COMPUTER GAMING TECHNOLOGY AND POROSITY

Using computer gaming technology and environmental sensors to represent Porosity.

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ABSTRACT: In 1996 artist-architect Richard Goodwin coined the term "Porosity". Porosity describes the publicly accessible spaces within privately owned parts of the city. Any mixed use building is necessarily Porous; for example, clients must be able to visit their dentist's surgery on the 14th floor, their lawyer on the 5th floor, or a restaurant on the roof. A buildings Porosity is a measure of the quantity and quality of pathways to a given destination (Goodwin 2006).

More recently, the growing list of urban mapping projects suggests that there is an urgent need for a deeper understanding of the dynamic relationship between public access and the occupiable spaces of the city (see Reades et al 2007, for a representative range of these, C. Nold's work is worth a special mention). The Porosity of a building is an excellent example of the dynamic relationship between people and the built fabric of the city. Due to the manual data gathering techniques employed, the first incarnation of the Porosity maps were only able to create a 'snapshot' of the buildings selected. To understand how the Porosity of a specific building might change over time the mapping process would need to be automated.

The questions that initiated this research were, "could Porosity be represented in real time? What should that representation look like? And can the combination of computer gaming technology and environmental sensors automate the representation of Porosity?"

In response to these questions the authors have developed a prototype that translates the movement of a person in the real world into the virtual environment of a computer game; note the pedestrians' participation is entirely passive (i.e. they are not knowingly playing a computer game, they are simply going about their business). The movements of a Non-Player Avatar, standing in for the pedestrian, are then represented with a range of textures, geometries and behaviors. (The external sensor that is being used to demonstrate proof of concept is the Nintendo Wii Balance Board, employing a custom script to interface with the PC). The authors call these representations of movement and time 'Porosity Lenses'. Their development draws from Goodwin's Porosity Index but, significantly, construct it in real time. In one lens the movement of the avatar constructs a facsimile of a space as sensors passively capture a person's movement through the real one.

Finally the paper compares the lenses developed with recent representations of movement over time to highlight strengths and weaknesses of the approach.

KEYWORDS: Porosity, Computer Games, Sensors, Representation, Mapping.

1. INTRODUCTION

A growing list of urban mapping projects suggests there is an urgent need for a deeper understanding of the dynamic relationship between public access and the occupiable spaces of the city (see Reades et al 2007, for a representative range of these, C. Nold's work is worth a special mention). In many cases these projects represent dramatically changing patterns of use, mobility, and security. The term *"Porosity"*, coined by Richard Goodwin, describes the publicly accessible spaces within privately owned parts of the city. With the support of an Australian Research Council Discovery Grant from 2003-2005 Goodwin and his research team mapped these “Porous” spaces within the Sydney CBD. The results suggest new opportunities for pedestrian movement through the city. In contrast to many of the urban mapping projects cited above the Porosity maps are fully three dimensional. By recording the member of the public’s duration of stay they also capture the dimension of time. However, due to the manual data gathering techniques employed, the first incarnation of the Porosity maps were only able to create a ‘snapshot’ of the buildings selected. To understand how the Porosity of a specific building might change over time the mapping process would need to be automated. This prompted questions such as can Porosity be represented over time, and ideally in real time? What should that representation look like? Can the combination of computer gaming technology and environmental sensors automate the representation of Porosity?’

In this paper the authors describe a new way to map the Porosity of a building by modifying an off-the-shelf computer game, Unreal Tournament 3 (UT3) by Epic games, and using sensor controlled “Non-Player Avatars”. In a typical single player computer game the player *knowingly* controls an “Avatar” (which is the players embodiment within the virtual world) and may compete against or be assisted by Non-Player Characters (NPC’s) which are controlled by the computer game’s artificial intelligence. In a multiplayer game the player is usually competing against or being assisted by Avatars that are knowingly controlled by other real people. In contrast to these typical situations the authors have created a prototype where a real pedestrian’s presence in the virtual environment is entirely passive i.e. they are not *using* the computer or *knowingly* playing a computer game, they are simply going about their business. This also contrasts Gemeinboeck et al’s (2005) approach where the “spatial evolution … unfolds in the mutual interplay between the participant and the virtual opposite.” To clarify this distinction the authors have coined the hybrid term “Non-Player Avatar” or NPA. The movements of an NPA are driven by sensors recording a pedestrian’s movement within a real environment and simultaneously traced in virtual space and time with a range of textures, geometries and behaviors. The authors call these representations of movement and time ‘Porosity Lenses’.

