Economic Value of 3D Geographic Information

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EXECUTIVE SUMMARY

Geographic information systems are becoming increasingly ubiquitous within our lives offering a range of societal benefits. Significant developments in data acquisition techniques, visualisation, image-processing and computing power have facilitated the creation of 3D geographic information (3D GI). While the benefits of using geographic information are clear, formal analyses of its economic value are scarce. As executives face pressure to justify expenditures, there is a global demand to improve accountability, business efficiencies, competitive advantage and resource utilization (Maguire *et al.* 2008). A comprehensive assessment of the economic value of 3D GIS is not only important for judging the viability of investments in information collection, production and provision (Borzacchiello and Craglia 2011) but also for identifying the sectors of society that would benefit the most from such efforts (Castelein *et al.* 2010). Through quantifying value, the following questions can be answered:

- Why invest in 3D GIS? What is the level of investment needed?
- Who is going to deliver these benefits? And what resources are required?
- When will the benefits be delivered? What is the proven financial case?

Quantifying economic value of 3D geographic information, however, is not a straightforward task – there is a lack of a standardised technique and value is highly subjective and context dependent. The majority of existing methodologies focus on tangible measures such as turnover and market size but neglect intangible benefits such as societal impact which may be equally, if not more, important.

This report has provided a preliminary assessment of the economic value of 3D geographic information. Through defining what constitutes economic value and examining 3D GI as an economic good, an improved understanding of the most suitable methods in quantifying value can be gained. Assessing the GI sector through the value chain framework provides a better insight into the various value-generating activities and helps us to capture the full value of 3D GI. The following areas of research for future work are recommended:

1. **Review of the applications of 3D GI** – As value is highly context-specific, there is a need for an extensive review of the applications and uses of 3D GI

2. **Detailed mapping of 3D GI value chain** – Through mapping the different actors within the 3D GI ecosystem and identifying their respective value creating activities, a more comprehensive economic value can be calculated.

3. **Comprehensive comparison of valuation techniques** – A direct comparison between the methodologies on the same case would allow for techniques to be combined in the future to complement and mitigate each other's strengths and weaknesses.

4. **Develop technique(s) in capturing and monetizing intangible benefits** – There is a need of a standardized methodology in capturing intangible benefits such as societal value. Methodologies which include interviews and surveys to capture willingness to pay or self-reported avoided costs are a good starting point to begin monetizing these intangible benefits.

In summary, steps have been made towards understanding the full economic value of 3D geographic information but challenges still remain in identifying the applications and end users; fully mapping the 3D GI value chain; comparison of valuation techniques and; development of techniques in capturing intangible benefits

1 INTRODUCTION

Geographic information systems are becoming increasingly ubiquitous within our lives offering a range of societal benefits from oil and gas exploration to urban planning to humanitarian applications. Significant developments in 3D data acquisition techniques, visualisation, image-processing and computing power have facilitated the creation of 3D geographic information around the world and the ability to handle and work with three-dimensional data (Jazayeri et al., 2014). While the benefits of using geographic information are clear, formal analyses of its economic value or benefit are scarce (Longhorn and Blakemore 2008; Genovese *et al.* 2009).

3D GIS is still a maturing technology and hence there is a practical need to quantify the economic benefits in order to justify continued research and investment within private companies, data vendors, software developers and data producers such as national mapping and cadastral agencies (NMCAs) (Stoter *et al.* 2015). Through quantifying value, it should help accelerate adoption within the consumers of GI and encourage uptake. The ability to assess economically the value of GIS will provide key support in strategic business decisions, helping private companies achieve positive return on investment, improve citizen's quality of life and deliver more efficient government (Genovese *et al.* 2009).

This report is prepared by University College London for EuroSDR 3D Special Interest Group, offering a preliminary assessment on the economic value of 3D geographic information. It will focus on the data aspect of 3D and will not cover 3D geospatial services or systems. The report is supplementary to an extended research plan for a full study in the future. This report aims to define the value of 3D geographic information and critically assess possible methodologies and approaches to quantifying its economic value. It will look at the different actors within the GI sector and their respective roles in creating value within the 3D GI value chain. To conclude, key areas of research for future work will be identified. While this report will offer a better and deeper understanding of economic value, it will not seek to directly quantify economic value due to the restricted nature of financial data but will provide the methodology and means to do so in future studies

Aims:

1. To provide a preliminary assessment of the economic value of 3D geographic information.
2. To identify key areas of research for future work.

Objectives:

1. Define what constitutes "economic value".
2. Evaluate the methodologies to quantify economic value.
3. Assess the role of NMCAs as a data supplier, the data vendor and consumer in creating value.
4. Outline future work and research questions.

The report is structured as follows:

- Section 2 defines what 3D geographic information is.
- Section 3 provides an overview of value in economic theory and 3D GI as an economic good.
- Section 4 evaluates previous methodologies in quantifying value of geographic information.
- Section 5 describes the value chain concept in relation to 3D geographic information.
- Section 6 summarises the main findings of the report

2 WHAT IS 3D GEOGRAPHIC INFORMATION?

Key messages

3D GIS is an emerging technology with many applications and benefits and is available in multiple formats, shapes and forms. As businesses and individuals seek to justify cost and investment, there is an increasing practical need to quantify the economic value of 3D GI. While the tangible benefits of 3D GI are fairly straightforward to calculate, the intangible benefits are much harder to quantify.

