A framework for designing sustainable real estate developments using Quadruple Net Value Analysis and Building Information Modelling

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Abstract

A decision-making framework for real estate development incorporating sustainable principles and using Building Information Modelling (BIM) may enable developers to explore real estate value in more comprehensive and profound ways than achievable through conventional practice. The framework uses the concept of Quadruple Net Value Analysis to structure evaluation of a project. Quadruple Net Value Analysis combines the triple bottom line of sustainable development (economic, environmental, and social sustainability) with sensory value that measure the appeal of the project with respect to sight, sound, touch, taste and smell.

The framework is described from a conceptual vantage and several proof-of-concept experiments of components of the software system are presented. The researchers envision a parametric BIM as a medium for representing designs with 3D modelling, rendering and animation, and the use of interoperable analysis tools to aid the developers and designers in exploring the consequences of the scheme along quantitative and explicit measures. Immersive visualization will help the users perform qualitative assessment of the sensory aspects of the design. Experiments with the software and analytic techniques provide evidence that the tools can enable rapid design of land and property development schemes, automated analysis of the performance of the schemes, rapid alteration of a scheme supporting what-if analysis, and sensory assessment in the immersive visualization environment.

The Quadruple Net Value Analysis framework implemented in a computer platform should enable a real estate developer to analyze a project proposal more holistically and more rapidly, explore more options through what-if scenarios and reach a wide range of empowered and unempowered stakeholders. A development can be designed not only to fulfil the demands of the triple bottom line, but also to appeal at the sensory level to become something that people want to preserve.

Keywords: **land and property development**, **real estate development**, **immersive visualization**, **sustainable development, decision support.**

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1. Introduction

We shape our natural, built and virtual environments and then these environments shape us. Whether it is the clearing of the Amazon rainforest, the building of the world's tallest building, or the latest version of the video game Halo 4, this shaping of our environment touches our lives and influences our experiences. In the mid to late 20th century, Lynch (1960); Alexander (1977); and Relph (1976) equipped us with the tools and the phenomenological framework to read and understand these elements and changes in our environment. The advent of personal computing and the development of CAD, BIM and a range of other simulation programs allow us to virtually design and model changes to our environment. Our research investigates how to capture and apply both tacit and explicit knowledge and test the impact and consequences that environmentally modifying actions would have on our lives.

The issue that interests us is how to increase the ability of real estate developers to design successful and sustainable projects. Our research envisions a computer-based platform for land and property development and design that enables the user to create and evaluate schemes from a comprehensive viewpoint of sustainability. We are employing the concept of Quadruple Net Value Analysis to assess a real estate and land development project along economic, social and cultural, environmental, and sensory (perceptual) dimensions (Jerke, 2008). By using Building Information Modelling technology to create a data-rich 3D model of an alternative scheme, we are able to analyze the scheme rapidly. Parametric modelling capabilities allow us to alter the scheme rapidly, permitting the exploration and comparison of many alternatives. An immersive visualization tool allows us to put people into the planned development in an interactive visual simulation with a full field of vision and the ability to walk or fly through the environment. The platform is intended to allow the user to base choices upon not only quantitative analysis but also, through use of virtual reality tools, formerly tacit knowledge that is now made explicit. We intend it to be a decision-support platform for real estate and property development.

Although our research is still in an exploratory stage, we have conducted several experiments to test feasibility and prove the concepts. Graduate student teams have conducted Quadruple Net Value Analysis of sixteen land and property projects in Texas and one in Chicago, Illinois. By preparing video presentations that incorporate narratives and music audio tracks, we are able to explore filmmaking techniques for conveying tacit, sensory dimensions of the projects. Another exploration has made use of BIM tools to test rapid modelling of alternatives using parametric techniques and the automation of analysis using software interoperability. These models have been introduced into the "BIM CAVE" immersive visualization environment to test both the speed of transfer from the designer's modelling environment to the immersive visualization environment and the sensory presence achieved. Finally, we are beginning a test study of our methods in the real world in conjunction with a homebuilder who is developing a subdivision.