The Porosity Lenses are designed to facilitate analysis, by Avatars within the virtual environment, of NPA movement from many different points of view thereby taking advantage of Sun et al’s (2007) research that notes the importance of three dimensional space and point-of-view in shaping human behavior in urban spaces. In an extension to Sun el al’s work the authors propose that if three dimensional space and the first person point-of-view is important in shaping human behavior in urban spaces then they may be equally important in understanding and analyzing human behavior in these situations.

This paper will describe the theoretical context, design and development of the Porosity Lenses, while comparing and contrasting them to recent representations of movement over time. In one example the movement of an avatar generates three dimensional building blocks that construct a facsimile of the pedestrian’s environment in real time as sensors record their movement through it. It will also describe the development and preliminary testing of a prototype sensor solution that uses off the shelf computer gaming hardware.

As noted above there are many examples of projects that map the movements of people in cities and the developers of Halo 3 (Bungie Studios in collaboration with Microsoft) have mapped and analyzed over 3,000 hours of game play (Thompson 2007). The research presented here uses off the shelf computer gaming software and hardware with a view to combining and extending the two approaches.

2. THE POROSITY STUDIO.

In 1996 artist-architect Richard Goodwin established the *Porosity* studio within the College of Fine Arts (COFA) at the University of New South Wales. Goodwin notes that the public space of the city doesn’t end at the building envelope; that any mixed use building requires access by the public and is necessarily porous.

For example, clients must be able to visit their dentist’s surgery on the 14th floor of a building, their lawyer on the 5th floor, or a restaurant on the roof. A buildings Porosity is a measure of the quantity (and quality) of pathways to a given destination (Goodwin 2006). The primary concern of Goodwin’s research was the amount of time that the Porosity researcher could spend within a privately owned building without detection. After comprehensive fieldwork detailed three dimensional maps of three major zones within the Sydney Central Business District (CBD) were produced. Architectural data on the buildings within those three zones, combined with the results of the field work, gave each building a qualitative *Porosity Index*. In the original Porosity Index Goodwin cited orientation, duration of stay, adjacency to lifts, stairs and other distinctive architectural qualities as factors that contribute to a building's Porosity Index.

Goodwin proposed that reading these Porosity Indexes could give planners and architects direction as to the way in which new linkages may be made which enhance the public space in the city. But from a slightly more sinister point of view the Porosity Index's can also measure and qualify the dilemmas of security versus access in relation to public and private space. In other words the *Porousness* of a building relates to the ease by which a building might be accessed and evacuated; the irony here is that high levels of Porousness would seem to facilitate both.

3. THE APPROPRIATENESS OF USING COMPUTER GAMING TECHNOLOGY TO REPRESENT POROSITY IN REAL TIME.

Rather than being fully spatial many urban mapping projects still represent the city in two dimensions. A few projects supplement those dimensions with other, non-spatial, dimensions such as information about the users itinerary (E. Polak's "Amsterdam RealTime: Diary in Traces") and physiological responses (C. Nold's Biomapping project, 2004 - ongoing). In "The Language of New Media" (2000) Lev Manovich says that "along with providing a key foundation for new media aesthetics, navigable space has also become the new tool of labor." He goes on to say that "the 3-D virtual space combined with a camera model is the accepted way to visualize all information". Demonstrating the pragmatic advantage of visualizing information in this way Sun et al (2007) recognized the importance of point-of-view in shaping human behavior in urban spaces. By using a head cave and three dimensional virtual environments they found that some assumptions about human behavior in urban spaces could be challenged. It's interesting to note here that their research utilized an environment that was "designed to be something like a first person shooting game, such as DOOM." In contrast the authors did not use *something like* a first person shooting game, they actually used an off the shelf computer game. So why take Sun et al so literally and use an off the shelf technology designed in the first place for entertainment? The answer lies in the underlying sophistication of computer games and, more recently, their versatility regarding modification; not to mention the widespread encouragement by game developers and large "modding" communities that users create custom game dynamics and content.