This report focuses on the economic value of 3D geographic information and will not cover geospatial services or systems.

A geographical information system (GIS) incorporates hardware and software to manage, analyse and display geographically reference data (Longley *et al.* 2001). It provides a medium to visualize, understand and interpret data and help answer questions and solve problems in a way that is quick to comprehend and accessible to a wider audience. Prior to GIS, geographic information was represented on physical media such as paper maps, which restricted representation to two dimensions (De la Losa and Cervelle 1999). This has contributed to the fact that the majority of contemporary geographic data are in 2D[1]. While humans have spent over two millennia devising increasingly ingenious methods in an attempt to represent our oblate spheroid Earth on a flat surface, there are still certain limitations which restriction our use of 2D geographic representations. Our world is full of complex phenomena and in certain situations, two dimensional abstract representations do not suffice. This, coupled with the rise in computer power, there is a push towards 3D GIS, whereby the extra dimension mitigates the level of abstraction required.

3D geographic information systems is an emerging field within academia and the commercial world. It offers additional functionality not possible in 2D including 3D topology as well as techniques in analysing and querying volume, visibility, surface & sub-surface and shadowing (Zlatanova *et al.* 2002). For example, the combination of subsurface analysis and 3D topological relation allow for strong application in clash detection for utilities and underground infrastructure projects (Frédéricque *et al.* 2011). Another example for 3D specific applications include volumetric calculations allowing for accurate assessment of building capacity as well as forest size (Vanegas *et al.* 2012; Rahlf *et al.* 2014). While the focus of 3D GIS tends towards urban areas and building, it is important to remember there are also non-urban applications such as natural resource management (i.e. forestry) (De la Losa and Cervelle 1999).

Although topology and its various benefits are well understood within the context of 2D, the requirements for 3D data is ambiguous and lacks standardization (Ellul and Haklay 2006). While much has been done in establishing industry-wide standards such as CityGML's level of detail (LoD) classification, the concept is incoherent and inconsistent between practitioners, standards and institutions (Biljecki *et al.* 2014) On a generic level, 3D geographic information is a broad umbrella term, including anything from extruded 2D data with a height attribute (2.5D or pseudo-3D) to true 3D with the possibility multiple Z values at any given XY coordinates. 3D GI can come in multiple levels of detail and can include any combination of the following: simple geometry, complex geometry, semantic information, roof detail and geometry, façade detail, façade texturing, interior structures, vegetation. Further, 3D can come in various scales. Mostly commonly, 3D GI are provided as local

[1] Further, almost all electronic displays are flat and thus perpetuates the usage of 2D data. The emergence of affordable stereo displays technologies such as the Oculus Rift, however, are beginning to enable 3D as an accessible display format (Oculus VR 2015).

and/or project-based models but increasingly they can include city, regional and national level models (SLA 2013; City of Toronto 2015; BBLC 2015). Another difference is that 3D GI can be represented in a multitude of spatial representations. From triangulated meshes to simple extruded polygons to true 3D models, there is a lack of consensus which format is most suitable (Xue *et al.* 2004). Within this report, an all-inclusive definition of 3D GI which covers all of the above is considered as we do not seek to dissect the semantics of the term "3D geographic information". Rather, this report seeks to look at the broader economic ramifications for this particular group of geospatial data.

Despite the fact that GIS users are aware of the potential of 2D data for spatial analysis, the majority of users of 3D data (such as city models) are only aware of the potential as geometric data to produce 3D visualisations and virtual worlds (Walter 2014). 3D GIS, however, is beyond simply rendering of geometry as it draws its strengths from both intrinsic and extrinsic semantic richness, allowing for complex geospatial analysis. The extra dimension removes the need for abstraction and allows for the representation of complex concepts and allows for spatial analysis in three-dimensional space. It is important to remember visualization is only an application and should not be the objective for 3D GIS (De la Losa and Cervelle 1999). Regardless, it is important to not dismiss the power of 3D visualisation. It is visualisation that allows for cognition and evaluation of complex spatial circumstances (Koninger and Bartel 1998). Without visualisation, it would be incredibly difficult to process and understand phenomena in three dimensions

Through providing the tools and spatial data, traditional GIS has a wide of array of both tangible and intangible benefits. Implementation of 2D GIS can save time, improve efficiency, increase accuracy, increase productivity, automate and improve workflows, reduce costs, manage resources better for existing operations, improve quality of services, support informed decision making, increase communication collaboration and help identify new opportunities (Maguire *et al.* 2008). Huxhold (1991) groups benefits of GIS in three major categories: 1) cost reduction; 2) cost avoidance and; 3) increased revenue. In general, the benefits of GI are most significant when it helps decision makers indifferent towards alternative choices; action can be taken in response to the information; the consequences of making the wrong choices is large; the constraints on using the information are few; and the costs of using the information are low (Macauley and Laxminarayan 2010). Similarly, 3D GIS can offer the same benefits but in addition, provide further functionality through the extra dimension including 3D topology and volumetric analysis (Zlatanova *et al.* 2002).

