



**The use of GIS within the Icelandic Construction Industry
in light of propositions about its potential
to implement Lean Principles**

by

Ásgeir Sveinsson

Thesis

**Master of Science in Civil Engineering
with Specialization in Construction Management**

December 2012



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**(Notkun landupplýsingakerfa í íslenskum byggingariðnaði í ljósi
staðhæfinga um getu þess til að innleiða straumlínustjórnun)**

Ásgeir Sveinsson

Thesis submitted to the School of Science and Engineering
at Reykjavík University in partial fulfillment
of the requirements for the degree of
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Supervisor:

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Abstract:

The task of this research was to explore how GIS could be used to implement the principles of lean production in construction projects, and compare the results with related information and communication technology (ICT) use in Icelandic construction industry. The objective was to describe the possible applications of the properties of GIS to enhance the execution of construction projects.

The method used was to juxtapose GIS functionalities with lean principles in order to detect possible positive effects that GIS have on project-driven production. 27 propositions to implement lean principles with the functionalities of GIS were presented supported by theories, concepts and research examples. These propositions along with the definition of key activities in the project delivery phases constituted the basis of the survey of the status and prospects of the use of GIS within leading organizations in the Icelandic construction industry. From those propositions 17 technical methods of GIS integration in construction were derived in order to measure the current state and predict future outlook.

The main findings were that the implementation of lean principles in combination with GIS functionalities has been effective throughout the construction process, but most important is their holistic and early adoption. Using GIS is widespread in the Icelandic construction industry. However, the use is fragmented since GIS is rarely used throughout an organization's projects and only in a portion of the activities where the opportunities lie. On average, the respondents felt that the implementation of the technical methods would have a positive impact on their organization, but hesitation was detected due to business reasons rather than technical.

In the field of ICT, the leading Icelandic organizations in the construction industry are on the threshold between the use of two-dimensional production models and three-dimensional ones. The propositions presented herein could facilitate and accelerate this trend, as well as provide means of measuring the success of the implementation of lean principles and be a basis for further research.

Keywords: Information and communication technology, lean construction, collaboration, project management

Úrdráttur:

Verkefni þessarar rannsóknar var að kanna hvernig nota mætti landupplýsingakerfi (LUK) við að innleiða reglur straumlínustjórnunar í framleiðsluferla byggingarverkefna og bera saman við skylda notkun upplýsinga- og samskiptatækninnar (UST) í íslenskum byggingariðnaði. Tilgangurinn var að lýsa þeim möguleikum sem felast í eiginleikum LUK til að bæta framkvæmd byggingarverkefna.

Aðferðin við að leysa verkefnið var fólgin í því að stilla saman virkni LUK og reglum straumlínustjórnunar til að greina mögulegar jákvæðar verkanir LUK á verkefnadrifin framleiðsluferfi. Settar voru fram 27 staðhæfingar að innleiðingu straumlínustjórnunar með virkni LUK sem spönnuðu allan feril verkefnadrifinna framkvæmda studdar með fræðum, afleiddum hugmyndum og rannsóknardæmum. Þessar staðhæfingar ásamt skilgreiningum á helstu verkþáttum verkefnisfasanna voru lagðar til grundvallar könnunar á stöðu og framtíðarhorfum á notkun LUK hjá leiðandi íslenskum fyrirtækjum í byggingariðnaði. Af þessum staðhæfingum voru dregnar 17 tæknilegar aðferðir við notkun LUK í framleiðsluferli byggingarverkefna til að máta stöðu notkunar tækninnar í íslenskum byggingariðnaði og framtíðarviðhorf.

Meginniðurstöðurnar voru þær að innleiðing sparneytnireglna með virkni LUK hafa skilað árangri víðsvegar í byggingarferlinu en þó er mest um vert að taka þær upp heildstætt og strax í upphafi hans. Notkun LUK er víðtæk í íslenskum byggingariðnaði en er þó brotakennd þar sem LUK er sjaldnast notað í öllum verkefnum fyrirtækis og aðeins í hluta þeirra verkþátta þar sem möguleikar þess liggja. Að meðaltali töldu svarendur að innleiðing tæknilegu aðferðanna hefði jákvæð áhrif á rekstur síns fyrirtækis en vart var við hik sem var fremur sprottið af viðskiptalegum ástæðum en tæknilegum.