Microsoft Research wrote in 2005 that computer game technology "pushes the technology envelope". Also recognising this, the game developer "Virtual Hero's" (the developer of the groundbreaking simulation/marketing tool "Americas Army") has recently licensed the UT3 game engine to develop an urban training simulation called Zero Hour: Americas Medic. Illustrating the growing institutional acceptance of repurposing entertainment technology Virtual Hero's are also working in collaboration with the American Department of Homeland Security. In 2006 Price provided a useful summary of the recent "deployment of game engine technology" for education and training applications, noting that their use in such ways has occurred only in the "last few years". In 2000 Bouchlaghem et al noted that "the benefits and applications of virtual reality (VR) in the construction industry have been investigated for almost a decade" but that "the practical implementation of VR in the construction industry has yet to reach maturity owing to technical constraints". Ten years on from Bouchlaghem et al's study we find that industry heavyweight Autodesk has recently become a member of the "Integrated Partners Program" with EPIC games and, as Author 1 has mentioned in a previous paper, the use of computer gaming technology in education reflects moves in practice by large firms such as Texas based HKS and small by Lara Calder Architects, Sydney. In a move that represents an alternative way forward to their main Building Information Modeling (BIM) competitor (Autodesk's Revit) Graphisoft's Archicad has incorporated a real time interactive engine in its latest release. While the authors applaud the initiative they remain skeptical that Graphisofts resources and culture will facilitate their engines comprehensive development (or importantly, many alternative developments). The use of VR technologies in the construction industry is still not mature, but many of their technical constraints have been overcome … somewhat ironically, by the entertainment industry.

In the discussion relating to human behavior in public spaces Sun et al state their assumption that "from the set of architectural clues in sight, the human selects the one with the highest priority and performs a related strategy" (2001). To reiterate, in the context of the authors project as *humans* perform navigational strategies within a real environment NPA's mirror them within a virtual environment. The Porosity Lenses described below are mechanisms that add persistent traces of movement to the "set of architectural clues in sight" so that Avatar analysts can develop an understanding of the movement of NPA's; and by extension the pedestrians that are driving them.

By utilizing computer games the Avatar analysts can take advantage of the “positive benefits of video game play” that include “spatial visualization and mental rotation” (Rosser et al, 2007).

4. DESIGNING ‘POROSITY LENSES’ USING UNREAL TOURNAMENT 3.

Representing one of the latest generation of computer gaming technologies, Unreal Tournament 3 (UT3) incorporates an incredibly comprehensive tool set and has the support of a large game moding community (see the forums at www.3dBuzz.com and http://forums.epicgames.com/forumdisplay.php?f=335 for example). For these reasons UT3 was chosen as the computer game medium within which to develop the initial functional prototypes of the Porosity Lenses. The UT3 world editor, UnrealEd, “is a suite of tools for working with content in the Unreal Engine. At the core, it is used for level [virtual environment] design; but contained within are editors and browsers for importing and manipulating content for your game project (EPIC Games).” The toolsets used to design and develop the Porosity Lenses include UnrealKismet, Matinee, Cascade, the Material and Static Mesh Editors. Many of the toolsets require information generated in third party software (textures or geometry for example) and from other toolsets within the editor itself. While this interdependence adds to the complexity of modifying the game it does provide many opportunities to link different types of parameters and contributes to the sophistication of the interactivity.