There are many benefits to the implementation of 3D geographic information but executives are increasingly facing pressure to justify expenditure, improve accountability, business efficiencies, competitive advantage and resource utilization on GI projects (Maguire *et al.* 2008). There is, therefore, a practical need and impetus to quantify the value and benefits that 3D GI bring. The complexity of the GI sector, however, confounds the ability to calculate economic value easily. Although the costs of implementation and maintenance are very obvious and tangible, other benefits 3D GI brings are often intangible and thus much harder to quantify. Different consumers of 3D GI consider different properties significant and to the extent which these properties are valued (Krek 2002). Value is based on the perception of the buyer which in turn is based on the context and application in which 3D GI is used. Intangible benefits are not easily estimated and while it does not affect monetary analysis, they can be equally, if not even more important than the tangible benefits (Genovese *et al.* 2009). It is therefore important to consider the societal impacts of 3D GI as well as the impact of society on the development of these geospatial technologies (Chrisman 2005).

3 DEFINING VALUE OF 3D GEOGRAPHIC INFORMATION

Key messages

Economic theories of value are many and varying. Contemporary economics are based on subjective theories of value where value is dependent on individual preferences.

3D GI is non-rivalrous, non-excludable and knowledge-creating. It can be used by multiple users without detriment to its quality, has important wider societal benefits and its value is context-sensitive.

By exploring 3D geographic information as an economic good, its unique characteristics are can be taken into consideration when quantifying its value.

Before quantifying the economic value of 3D geographic information, it is important to define clearly the correct framework in which to assess value and to introduce concepts of value theory, the nature of information and the value of information generally (Genovese *et al.* 2010). The section will begin by covering a few basic economic theories of value, exploring historic and current views. Theories of value have been historically highly debated within the field of economics, varying from intrinsic labour cost of production to the subjective value placed by the consumer. Value as a concept can also take many forms: allocation, economic, exchange, option, market, social, surplus and so forth. It is important to remember this report focuses on *economic* value of 3D geographic information. This is beyond simple market value – economic value represents the maximum amount a consumer is willing to pay for a good or service in a free market economy and is not static (Investopedia 2015). It can vary with price or quality of a good or service and represents the consumer surplus over market value.

This section will then consider 3D geographic information as an economic good and assess its effects on its economic value. 3D geographic information, however, is not a traditional economic good and additional care must be taken when handling its unique characteristics such as its intangible benefits which are difficult to define. While the debate on the "correct" theory of value can be endless, this section focuses on identifying and adapting the framework which fits best when considering 3D geographic information. How can we quantify the value of 3D geographic information? How can we look at traditional theories of value and modify them to help us understand contemporary resources? This section will begin by looking at the varying definitions of value and how it may apply to 3D GI.

VALUE IN ECONOMIC THEORY

The concept of value is one that has evolved and developed over time with theories originating from multiple branches of economics. Traditionally, theories of value were intrinsic, in that the value of an object, good or service is self-contained and derived from the costs in producing and processing it. An example of an intrinsic value is the labour theory of value initially proposed by Adam Smith and further developed by Karl Marx (Kliman 2000). Here, it is argued that value is determined by the total amount of labour required to produce a good or service. By focusing on its practical and tangible aspects, however, the importance of the buyer's perception of value is disregarded and thus is not wholly representative[2].

[2] The classic paradox of value between water and diamonds as described by Smith (1776) demonstrates the flaws within intrinsic theories of value. Value can take two forms: "value in use" and "value in exchange". While water is clearly more useful overall (high utility and value

Contemporary economics are based on subjective theories of value whereby value is dependent on individual preferences. Value is based on how much people are willing to pay for the finished good or service rather than by the value of labour used to create it. It is no longer an inherent property of a good, but determined by the importance an individual places on a good or service for the achievement of their desired ends. This solves the paradox of value as individuals are faced with the choice between definite quantities of goods and the choice made is determined by which good will satisfy the individual's highest subjectively ranked preference or most desired end.

Building upon the subjective theory of value is the theory of marginal utility. Since value is neither determined by the amount of labour used to produce a good or service nor by its usefulness on a whole, it is suggested that price is determined by its marginal utility[3] . Simply, price value of a product is determined by a combination of its abundance and desirability.

Value is a complex concept; as goods and services evolve, so too do the theories that define their value. While valuing physical sacks of grain may be relatively straightforward, the valuation of an intangible good such as 3D geographic information may be more complicated. The next part looks at 3D GI as an economic good and its unique characteristics affecting its valuation.

3D GEOGRAPHIC INFORMATION AS AN ECONOMIC GOOD

Traditional economics focuses on tangible goods and services. Information, however, has now become a dominant resource in our society and is one of our most important and pervasive resource (Cleveland 1985; Onsrud 1995). By applying new information and knowledge, it is possible to gain productivity and efficiency for less labour, capital and physical resource and without reducing the good (Onsrud 1995). Being intangible, considering information as an economic good brings certain considerations and differences to traditional resources such as land, labour or capital. Harlan Cleveland (1985) outlines the following characteristics of information:

- *Information is expandable* – It can be consumed, but not depleted;
- *Information is not resource hungry* – Little physical or biological resources are required to produce and transmit information;
- *Information is substitutable* – It can replace capital labour and physical materials;
- *Information is transportable* – It can travel very fast and is affected very little by geography;
- *Information is shareable* – After information is shared, you can still possess it.

Geographic information and 3D GI possess the same characteristics as above but in addition it is non-rival, knowledge creating and non-excludible (Krek and Frank 2000; Stephan 2004; Haggquist and Soderholm 2015).

- *Non-rivalrous* – 3DGI can be reused and accessed by many users at the same time with no congestion cost[4].
- *Knowledge-creating* – 3DGI remains intangible until it is applied for visible benefits

in use), it has little trade value. Conversely, diamonds are fairly useless (low utility) but command a high trading price. Price is therefore not necessarily dictated by intrinsic value or utility.