2. Sustainability and modelling

Although some real estate developers achieve enviable records of profitability, there remains a significant amount of uncertainty in whether a project will be successful. Issues such as

carbon footprint and energy efficiency, social benefits, and inclusiveness of stakeholders both powerful and disadvantaged are leading to more complex definitions of success and more complex regulation and approval criteria. Our research makes use of two relatively new ideas in the hope of instigating profound change. Quadruple Net Value Analysis is a comprehensive system for assessing the economic, social and cultural, environmental, and sensory value that is created by real estate development. Building Information Modelling is a powerful information technology for accelerating processes.

2.1 Sustainability

In 1983 Gro Harlem Brundtland, the former Prime Minister of Norway, was asked by the Secretary-General of the United Nations to establish a World Commission on Environment and Development. The commission report formulates the idea that **"**Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations World Commission on the Environment and Development, 1987). It further defines three interdependent elements:

> "**Environmental sustainability** –involving the management and consumption of the Earth's renewal natural resources so as not to exceed the rate at which they are renewed, and ensure that the absorptive capacity of the natural environment to assimilate wastes should not be exceeded or degraded. The extraction of non-renewable resources should be minimized. Future degradation of the natural and man-made environment should be avoided and existing degradation remediated;
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> **Social sustainability** – relating to the cohesion of society and its ability to work towards common goals. Meeting individual needs, such as those for health and well-being, nutrition, shelter, education and cultural expression are considered a priority; and,
>
> **Economic sustainability** – working in concert with environmental and social sustainability to create and maintain robust economies that better meet the needs of its citizens." (United Nations World Commission on the Environment and Development, 1987).

This formulation is widely known as the "triple bottom line" of sustainable development. A good sustainable development must not only be economically viable and profitable, it must meet long term objectives of environmental stewardship and social progress.

2.2 Quadruple Net Value Analysis

While there is wide consensus that shaping our natural, built, and virtual environments has economic, social and environmental consequences, there is a fourth important consequence that is often overlooked: the sensory, perceptual aspect that greatly impacts the appeal of a project. The sensory aspect focuses on how we perceive the environment in which we live and how we sense and appraise change in both the physical and virtual environment.

Apart from eating, breathing and sleeping the fourth thing humans do throughout our lives is assess place—be it a room, a dwelling, a workplace, district or city. In doing this we rely on all our senses—sight, sound, smell, taste, and touch. Place-making is the essence of real estate development value and community building. Places that are desirable to the senses we reward with repeat visits and in so doing ascribe economic and social value and, to varying degrees, environmental protection.

Dennis Jerke (2008) developed the conceptual framework of Quadruple Net Value Analysis to measure the economic, social/cultural, environmental, and perceptual. The technique uses a standard range of metrics that allows us to determine the attributes and performance of real estate assets and allows us to distil the sustainability dividend that arises from their conceptualization, design, delivery, activation, and management. It establishes, structures, and makes explicit knowledge on projects that hitherto existed only in tacit form.

Jerke's original Quadruple Net Value Analysis model focussed only on the visual in its perceptual category. Our research found this focus to be too narrow. We have expanded the perceptual component to include all the senses: sight, sound, taste, touch, and smell. Human experience and resonance of real estate assets rely on a rich combination of all five senses.