For the first Porosity Lens the UnrealKismet toolset was used in conjunction with the Cascade toolset to attach, detach and control the emission of a sprite particle emitter that was attached to a NPA (a sprite is a 2d surface that always faces the player). UnrealKismet “allows non-programmers to script complex gameplay flow in level. It works by allowing you to connect simple functional Sequence Objects to form complex sequences (EPIC Games).” In this and the following examples visual scripting was used to create a mechanism for interactivity that didn’t exist previously within the UT3 game. The result is that as the NPA moves around the environment it leaves a trail of translucent squares that traces its movement through space and time; much like the breadcrumbs left by Hansel and Gretel in the well known fable, *figure 2*. The custom material applied to the sprite contains a variable opacity-parameter so that the translucency can be adjusted to balance between the clarity of the avatars path and the density of its representation. The density of the path at any one point represents the overlaying of multiple translucent sprites that build opacity and represent the duration spent at that point; a key factor to understanding Porosity.

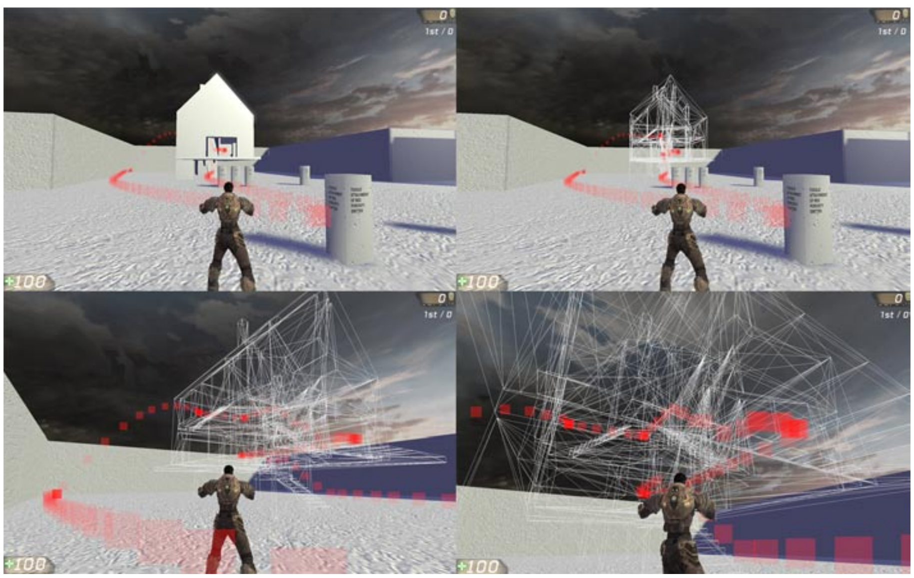

Figure 2. Shows the results of the Kismet sequence created by the authors that controls the relationship between a particle emitter and an NPA. The sprite is a translucent red square which is emitted at a rate of 10 instances per second. The effect is much like the breadcrumbs left by Hansel and Gretel in the well known fable but in this case records both the path taken and the duration spent at any point along it. Avatar analysts are also able to dynamically control the translucency of existing structures within the environment.

Extending from the notion of parametric interdependence mentioned above, every element within the game environment contains parameters that can be customized. Identifying parameters and referencing them within Kismet enables many to be changed over time. These changes can be pre-scripted (much like conventional animation) or can occur in real-time. For the second Porosity Lens a Kismet sequence was designed that modified a scalar parameter which controls the opacity channel of a material applied to a rectilinear block within the environment. The collision properties of the block are set to register "touch events" with NPA's but will not collide with them physically, so that they do not impede their progress. Every time a block is touched by an NPA its opacity drops by 0.2 (where 1.0 is opaque and 0 is transparent). The sequence continues reducing the resulting opacity, upon subsequent touch events, until it reaches zero; i.e. until the material is completely transparent. *Figure 4.* shows a simple arrangement of corridors filled with the blocks.