[3] Böhm-Bawerk's (1891) uses a farmer and five sacks of grain as an example to explain marginal utility. While the farmer uses the first sack of grain to survive and the second to become stronger to work, the third would be used to feed his animals. The fourth sack would then be used to make whisky and the fifth to feed the pigeons. Now, should the farmer lose a sack of grain, the activities would not be reduced equally by a fifth, but rather, he will not feed the pigeons. Therefore, the value of the sacks of grain are not equal but are dictated by the value of the activity and the respective gains.

[4] Goods such as a road or internet have a congestion cost in that each additional user decreases the speed for others. For 3D GI, there is no congestion cost as it can be accessed and used by many users without detriment to others (Stephan 2004).

- *Non-excludable* – It is often not possible or reasonable to restrict any person's use of 3DGI

These characteristics complicate the valuation of 3D GI. Further, the spread of the internet and democratising of GI have further emphasised these traits (Krek 2002). If an information product such as 3D GI was assessed under the labour theory of value, it would be assigned a high value. This is due to the large upfront cost required to produce it but it does not recognise the multiple subsequent advantages and benefits one may gain from it. Further, it does not consider the on-going maintenance and update costs to keep the data concurrent. Geographic information is therefore typically not effectively priced in existing economic markets (Haggquist and Soderholm 2015).

3D GI, however, may fit well in other economic frameworks. For example, the law of diminishing marginal utility states that as rates of commodity increases, marginal utility decreases. For 3D GI, at the first instance it may provide better understanding of world phenomena and allow for complex 3D visualisation and analysis previously not possible. As the volume of 3D GI increase, however, marginal utility may tend towards zero and even become negative if there is poor data infrastructure and management. When the amount of information available to an actor is extremely abundant or scarce, their ability to use that information becomes restricted (Schroder *et al.* 1967).

An alternative view is to consider 3D GI as a quasi-public good[5]. While 3D GI can be used and reused by many users simultaneously, it is not wholly non-excludible. The recent open data movement have provided increased access to geospatial information to the public, with cities around the world releasing 3D models of their respective locations for free (City of Toronto 2015; BBLC 2015). Licensing restrictions, lack of competence and suitable software within users, however, still restricts its use (Stiglitz 1999; Frank 2001). The public good characteristics of 3D GI means societal benefits must be considered beyond simply financial profitability (Bhagwat and Berg 1991).

In addition to the above, 3D GI hold characteristics of an experience good. An experience good is a product of service which its quality is difficult ascertain until consumption. For example, a movie or a book are experience goods as its value is discovered after watching or reading. Similarly, the benefits of 3D GI emerge only with after its use (Krek and Frank 2000). The uniqueness, context dependence and interdependence among the consumers and producers of 3D GI lead to uncertain benefits and costs. These traits have an effect on the pricing, marketing and design of 3D GI products in order to reduce the perceived risks a consumer may have (Sundbo and Sorensen 2013).

In summary, it is crucial to consider the unique economic qualities of 3D GI and its influences on its value. Its public good traits stresses the necessity to consider wider societal benefits beyond profitability and costs. Further, the economic value of 3D GI is context-sensitive and is determined by the way the information is processed and used. Its value emerges from application and therefore suppliers and vendors of 3D GI must be able to mitigate these perceived risks and gain the confidence of the consumer.

[5] A public good is one that is non-rivalrous and non-excludable. A quasi-public good is one that is essentially public in nature but do not fully exhibit the features of non-excludability and non-rivalry (Riley 2012). For example, roads are available to all, but can become congested and thus there is rivalry in consumption.

4 QUANTIFYING VALUE OF 3D GEOGRAPHIC INFORMATION

Key messages

There is a lack of a standardised technique for estimating economic value of 3D GI as value is highly context dependent. Of the existing methods, the focus is on tangible benefits and value of GI such as turnover or market size.

While intangible and societal value is recognised as part of the full economic value, they are often not considered due to its complexity, cost and the lack of time. Value-elicitation methods which involve stakeholders are most effective in capturing intangible economic value.

As executives face pressure to justify expenditures, there is a global demand to improve accountability, business efficiencies, competitive advantage and resource utilization (Maguire *et al.* 2008). A comprehensive assessment of value of 3D GIS is not only important for judging the viability of investments in information collection, production and provision (Borzacchiello and Craglia 2011) but also for identifying the sectors of society that would benefit the most from such efforts (Castelein *et al.* 2010). Through quantifying value, the following questions can be answered:

1. Why invest in 3D GIS?
2. What is the level of investment needed?
3. When will the benefits be delivered?
4. Who is going to deliver these benefits? And what resources are required?
5. What is the proven financial case?

Though there are many attempts, there is no standardised technique for estimating value or return on investment of using geographic information in an organisation, let alone 3D GI (Maguire *et al.* 2008). This section begins with a review of previous research and attempts to quantify economic value of geographic information. It will seek to identify methodological challenges that require more attention in future research. While it is useful to explore past attempts, it is difficult to compare results directly due to the varying scope and assumptions in their respective methodologies. Nevertheless, it should provide the relevant background to help shape tailor our own approach. It will conclude with suggested methodologies to include within the assessment of the economic value of 3D geographic information.

