

Often innovative ideas are birthed in speculative fiction of one sort or another. For example, William Gibson predicted much of the potential for the gamification of BIM-IoT in his Virtual Light novel, or the tablet computer was visualized in Kubrick's 2001: a Space Odyssey. Other technology seems nearly achieved, such as the communicators of Star Trek, or the space elevator theorized by Arthur C Clarke. Complications for this proposal include:

- Miniaturization: Current AR technology is too big and cumbersome for the average consumer to use daily. Hololens is a large visor, while Magic Leaps theoretical hardware prototypes have been described as very cumbersome at this point. The Osterhout Group's glasses are the closest to "normal" sunglasses, but even those are not exactly fashionable. AR technology has a long road ahead until it can be miniaturized sufficiently to deliver an acceptable form factor for mass acceptance in the consumer market.
- Patching the game: Fortunately, the games industry has solved the problem of updating their games through patches and downloadable content (DLC). A similar patching procedure could keep the BIM-IoT model updated as new buildings come online, and new IoT equipment is introduced. Who is responsible for upkeep? Is it an emergent system, where patching is handled in a decentralized way, or is a central authority responsible? Perhaps it could be both, for different levels of information.
- Revenue and payback: In general, building owners use very short term formulas when valuing payback for additions to the basic objective of the building. A 3 to 5 year payback period can be an acceptable target. BIM-IoT would almost certainly require higher design fees, and may add operation costs if updates to the underlying BIM model is required. New revenue streams are one way to achieve acceptance, for example microtransactions from users, telecommunication fees, or even advertising in the virtual space. In the retail space, the introduction of a new dimension to sales and advertising could be a valuable new type of payback.
- Security and propriety (Hackers): Some information about the interiors and data in buildings should be always be kept secure. The locations of vital systems, valuables, and people is clearly very sensitive information that should be controlled carefully. The example of Anders Breivik's attack on the Oslo offices of the Norwegian government illustrates this in the extreme. Systems need to have robust informational

security to block access. None of this is particular to BIM-IoT, but is a dimension that would need to be carefully considered. The evolution of the sophisticated hacker has shown that even the most isolated systems can be hacked.
- Proprietary information: The vast majority of buildings are privately owned, and the interiors of private buildings are by definition proprietary. The typical building owner has no requirement for opening their building to the virtual, and probably only a small fraction of private building owners would even entertain the idea of an open BIMIoT Game. However, we can consider the evolution of GPS and aerial photography as an example where the previously inaccessible was suddenly wide open for scrutiny. The satellite view in mapping services is taken for granted now, but at its dawn was the feeling that the world was being revealed at a level of detail previously only visible to national militaries. A similar evolution of public-private could occur in BIM-IoT gamification.
- Evolution of the contract: Currently, building owners are required to submit building permit drawings and certain zoning diagrams with supporting documentation. In the fully realized BIM-IoT cityscape, it would be conceivable that municipal authorities would require suitable BIM models. Designers, architects, and engineers also would need a revised contract that details the new type of deliverable. A BIM model limited to production can be very different than a BIM model that is targeted towards production and life-cycle BIM-IoT gamification. New standards could be required to help achieve acceptable levels of detail, and new subcategories of professionals could be necessary for creating and servicing the BIM-IoT Game.

I'm embarrassed to say that this paper was inspired by an episode of CSI, where the Crime Scene Investigators accessed a detailed 3d model of an existing building, complete with real-time information from building systems. As an architect I knew that this kind of persistent virtual building was nonsense at the time, and I have seen many examples of the same concept presented in various other shows and even cartoons. As an architect, I enjoy seeing the designs that we create become actual parts of the built environment. The actualization of architecture is one of the most gratifying aspects of the profession. What is less satisfying is the fate of the BIM model. Architects will spends months or years on the BIM models, only to see them largely discarded at the end of production. My intuition tells me there is more value to be delivered to our clients, our cities, and the people inhabiting it. The trend of technology and our information society tells me that BIM-IoT is coming in one form or another, and Gamification is the way forward.

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