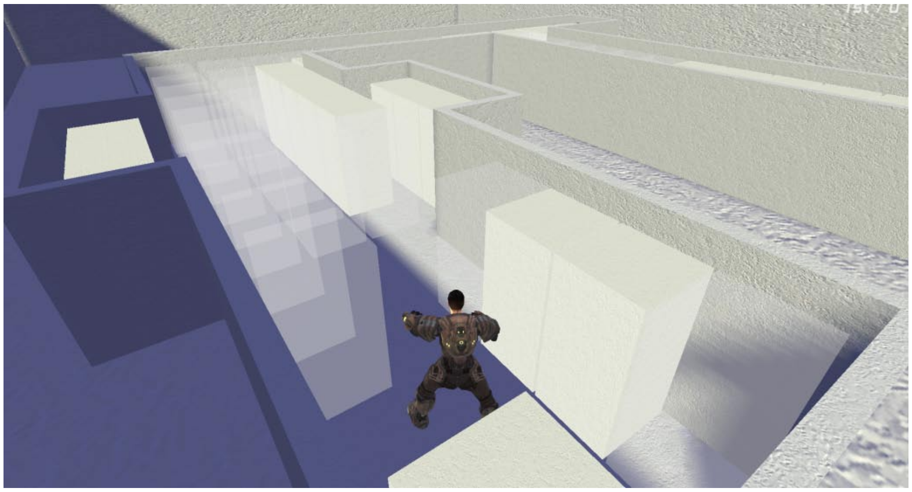

Figure 4. Shows the blocks in a corridor. Their opacity is controlled by a Kismet sequence linked to one of their materials properties, each time a "touch event" occurs the opacity of the block is reduced by 0.2, until the block is completely transparent. This gives the impression of the NPA or NPA's slowly carving out the space that they occupy.

Multiple touches by one or more NPA's give the impression of their movement slowly "carving out" the space of the corridors. One can see that as long as walls, floors, ceilings and doorways limit the pedestrian's movement in their real environment there would be no need to represent them within the virtual environment; the presence or absence of rectilinear blocks can perform this role. The authors imagine an environment totally filled with these blocks in a complete 3d matrix. The virtual representation of space that is occupied by pedestrians in a real environment would become clear as the NPA paralleling their movements traveled through it.

The third Porosity Lens adopts the additive approach of the Hansel and Gretel Lens with the 3d geometry of lens two. In contrast to the Hansel and Gretel Lens however the mesh is only emitted when the avatar "carrier" is moving; i.e. it records position rather than position and duration. The emitter could be set to emit mesh particles constantly, but the additional processing required by 3d geometry over a simple sprite slows the computer significantly when count rises into the thousands. At the current stage of its development the mesh elements do not collide with the NPA. Ultimately the authors intend that the mesh will collide with the footsteps of the NPA so as the pedestrians negotiate a real environment they passively construct a version of it beneath their feet in a virtual environment. See figure 5.

In the three lenses described above two representational strategies are employed; the sprites and tiles are additive, the rectilinear blocks are subtractive. Further, each of the prototypes utilizes arbitrary rectilinear shapes or geometry and the textures used are homogonous. As working prototypes they demonstrate that the answer to the question "can Porosity be represented in real-time?" is yes, but there is clearly room for improvement. The following section looks at three examples of urban mapping projects that highlight strengths, weaknesses and suggest possible directions regarding future development for the Porosity Lenses.

Figure 5. Real-Time construction of an environment. Blocks emitted by the NPA as they move around an empty virtual environment would construct a facsimile of the pedestrians real environment. Note the image above shows blocks leaping over ones previous laid avoiding an intersection; in those cases the NPA literally leaped over the earlier path. This demonstrate that environments that change in the vertical dimension (stairs, ramps, etc) are able to be replicated .

5. WHAT SHOULD THE POROSITY LENSES LOOK LIKE?

In the following examples the authors critically examine recent efforts by various researchers to represent the movement of people through space.