These four dimensions can be further defined to allow the computation of a "sustainability dividend" that measures the value of a project in a holistic manner (Booth, 2010). The definition of the sustainability dividend is, *the enhanced financial performance of real estate asset/portfolios that arises from the application of environmental design, science, and solutions to:*

(i) increase the percentage of the tenant's total occupancy cost that is paid to the landlord as net rent; and,

(ii) *groom existing assets, conceptualize, design and deliver new assets which cost less to operate thereby achieving comparatively lower capitalization rates*. (Booth, 2010)

Quadruple Net Value Analysis also allows us to better understand how costs and benefits are spread among the different stakeholders in real estate developments—which include the developer, owner, designers, constructors, regulators, government, tenants, neighbours, and the public. Through the expansion of Jerke's original focus from only the visual element of the perceptual component to embrace all five of the senses we are able to more accurately read real estate projects; determine what attracts repeat visitation; and, begin replication in computer modelling that will lead to refined economic, social and cultural, environmental and sensory performance.

2.3 Immersive visualization

Immersive visualization (also referred to as virtual reality) has advanced from an experimental technology to a commercial product category. The basic characteristics of an immersive visualization system are a computer display that captures enough of the field of

vision to achieve an illusion of reality, sufficient display speed so that the illusion of motion is achieved, and interactive tools that enable the user to navigate and transform the display in near real time. An early implementation was the CAVE (Audio-Visual Experience Automatic Virtual Environment) (Cruz-Neira, et al 1992). We hypothesize that the assessment of sensory aspects of a development project could be achieved through immersive visualization technology.

Architectural projects have been portrayed in animations of 3D models. The animation of the construction sequence as a so-called “4D model” has achieved widespread adoption in industry and is analyzed for effectiveness using numerous industrial cases (Hartmann, Gao and Fischer, 2008). Mafty and Harty (2012) have employed a CAVE to study hospital patient rooms from the architectural and construction viewpoints.

2.4 BIM

BIM has been described thoroughly in various books and references. General discussions of the theory behind information modelling and its applications in architecture have been presented (Eastman et al. 2008; Smith and Tardiff, 2009). Training texts describe how to use tools such as the popular Autodesk Revit BIM authoring system (Vandezande, Read and Krygiel, 2011). Various authors have emphasized the data modelling and computer science perspectives for understanding BIM, the commercial products and how to use them in a practical setting, and the human factors and transformation of design workflow in adopting new integrated software systems.

For our discussion, it is important to emphasize software capabilities provided by BIM that can be exploited to produce our concept of a decision-support platform for real estate and property development. These can be summarized as modelling and visualization, rich models, analysis and simulation, parameterization, and software extension.

BIM builds upon the capabilities long offered by Computer-Aided Design (CAD) software. CAD has been widely used in architecture firms since the 1980’s (Kemper, 1985) to provide 2D drafting and 3D modelling capabilities. Generation of photorealistic imagery and even physically accurate lighting studies has been possible for many years. BIM provides all of the capabilities of CAD so that the designer can create and depict a building of any shape and complexity.

Although CAD systems are essentially graphic editors and visualization tools, BIM adds the ability to create enriched models that associate non-graphic information with the elements in the digital model, a concept often described as “intelligent objects.” While CAD systems consist of tools for drawing lines, arcs, cubes, spheres and other geometric figures, BIM systems provide tools for drawing walls, roofs, floors, windows, doors, and other architectural components. The elements inserted into the model have non-graphic attributes in addition to the geometric descriptions. A wall element may, for example, have a construction type, an assembly definition that describes gypsum board, studs, insulation, and sheathing, a materials cost per unit, an installation cost per unit, and thermal attributes. While CAD models inherently suffer from a paucity of building description limited to the

geometric description, a BIM is more dense and rich in terms of the information expressed about the building.

This rich and extensive building information can be extracted from the BIM to provide input into analysis and simulation tools that can aid in the decision process. Building energy simulation, airflow simulations, daylighting analysis, construction cost analysis, construction scheduling analysis, structural performance and other kinds of analysis have all been integrated with BIM, although these capabilities are not all fully commercialized.