BENEFITS AND COSTS

Prior to exploring the examples, it is important to consider the two main components of any new implementation: benefits and costs. A benefit, which can be tangible or intangible, is an advantage or profit gained from something. Tangible benefits can be quantified usually with a currency value and is related to future revenue or cost savings (avoided cost). In addition, revenue can be derived from growth in demand or introduction of a new service (Samborski 2007). Cost savings can include reductions in operation costs such as payroll, material, equipment, data and technology license fees. Tangible benefits are more or less straightforward to quantify. Some benefits, however, are much harder to quantify. These are intangible benefits. Intangible benefits may include customer goodwill, improved employee morale, quality of life, environmental health, societal benefits, and community growth (Kirchhoff 2015). While they may not affect financial analysis, they can be equally if not more important than tangible benefits when assessing value. Regardless of tangibility, the benefits of geographic information are largest when 1) decision makers are indifferent to the alternative choices; 2) action can be taken in response to the information; 3) the consequence of making the wrong choices is large; 4) the constraints on using the information are few, and; 5) the cost of using the information is small (Macauley and Laxminarayan 2010).

Contrasting to benefits are costs. Like benefits, costs too can be tangible and intangible. In economics, cost refers to the sacrifice involved in performing an activity whether that is effort, material, resources, time, risks incurred or opportunities forgone. Tangible costs such as salaries, wages, expenses and benefits are easy to ascribe a monetary value. Conversely, intangible costs such as a drop in employee morale, dissatisfaction and decline in service are much harder to measure.

Two categories of costs are relevant when considering 3D GI: start-up and on-going. Start-up costs are incurred at the beginning of implementation and are usually high. They may include new hardware, new software, data acquisition and conversion and start-up services. After the initial investment, on-going costs include new hires, salary adjustments, hardware and software maintenance fees, training, support services and data license fees (GITA 2006). It is critical to when valuing 3D GI to consider thoroughly the wide reaching benefits, start-up costs and on-going costs in order to justify the business case correctly.

METHODS IN QUANTIFYING VALUE OF GEOGRAPHIC INFORMATION

While there is research in overcoming technological barriers of 3D GI such as data capture, processing and reconstruction, there is a lack of research into and real practical need to address business barriers to adoption and uptake. For organisations to improve the business case for GIS, they must be able to: 1) link benefits to strategic goals and objectives; 2) ensure the program is business led and not technology driven 3) build a community of advocates; 4) and consistently deliver benefits through a well-structured program that delivers value and not applications (Maguire *et al.* 2008). In order to measure business benefits and its alignment to corporate strategic goals and missions, it is vital to be able to quantify the value of implementation any new software, hardware or data product in a consistent and comparable manner (Craglia *et al.* 2012).

From the previous section, it can be seen that 3D geographic information holds characteristics which does not conform to traditional economic goods and thus quantifying value is not a straight forward task. This section will examine a series of examples and evaluate their context and methodology. As 3D geographic information have very similar economic characteristics to other earth observation derived products, the examples will also include alternative spatial information valuation examples.

Table 1 – Examples of quantifying value of geographic information

Oxera (1999)	• A value-added[6] approach to estimate the economic contribution of Ordnance Survey, Great Britain. • Analysis based on willingness to pay[7] would have been preferred, but not feasible in time limit. • Ordnance Survey contributed 12-20% gross value added[8] in key sectors in the economy (utilities, local government and transport). • Mentions but does not measure intangible social gains within analysis.

[6] *Value-added*: This is the difference between costs of inputs to production and the price of output.
[7] *Willingness to pay*: The maximum amount an individual is willing to pay to procure a good or service.
[8] *Gross value added*: Measure of the value of goods and services produced in an area or sector of an economy

PIRA (2000)	• Assesses economic value of public sector information in Europe. • In every EU country, the largest component of public sector information investment is the geographical sector. • European geographical information industries account for €36 billion per year. • Economic value derived from National Accounts information. Where data is missing, information on the investment value and estimates of the value added by users are used to provide figures for economic value.
Frank (2001)	• Cost-Benefit analysis[9] of topographic survey in Austria • Methodology to calculate benefits based on Oxera's (1999) gross value added approach. • Topographic data contributed €100 million to private sector activities.
Roger Tym and Partners (2003)	• A value-added approach and interviews to assess the economic benefits of the British Geological Survey. • Recognises the true value of benefits is measured by customer's willingness to pay. • Of 17 customers interviewed, 4 provided direct estimates of willingness to pay, 3 stated BGS products and services were worth twice to ten times the price. Cost savings and additional revenue produced was used if the interviewee could not provide figures. • The total value added by BGS to national output is between £34-61 billion.
Halsing *et al.* (2004)	• Cost-Benefit analysis of the National Map by U.S. Geological Survey • Developed a simulation model "NB-Sim" to estimate how many application implementation occurred in a given year in order to calculate value. • Net present value[10] of a fully implemented version of "The National Map" is just over $2 billion. Project breaks even in year 14 due to high upfront costs.
Booz Allen Hamilton (2005)	• Return on investment[11] study on quantifying the value of geospatial interoperability at the National Aeronautic and Space Administration (NASA) • Value of geospatial standard measured on projects which have been implemented. • Used the Value Measuring Methodology[12] to evaluate the impact across five value factors: 1) direct user value; 2) social value; 3) operational value; 4) financial value and; 5) strategic and political value. • Projects that adopted and implemented geospatial interoperability standards had a risk-adjusted ROI of 119%.
GITA (2006)	• ROI methodology in assessing geospatial information technology. • Uses questionnaires and surveys with public and private organisations to ascertain benefits received from GI applications. • Conducted site visits for individual case studies of financial performance and strategic impact of proposed or completed geospatial projects.