In C. Nold's work, seen at www.biomapping.net, "participants are wired up with an innovative device which records the wearer's Galvanic Skin Response (GSR), which is a simple indicator of the emotional arousal in conjunction with their geographical location. People re-explore their local area by walking the neighbourhood with the device and on their return a map is created which visualises points of high and low arousal." The resulting maps of Stockport, Greenwich and San Francisco are two dimensional. The map for San Francisco uses stacked red disks and at first appearance bears some similarities with the sprite based Porosity Lens. This similarity is short lived however as the colour intensity isn't built up in layers but comprises arbitrary steps on a scale; each disk is opaque. A sample video on www.biomapping.net shows a three dimensional structure built over Google Earth.

Figure 6. Screen capture from www.biomapping.net showing C. Nold's mapping of "emotional arousal in conjunction with geographic data." The effect is similar to a line graph, folded over a surface in Google Earth. Note the horizontal surface is completely flat and that any rise in elevation could confuse the reading of data in the z-axis.

The line in the xy plane traces the participant's movement through the environment while the z-axis is used to represent emotional arousal. The effect is similar to a line graph, with solid fill beneath, which is folded so that it might stand up unsupported. Figure 6. The height in the z-axis plays the same role as the density of the Hansel and Gretel sprite trail, but this approach would quickly become confusing if the ground plane was not completely flat (i.e. a point on the terrain, or within a building, with a higher elevation could give the impression that the experience there is more intense). Expressing the data as a cross section area perpendicular to the direction of movement may alleviate that confusion and suggests a future direction of research for the authors.

E. Polak et al's project Amsterdam RealTime tracks people equipped with GPS enabled devices in real time and projects the resulting lines onto a black background. The map is 2 dimensional but expresses a direct precursor to a key strategy of the Porosity Lenses (using people movement to build an environment); as explained by the Waag Society "this map did not register streets or blocks of houses, but consisted of the sheer movements of real people." The time lapse animation shown here: http://www.waag.org/project/realtime shows the map glowing and pulsating at points where multiple pathways cross. The representation of intensity is unmistakable qualitatively but vague in a quantitative sense. This may be a strength and weakness of all strategies that rely on multiple 2 dimensional layers.

Bungie Studios the developers of Halo 3 (in collaboration with Microsoft) have developed tools to extract gameplay data so they could map and analyze over 3,000 hours of game play (Thompson 2007). In one example "player deaths [are] represented in dark red on [a] 'heat map' of the level". Alison Mealey manipulates a similar approach to create portraits by recording and representing the movements of NPC's in the game UT2004 (Petersen 2005). Another example from Bungie shows "superimposed locations of about 30 testers after half an hour of gameplay"; players left different "coloured dots showing player location at five-second intervals (each colour is a new time stamp)". When the dots were clustered by colour it demonstrates that "players were moving smoothly through the map". Currently the Porosity Lens's don't implement a similar facility; not only would it show consistency of movement through an environment it would also confirm the direction of that movement. Once again these examples are 2 dimensional, but the final example from Bungie shows the importance of understanding actions from a player's perspective in 3 dimensions. In this example Bungie's analysts noted a high rate of "suicides" in a particular area of a map; the "heat map" would show them the location but the action in this case was not shaped environmentally but locally. "The players were firing the tank's gun when its turret was pointed toward the ground, attempting to wipe out nearby attackers. But the explosion ended up also killing (and frustrating) the player"

(Thompson 2007). In this example 2 dimensional orthographic views and real-time spatial experience combine to give a more complete representation of the causes and effects of a user's navigation through an environment. See Figure 7.

Figure 7. On the left is a 'Heat Map" showing the number of player deaths at particular points within the environment. The map on the right shows specific colours marking player location at five-second intervals. This is one strategy for confirming direction of movement; as well as clearly marking trends and those opposing them.