Parameterization enables the rapid creation of complex forms and investigation of designs using “what if” analysis. A BIM tool such as Autodesk Revit allows the user to adjust control points for curves and shapes based upon formulas and computations. By changing the parameters of an equation, a design can be “flexed” to alter the shape in subtle or dramatic ways. Each variant may be analyzed and the variant with the best performance selected. Closely related to parameterization is the concept of constraint modelling that permits the software user to define limits upon dimensions between elements, enforcing such concepts as symmetry, equal spacing, alignments, or offsets.

Autodesk Revit also provides an Application Programming Interface (API) that enables someone with skills in software development to extend the software in profound ways. API extensions may include complex geometric modelling, preparation of input to analysis software, validation and verification of designs, or presentation of analysis output on the geometric model.

These various capabilities appear sufficient to allow the implementation of a modelling, analysis and simulation platform for land development. The API and parametric modelling allow the creation of extensions to the software that enable rapid modelling and exploration of design alternatives. Three-d modelling and visualization enable the portrayal of the design alternative in an immersive visualization environment. The rich model and its integration with analytic tools supports the decision process of the developers and designers.

3. Experiments

Our exploration of contemporary software tools from a theory standpoint suggests that they are sufficient for developing a decision-support platform for real estate and property development. We have conducted several experiments to test the capability of our methods from a practical standpoint.

3.1 Case studies and video documentation

We hypothesize that computer-based modelling which combined visualization with auditory elements has the potential to evoke the other three senses. Although ultimately, we hope to integrate auditory cues in an immersive visualization environment, we have used filmmaking as an intermediate step in the virtualization of real estate projects. In one ongoing experiment, students have tested and refined the Quadruple Net Value Analysis method by analyzing sixteen land and property projects in Texas and one in Chicago, Illinois.

Teams of graduate students conducted site investigation and research using each of the economic, social and cultural, environmental, and sensory value criteria outlined in this paper. A detailed written report was produced for each of the sixteen case study real estate projects. Each team also prepared a video using filmmaking techniques such as combining live footage with still images, panning and zooming on still images, dubbing a narrative onto a visual track, and overdubbing an evocative music track. The videos are meant to express and convey sensory aspects of the project.

An example of these films can be viewed at:

http://www.youtube.com/watch?v=8o_Megxg2fk

The video details the conceptualization of the project, identifies the component parts of the design of the project that accentuate each of the five senses, and presents details on the project's delivery, activation, and management (Sierra, 2011).

Students also used this approach in the interdisciplinary submissions made in the 2010, 2011, and 2012 ULI—the Urban Land Institute HINES competition submissions.

3.2 Seed BIM

To explore the power of BIM to enable a designer to design quickly a building and assess the design with analysis tools, a series of studies have been conducted that resulted in the concept of Signature Architecture Franchising (Clayton et al. 2012). These studies have used Autodesk Revit software for BIM authoring to enable student designers to model a building in a matter of hours. The process depends upon use of template files, referred to as a "seed BIM", that collect the graphic presentation style, the sheet layout, the components to express a design style, and the use of constraint modelling to enforce dimensional and proportional requirements. Depending on the skill of the designer, schematic design of a modest house can be accomplished in as short as four hours of work and modifications can be made in a matter of minutes. Further work is attempting to accelerate the process and include the creation of construction documents.

3.3 BIM CAVE

Other research at our institution has produced an example of a "BIM CAVE" that achieves an immersive visualization environment by using popular commercial software for BIM coupled with multiple displays and high-powered commodity computers (Ganapathi Subramanian, 2012). To test the interoperability between our design tools of Autodesk Revit and the BIM CAVE, seven house models were collected into one immersive visualization model and viewed in the BIM CAVE. The modification of the BIM files for use in the CAVE required no more than five minutes of effort, demonstrating that it is feasible to employ immersive visualization in a design process that involves iteratively viewing a model, and changing it. Students with minimal training are able to navigate the models in the BIM CAVE. Future studies will explore the ability of extending the BIM CAVE to support tacit, sensory evaluation of projects.