[9] *Cost-Benefit analysis*: technique to assess social costs and benefits of an investment over a period of time.
[10] *Net present value*: Sum of present values of incoming and outgoing cash flows over a period of time.
[11] *Return on investment*: Benefit to an investor resulting from an investment.
[12] *Value Measuring Methodology:* a tool which develops a framework of values including costs, risks, tangible and intangible returns.

ACIL Tasman (2009)	• Assessed productivity gains from the use of spatial information in New Zealand with sector-by-sector analysis. • Due to the absence of official statistical information on the use of modern spatial information, economic impact assessment presented is based on modelling "with-and-without" scenarios using a computable general equilibrium model. • Non-productivity gains including social, environmental and other long term benefits are recognised but not considered within the scope of work. • The use and re-use of spatial information added $1.2 billion productivity-related benefits to the New Zealand economy. Without key barriers such as data access, inconsistent data standards and lack of skill and knowledge, an additional $481 million of benefits could have been realised.
Castelein *et al.* (2010)	• Assess the economic value of the Dutch geo-information. • Measures economic value in terms of turnover, employment, activities and the market. • Three-fold method: 1) defined the geo-information sector and its main activities with stakeholders; 2) economic data survey and; 3) private sector survey. • Estimated economic value of the Dutch geo-information sector is €1.4 billion.
Genovese *et al.* (2010)	• Using the value chain concept to assess value of GI in Quebec. • Value chain is one of the most suitable approaches to measure the way value is created for the end user amongst the contributors • Developing a tool "Socioscope" to map the links existing between various public and private contributors.
Dewberry (2011)	• Report on USGS National Enhanced Elevation Assessment as a national program • Defined business uses in 34 federal agencies, 13 other private and non-profit organisations • Cost-Benefit Analysis including tangible and intangible benefits • Data collection methodology: online questionnaires and extensive interviews/workshops with key managers and elevation data users. • The assessment results provide significant evidence that an enhanced national elevation program could provide conservatively-estimated net benefits between $116M/year and $620M/year
Booz Allen Hamilton (2013)	• Socioeconomic impact analyses of Earth observations using a variety of methods including impact assessment, cost-based assessment and impact monetization. • Uses an 8-step impact analysis flow which estimates baseline projection, quantifies impacts then monetize the impacts if possible. • If no straightforward monetary valuation is available, more complex non-use analytic methods (contingent valuation) may be used such as stated preference or revealed preference.
OXERA (2013)	• Assessed economic impact of Geo services for Google.

	• Global revenues for geo services are $150-270 billion per year, with a global added value of around $100 billion per year • Quantifies impact of geoservices in three groups: direct effects (gross value added; jobs produced), consumer effects (journey time and fuel savings; educational benefits) and wider economic effects.
Haggquist and Soderholm (2015)	• Reviews methods in assessing economic value of geological information and identifies any methodological challenges. • Suggest further research into public and experience good characteristics of this type of information.

From the above review, it can be seen that the majority of methods (return on investment, cost-benefit analysis) focus on the tangible and easily quantified benefits of GI. These studies focus on turnover and market size rather than societal value which, while useful and important, does not truly represent economic value. Analysis such as cost-benefit have been critiqued as a "dogmatic approach that knows the price of everything and the value of nothing" (Zerbe and Dively 1994). The majority of methods are ex-ante and are estimates or projections from simulated "with-and-without" scenario models. When straightforward monetary valuation is not available or benefits are difficult to measure, more complex non-use analytic methods may be used. Surveys, focus groups and expert panels can be used to produce a contingent valuation. The importance of intangible and wider effects of GI are usually recognised but they are often not considered within the valuation due to resource constraints.

In order to account for the effects of time and economic inflation there is also a need for appropriate discounting during valuation (Obermeyer 1999). This is crucial in providing a realistic assessment of value although ascertaining a suitable discount rate is difficult when interest rates vary year on year and country to country. Further, by discounting, another issues arises whereby the present high upfront costs are exaggerated and the long term benefits of GI in the future are diminished in value. It is therefore essential to understand the characteristics of GI as an economic good when designing a valuation methodology including discounting.

In summary, it is important to remember that value is a perception of the buyer and that it is only realised through application. For estimates more representative of the true value of GI, methodologies which involve stakeholders and consumers such as ones considering "willingness-to-pay" are most effective. There is yet to be a convergence in terms of valuation methodology as the value of 3D GI is highly context dependent.

5 DERIVING VALUE FROM 3D GEOGRAPHIC INFORMATION

Key Messages

The value chain is an effective framework to identify how value is created from initial data collection to the end-user.

NMCAs, data vendors and end users within a simplified value chain all have differing roles and responsibilities. Benefits are accrued by each actor through generated revenue and the public and economy also gain from positive externalities of their activities.

Context dictates value. There is a need to understand better the end users' needs and values through reviewing the different possible applications of 3D GI.