Within these examples three major issues arise; the qualitative vs quantitative advantages of utilising Colour Intensity and Size as mechanisms to represent duration of stay in any one place; the obscuring of data by either subsequent entries by the same person or by entries from another person; and the representation of the "activity workspace" (Mallasi, 2004). The obscuring of data is seen in Nold's work (Figure 6) and in the authors (Figure 4) and would be a consideration in the development of a cross sectional area representation mentioned above. Currently the authors are able to adjust the translucency of elements within the UT3 environment in real time; extending this functionality to the Porosity Lenses themselves may prove beneficial.

In a paper regarding construction activities' workspace conflicts Mallasi (2004) sees that "to specify the workspace requirement in a dynamic way, while satisfying a set of spatial dynamics and change of workplace over time intervals, is a difficult problem". To mitigate this problem in his research he uses a technique that represents the activity workspace in a series of 3dimensional boxes. Each box defines a workspace (such as above, below, or surrounding) that is a "generic capture of different workspace requirements." While the second Porosity Lens similarly utilises rectilinear blocks it indexes them to the size of the construction worker him or herself. By doing this a more fine grained understanding of the activity workspace would result (see Figure 4).

6. THE NINTENDO WII "BALANCE BOARD" AS AN EXTERNAL SENSOR LINKING PEDESTRIAN MOVEMENT TO UT3 NON PLAYER AVATAR MOVEMENT; AUTOMATING THE COLLECTION OF DATA.

In a typical computer game the avatar translates the actions of real people into the virtual environment. Conventionally one controls their avatar directly and might use a computer keyboard and mouse or gamepad to do so. In addition the computer controls various other characters within the game environment with artificial intelligence. A third category, sensor controlled avatars, has recently emerged. These avatars are controlled by sensors that pick up the movement of a person in a real environment and translate it to a virtual environment. Groenda et al (2005) use tracking and Motion Compression to allow the exploration of "an arbitrarily large virtual environment while the user is actually moving in an environment of limited size". While Motion Compression would be useful for play in gaming halls or at home it takes this tracking technology in the opposite direction to the authors' project that uses sensor controlled avatars for mapping real spaces. In other words, while Gronenda et al saw that the virtual environment would be "limited to the size of the user's real environment" the authors see this as an opportunity to *map the limits* of a real environment by tracing pedestrian movements through it.

Devices for tracking people through environments include GPS (Global Positioning Systems) INS (Inertial Navigation Systems) and Radio Frequency (RF) based positioning systems. Due to the particular challenges of urban environments none of the systems listed above offer a comprehensive solution. A hybrid system is required. Allen et al note the "widespread availability" of low-cost computer game peripherals and see an opportunity to "adapt technology designed for the entertainment industry and develop low-cost measurement tools for use in clinical science and rehabilitation engineering (2007)." A major advantage for Allen et al is to break free from the limits of the clinic; a key limit being expensive equipment. For the author's the major advantage is that with "widespread availability" ultimately there may be a good chance that a pedestrian might already be carrying the sensor we could use to track them.

With the notion of repurposing off the shelf computer game peripherals in mind the authors tested a Nintendo Wii "Balance Board" that employed a custom script to interface with a laptop computer. The first version of the code that connected the Balance Board with the PC was written by Nedim Jackman as a part of his undergraduate degree in Computer Science. Jackman originally wrote the software to "measure the deterioration of aged people's balance (Schwarts 2009 in conversation with the authors)." Jacob Schwarts, a Masters student studying with author 1, worked with Jackman to adapt the code so that it translates motion on the WiiBoard to a set of configurable keyboard signals. See "Jackman" in the references for a link to the code.