3.4 Parametric Urban Modelling

Another experiment investigates parametric urban model development using BIM to enable stakeholders to explore rapidly the implications of urban developments. A software prototype is under development using the Autodesk Revit API. The first step of our implementation is creation of a parametric urban model that can represent a set of urban design components, such as open spaces, roads, pedestrians, properties, buildings, and parking structures, and representation of the associations among urban components using parametric modelling in BIM. With the parametric modelling approach, urban models can store any information as parameters, elements of urban models may be generated according to any parametric values, and relationships among parameters can be demonstrated in the urban model. As such, our prototype enables real-time design changes as users manipulate the model data using parameters, which offers a degree of flexibility for testing multiple development scenarios.

The second implementation step is creating analytical applications using Application Programming Interface (API) and Object Oriented Programming (OOP) in C#. OOP is an advanced software development approach that allows for rapid software development, high degree of maintainability, and high performance with a formal set of rules for creating and operating objects (Cox, 1986; Pinson, 1988). API allows users to access the model data, generate and edit model elements, create customized functions and user interfaces, perform analysis, as well as produce documentations. With API and OOP BIM platform provides, users will be able to modify building information in parametric urban model and link such model information to external databases and calculation engines for performance assessments.

The parametric urban model in BIM and our OOP applications will enable iterations of design, real-time evaluations, and interactive redesign by applying a set of model parameters. It will allow design optimization for a set of evaluation criteria throughout the life cycle.

3.5 REAL PROJECTS

To guide further development of our concepts, we have embarked upon a test case of a real development in partnership with a commercial homebuilder and land developer as part of the REAL PROJECTS educational initiative. Pursuant to a grant made by the College of Architecture, Master of Land and Property Development and Master of Landscape Architecture students are currently undertaking a Quadruple Net Value analysis of the Brazos Valley Affordable Housing Corporation's *Falls Creek Ranch* land subdivision to ascertain how the project's sustainability dividend can be enhanced. Using the BIM platform, Department of Architecture students are conceptualizing, designing, and building a new prototype home. In future semesters, the design process will be supported by a seed BIM, immersive visualization system, and analysis software.

3.6 Quadruple Net Value Analysis

While our previous studies using Quadruple Net Value Analysis, we believe that the technique can be scaled to all types of real estate development, including the residential scale effort in the REAL PROJECTS initiative. Table 1 presents important categories for achieving a thorough and effective analysis. Some of the metrics are already supported by analysis tools or simulation software. We are in the process of developing standard procedures and new software to implement additional metrics.

Table 1. Factors used in Quadruple Net Value Analysis.

Economic	
Return on investment	Profitability, occupancy revenue to investor.
Tax revenue increases	Increased assessed value, sales tax revenue
Increased employment	Construction employment, long-term employment
Economic and infrastructure enhancement	Community advantage and improvements
Cost avoidance	Energy, maintenance, and transportation cost
Insurance and legal costs	Fire, flood, health, lawsuits
Environmental	
Waste reduction	Construction waste, landfill waste, and sewage
Carbon reduction	Energy use, embodied energy, landscape
Water conservation	Rainwater capture, storm water management, flood reduction
Biodiversity	Ecological preservation, native plants, wildlife
Indoor air quality and health impacts	Health, walkability, nature, greenways, paths
Food production	Gardens, farmland
Shelter	Structural integrity, climate protection
Social	
Security and safety	Crime prevention, injury avoidance
Recreation and community interaction	Parkland, public gatherings
Private space	Contemplation, spirituality
Diversity	Racial, socio-economic, cultural
Convenience	Shopping, transportation, schools, place of employment
Sensory	
Sight	Architectural beauty, natural beauty
Sound	Nature, nuisance
Taste	Associations
Touch	Texture, material
Smell	Planting, materials, attractions, nuisance
Temperature and thermal	Temperature, humidity, insolation and shade, wind

4. Platform

From our experiments, we suggest a computational platform for supporting the land and property development process. The activity of creating candidate scheme can be aided by 3D modelling within a parametric BIM software system. The analysis activity produces scores for the scheme from each of the dimensions of the Quadruple Net Value. Quantitative analyses of economic, environmental and social dimensions will be computed using software tools that are interoperable with the BIM and can be done largely in an automated way. An immersive visualization system will be used to assess the sensory effectiveness of the scheme. Finally a scheme may be selected for execution based upon comparison of the sustainability dividend of the multiple candidates. The process and the tools are illustrated in Figure 1.