The previous section offered various options in quantifying value but it is important to understand how and where value is generated within the 3D GI sector. In order to do this, it is fundamental to know the stakeholders involved in the value process and understand their roles and responsibilities when defining the value of 3D GI (Genovese *et al.* 2009). As geographic information has a high value, is expensive to produce but inexpensive to disseminate, different actors have varying roles and impact at each stages of its production (Longhorn and Blakemore 2008). Further, each actor have their specific goals as well as their own perception on the value of 3D GI. For example, within the private sector, the monetary value of a GI product must cover the costs of data collection, processing, dissemination, management with a return on investment (Krek 2004). Conversely, within the public sector, GI has direct and indirect social value which are much harder to quantify (Longhorn and Blakemore 2008). Here, GI is valuable not to just the data owner or user, but also to society (Genovese *et al.* 2009).

This section will provide a brief overview of different frameworks in defining how value is derived and the roles of different actors and agencies. We will also look towards three main actors which interact with 3D GI in a different ways: 1) national mapping and cadastral agencies (NMCAs); 2) data vendors and; 3) end users. How is value created at each stage? What are each of the actor's roles in adding value? What are the benefits each actor gains? The value chain concept will be used to help structure the discussion.

THE VALUE CHAIN

Porter (1985) defines the value chain as a process where an organisation as a system is made of subsystems each with its own inputs, transformation process and outputs. This sequential value-adding flow mirrors the production of GI well: from collection to processing to dissemination and analysis, GI is a multi-stage process where revenue is derived at each stage. This makes the value chain framework one of the most suitable approaches to assess GI as the multiple steps in processing GI from its original form into derived products are fundamental when assessing the economic value of GI (Genovese *et al.* 2009). Due to the complex number of variables connected to how GI is produced and used, however, an example of a formal economic analysis based on the value chain framework still does not exist (Genovese *et al.* 2009). Alternative frameworks proposes complex value networks over sequential chains plus sector specific value chains (Crompvoets *et al.* 2010; Macauley *et al.* 2010).

Role of NMCAs (as data suppliers), data vendors and end users

For geographic information and indeed 3D GI, most of the costs are incurred during the initial data collection and is common for information goods (Shapiro and Varian 1999; Krek and Frank 2000). This is due to the high cost of labour of capturing, transformation, analysing and processing the data as well as the on-going cost of maintenance. For 2D datasets at a national level, this task and its relevant costs are usually addressed by the relevant NMCAs. As a data supplier, NMCAs are responsible for creating, maintaining and attributing data. The question here for NMCAs is whether they hold the same responsibilities for 3D. While NMCAs are beginning to produce 3D data, there are still many challenges they face from data management and dissemination to automated 3D reconstruction to justifying the business case and investment (Stoter *et al.* 2015). Should NMCAs produce 3D at a national level or on-demand and to what level of detail? How much should be left to the market and alternative commercial data producers and suppliers? For NMCAs, the country wide coverage and high frequency of updates presents a unique selling point for 3D building models produced by NMCAs and thus preserves value and avoids inconsistences between existing 2D datasets (Stoter *et al.* 2015). NMCAs tend to be publicly owned organisations with an overall goal to provide geographic information of its respective country. This means that while financial profitability is important, they may also be driven by external concerns such as societal benefits and the public good. The balance between the two factors, however, is hard to quantify and is unique to each organisation and country.

As an intermediary step between suppliers and consumers is the role of data vendor. This role may be integrated within the data supplier role occupied by NMCAs or third-party commercial organisations but can also be standalone. The role here is to effectively and efficiently disseminate the geographic information in an easily accessible and user-friendly format. The vendors have an onus in identifying user requirements, enriching datasets and ultimately transform the 3D data into an information product. During this product definition phase, it is critical to correctly understand the customer's needs and values in order to design and develop a successful product to market (Wilson 1993). The vendor also holds the role in increasing market awareness, educating the consumer and encouraging uptake. This is vital, as without the support, the perceived risks of a new information product such as 3D GI is too high and limits adoption. Traditionally the data vendor role is predominantly financially driven although the open data movement and the public desire for free data has disrupted this somewhat.

Lastly, the end users. Arguably the most important group within the value chain as they justify the existence of actors higher up in the chain. From section 2, in general users of GI benefits include time saving, improved efficiency, increased productivity, improved workflows, reduced cost, improved quality of services and improved decision making. As an experience good, however, the exact benefits of 3D GI only emerge after its use and are highly context dependent and specific (Krek and Frank 2000). For example, the avoided cost of a clash within a large utilities national infrastructure project or avoided life loss within the aviation industry can arguably have far higher value than an efficient placement of solar panels on a domestic building using 3D geographic information. There is, therefore, a practical need to identify the existing and potential end-users of 3D GI in order to begin understanding their activities and quantify their perceived value of 3D. This also allows the identification of where 3D has the highest potential and thus valuation can be targeted at these applications in order to capture the most representative result. Table 2 outlines a subset of 3D GIS applications and is by no means an exhaustive list. Of the applications, the next step is to identify each of their 3D requirements from basic building height to detailed roof geometry to textured facades. Alongside this, the market size of each sector should be analysed in order to be assess the economic potential of each application.