Both Schwarts and the authors have used the first version of the code to control the movements of avatars within UT3; Schwarts to design and demonstrate his graduation project and the authors to create a three dimensional real-time map of a person's physical movement within a virtual environment. In the first iteration the test subject's movement is very limited; leaning forward/backwards/left/right replaces taking actual steps. While this represents an alternative way to interact with the computer (i.e. not a traditional keyboard or game pad, Jefery Shaw's Legible City 1989-1991 is probably the most well know early example of this) it doesn't capture the act of walking passively. Subsequently the authors worked with Jackman to enable the connection of up to 7 balance boards with the PC. A video clip (www.russelllowe.com/publications/convr2009/convr2009.htm) shows author 1 walking forward across three boards with his movement being translated to the NPA in real time. The second part of the clip shows the author (and NPA) walking to the left. These clips demonstrate that the steps by the author in the physical environment produce a related amount of steps by the NPA in the virtual environment. Demonstrations on www.youtube.com show a Nintendo Wii controller (youtube, 2009) being used to interface with Half-Life 2 (a first person shooter game in many ways similar to UT3) and implicate a further related area for investigation i.e. the integration of multiple gyroscopic devices. While these devices do not represent the ultimate solution they do suggest computer game peripherals could play a role in it.

In contrast to GPS based systems that represent a 'collaboration' between sensors mounted in the environment and sensors carried by pedestrians INS systems record the pedestrian movements independently. Rizos et al (2008) present the notion of "bridging … GPS gaps" with INS systems which overcomes a significant drawback with INS systems; "sensor errors that grow unbounded with time". When a player uses the Wii controller to manipulate an avatar in Half-Life 2 cumulative error is overcome by constant adjustments made by the player in response to their avatars position compared to their desired position. In the case of the NPA no such adjustments can/are be made (the pedestrian sees neither the avatar nor environment). The construction site, by very definition, is in constant flux … the physical environment may not exist to support sensors at one stage of construction and then may make GPS based systems ineffective at a subsequent stage. Strategies for incorporating sensors within buildings as they are constructed are necessary.

7. CONCLUSION AND FUTURE WORK.

Richard Goodwin's Porosity Project contributed to urban mapping in two very important ways; it recognised that public spaces don't end at the envelope of a building and by extension it understood that navigating the city is a 3 dimensional proposition. A key factor of a buildings Porosity is the amount of time a person can spend in different parts of a building; and this duration changes over time.

This research finds that it is possible to represent Porosity in real-time and that an advantageous medium to use to achieve this is computer gaming technology. Extending from Sun et al the Porosity Lenses add persistent traces of movement to the "set of architectural clues in sight" that analysts would be able to use to understand pedestrian movement and space usage within an urban environment. By using computer games the analysts can take advantage of the "positive benefits of video game play" that include "spatial visualization and mental rotation" (Rosser et al, 2007). The computer game UT3 was chosen to construct these prototypes because it represents one of the latest generation of computer gaming technologies, it has a comprehensive and interconnected toolset, and the support of a large game modding community. The Porosity Lenses develop additive and subtractive strategies that have grown out of an examination and criticism of recent urban mapping projects. In this examination three major issues arise; the qualitative vs quantitative advantages of utilising Colour Intensity and Size as mechanisms to represent duration of stay in any one place; the obscuring of data by either subsequent entries by the same person or by entries from another person; and the representation of the "activity workspace" (Mallasi, 2004). Both mechanisms have strengths and weaknesses and further work is required to create a hybrid or develop new alternatives. By utilising a base unit of workspace indexed to the construction worker, which follows them and build's (or carves as the case may be) a total model of their space use over time, a more fine grained understanding of the activity workspace would result.

To represent Porosity in real-time first one must collect the data in real-time. Allen et al note the "widespread availability" of low-cost computer game peripherals and with this in mind the authors the authors sought to extend the modified off the shelf software approach to include hardware. With Nedim Jackman the authors connected 3 Nintendo Wii balance boards to a PC and were able to passively control an Avatar (now a Non Player Avatar, or NPA). This demonstrates proof of concept, but it is by no means a complete solution; future work will look at repurposing the Wiimote, Cellphones and Wireless Motes. Finally, while Gronenda et al saw that a virtual environment would normally be "limited to the size of the user's real environment", and developed "Motion Compression" to circumvent those limits, the authors see restricting the *player* to their real environment as an opportunity to *map the limits* of that environment by tracing pedestrian movements through it.

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