5. Conclusions and next steps

We conclude that a framework for Quadruple Net Value analysis of real estate development projects using a modelling system for rapid creation of designs, analysis tools that are interoperable with the modelling environment, and immersive visualization for sensory assessment is feasible with modest enhancements to current technology. The capabilities of BIM to provide modelling and visualization, rich models, analysis and simulation, parameterization, and software extension all appear sufficiently robust to allow us to proceed with development of the envisioned platform.

Future work will implement a computer-based research testbed using commodity hardware and software. Research will develop custom software that integrates with the BIM tool to facilitate interoperability to analysis tools. Students will be trained in the theory and technique of using the testbed. Empirical studies in our laboratory will test whether the

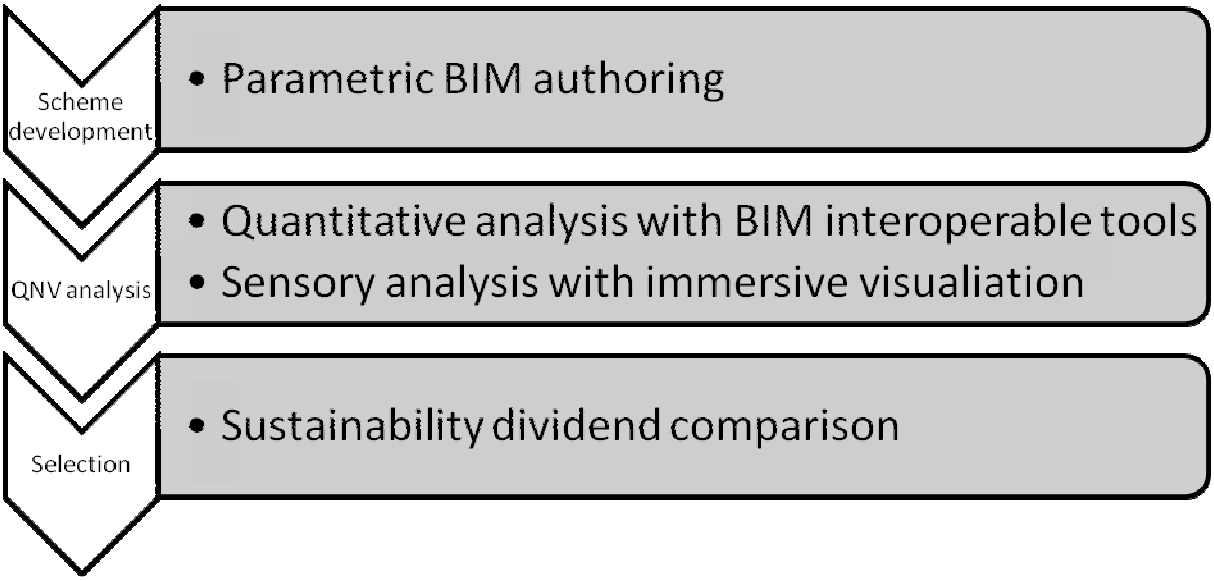

Figure 1. Platform for land and property development.

testbed enables better, more sustainable land and property development projects.

The goal of our research is to produce developments that will not only be profitable, but also will express good citizenship and have lasting appeal. They will be sustainable not only because they meet technical criteria, but also because people want them to be preserved.

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