Table 2 – A selection of 3D GIS applications

Area	Application	Example	Author(s)
Commercial	Acoustic Modelling	Geoinformatic prediction of motorway noise on buildings in 3D GIS	Pamanikabud and Tanasatcha (2009)
	Air Quality Modelling	Ontologies for the Integration of Air Quality Models and 3D City Models	Metral *et al.* (2012)
	Aviation	Research on Application of Airport Simulation System Based on 3D GIS	Tang and Xu (2012)
	Flood Modelling	A Data Model for Integrating GIS and BIM for Assessment and 3D Visualisation of Flood Damage to Building	Amirebrahimi *et al.* (2015)
	Line of Sight and Viewshed Analysis	Assessing Façade Visibility in 3D City Models For City Marketing	Albrecht *et al.* (2013)
	Real Estate	Modelling the value of view in high-rise apartments: a 3D GIS approach	Yu *et al.* (2007)
	Solar	Viewsphere: a GIS-based 3D visibility analysis for urban design evaluation	Yang *et al.* (2007)
Cultural & Societal	Archaeology	Kinect and 3D GIS in archaeology	Richards-Rissetto *et al.* (2012)
Health	Emergency Services	Emergency response after 9/11: the potential of real-time 3D GIS for quick emergency response in micro-spatial environments	Kwan and Lee (2005)
	Epidemiology	Exploring the Benefits of 3D City Models in the Field of Urban Particles Distribution Modelling—A Comparison of Model Results	Ghassoun *et al.* (2014)
Local & National Government	Emergency Planning	A 3D-GIS Implementation for Realizing 3D Network Analysis and Routing Simulation for Evacuation Purpose	Atila *et al.* (2012)
	Local Amenities	Computer aided design system based on 3D GIS for park design	Lu and Wang (2014)
	Transport Planning	Traffic Management and Forecasting System Based on 3D GIS	Li *et al.*(2015)
Natural Resources Exploration, Extraction and Conservation	Forestry	Comparison of four types of 3D data for timber volume estimation	Rahlf *et al.* (2014)
	Geology	Delivery mechanisms of 3D geological models - a perspective from the British Geological Survey	Terrington *et al.* (2013)
	Natural Disasters	Tsunami Risk 3D Visualizations of Okha Coast, Gujarat (India)	Patel *et al.* (2013)

	Water Bodies	Research and application of 3D GIS technology on the delineation and management of urban drinking water source protection area	Chen *et al.* (2012)
Utilities & Infrastructure	Pipeline management	3D Visualization of Sub-Surface Pipelines in Connection with the Building Utilities: Integrating GIS and BIM for Facility Management	Liu and Issa (2012)
Other	Navigation	3D Navigation for 3D-GIS — Initial Requirements	Musliman *et al.* (2006)
	Virtual Reality	Key to Virtual Insight: A 3D GIS and Virtual Reality System	Van Maren (2003)

In summary, value can be generated at each step of the value chain. Consumers, businesses and government organisations accrue benefits while the public and economy also gain from positive externalities of their activities. The above is a simplified value chain, with three of the main groups of actors and offers a preliminary insight into each of the actor's roles in adding value. The GI industry is complex and has an increasing number of horizontal and vertical links between companies within the supply chain (OXERA 2013). There is a need to map out and identify all the links within the 3D GI ecosystem in order to calculate a representative economic value. There is also a need to understand better the end users' needs and values through reviewing the different possible applications of 3D GI.

6 SUMMARY AND DIRECTIONS FOR FUTURE RESEARCH

This report has provided a preliminary assessment of the economic value of 3D geographic information. Through defining what constitutes economic value and examining 3D GI as an economic good, a better understanding of the most suitable methods in quantifying value can be gained. Assessing the GI sector through the value chain framework provides a better insight into the multiplicity of value-generating activities and helps us to capture the full value of 3D GI. Overall, this report demonstrates that the characteristics of 3D GI as an economic good must be considered during valuation and that the value of 3D GI is highly context dependent. It has identified the following key areas of research for future work:

1. **Review of the applications of 3D GI** – As value is highly context-specific, there is a need for an extensive review of the applications and uses of 3D GI. The adoption of 3D is still in its infancy and its applications are still emerging. Questions include: Who uses 3D GI? Who might use 3D GI? What is the market size of the sector? By identifying the use cases whereby 3D has the highest potential, valuation can be targeted at these applications in order to capture the economic value most effectively.

2. **Detailed mapping of 3D GI value chain** – Value is created and benefits are accrued at each stage of the value chain. Through mapping the different actors within the 3D GI ecosystem and identifying their respective value creating activities, a more comprehensive and representative economic value can be calculated.

3. **Comprehensive comparison of valuation techniques** – Existing studies employ a wide range of methodologies in ascertaining the economic value of GI but there is a lack of research into the between each technique. A direct comparison between the methodologies on the same case and implementation would provide a better insight into the advantages and disadvantages of each approach. Through understanding the limitation, techniques could be combined in the future to complement and mitigate each other's strengths and weaknesses. Retrospective verification of ex-ante valuations could also reduce the level of uncertainty into each technique.

4. **Develop technique(s) in capturing and monetizing intangible benefits** – It is noted that many existing studies fail to address the full economic value of geographic information by focusing on turnover and market size. There is a need of a standardized methodology in capturing intangible benefits such as societal value. Methodologies which include interviews and surveys to capture willingness to pay or self-reported avoided costs are a good starting point to begin monetizing these intangible benefits.

By addressing the above research questions, potential 3D consumers can be identified and their perceived value of 3D can be elicited. This should provide the necessary basis in building effective pricing strategies for 3D data producers and vendors as well as procurement strategies for consumers.

In summary, steps have been made towards understanding the full economic value of 3D geographic information but challenges still remain in identifying the applications and end users; fully mapping the 3D GI value chain; comparison of valuation techniques and; development of techniques in capturing intangible benefits.

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