Á sviði UST standa leiðandi fyrirtæki í íslenska byggingariðnaðinum á þröskuldi milli notkunar á tvívíðum framleiðslumódelum og þrívíðum. Framsettar tillögur gætu auðveldað og hraðað þessari þróun ásamt því að leggja grunn að hvernig hægt er að mæla árangur af innleiðingu sparneytnireglanna og gera frekari rannsókir byggðar á ramma rannsóknarinnar.

Lykilorð: Upplýsinga- og samskiptatækni, straumlínustjórnun mannvirkjaframkvæmda, samstarf, verkefnastjórnun

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List of abbreviations

TFV	=	Transformation-Flow-Value
ICT	=	Information and Communication Technology
GIS	=	Geographical Information System
TPS	=	Toyota Production System
JIT	=	Just in Time
TQM	=	Total Quality Management
VDC	=	Virtual Design and Construction
LPD	=	Lean Project Delivery
BIM	=	Building Information Modelling
SDI	=	Spatial Data Infrastructure
CAD	=	Computer Aided Design
CAM	=	Computer Aided Manufacturing
DBMS	=	Database Management System
RDBMS	=	Relational Database Management System
SQL	=	Structured Query Language
KM	=	Knowledge Management
LPS	=	Last Planner System
PPC	=	Percentage Plan Completed
AIA	=	American Institute of Architects
PD	=	Project Delivery
IPD	=	Integrated Project Delivery
CM	=	Construction Management
LPD	=	Lean Project Delivery
LPDS	=	Lean Project Delivery System
CPM	=	Critical Path Method
PM4D	=	Product Model and Fourth Dimension
IFC	=	Industry Foundation Classes
CAVT	=	Computer Advanced Visualization Tools
WBS	=	Work Breakdown Structure
OBS	=	Organization Breakdown Structure
IT	=	Information Technology
PC	=	Personal Computer

*“Although the world is created new every day it is always with regard to what it was
yesterday”*

(Laxnes, Halldór. *Vefarinn mikli frá Kasmír*, 1927)



1 Introduction

In this chapter the main line of reasoning for the choice of the research topic will be presented and its context to a real world problem. The aim and objective of the thesis will be stated and the research methodology reviewed. Finally, the outline structure of this thesis will be introduced.

1.1 Background

The world has been evolving at ever fasten rate in the last decades. The main incentives for this evolution are methods and technology based on scientific discoveries, as well as social and economic changes. This trend has resulted in a steadily increasing number of regulations and complex communication in the implementation of projects where sharing of information and knowledge is essential.

In the beginning of the last century a rigid linear solutions were developed in production industry such as the assembly lines at Ford to mention an example. This solution was fit to serve ever growing markets with homogenous needs in stable environment. Derived from the same ideology technical solutions where developed and implemented in urban planning. As the number of cars grew demands for better and bigger roads were pushed forward and as it came to be easier to travel back and forth to work, suburbs spread out with inefficient use of resources and negative environmental impact. This was the era of economics of scale, referred to as “modernism”.

After the mid-20th century problems were piling up in the production industry. Old markets were saturated, new markets emerged with different demands and the old manufacturing systems were too rigid to adjust to these changes. To keep up with the profit it was not enough to speed up the assembly lines or multiply the system, the need for diversity had to be met.

The oil crisis in the 1970s revealed the weaknesses of the economy that was built on such a homogenous and inflexible production methods. The collapse of the communism, growing markets in the developing countries, increasing human rights and democracy led to more diverse and fragmented markets. Information and communication technology see no boundaries and governments ceased protecting local industries. The free flow of goods, knowledge, technology and capital created the bases for what we call in our days “globalisation”. A need for a paradigm shift was advocated by post-modernists.

The movement of post-modernism is defined mostly by what it is not. In the opinion of Newman and Kenworthy (1999), it has no simple solutions and delights uncertainty and celebrates difference. The main reason for the decline of the modernism was: that all human beings are the same and can be programmed into lifestyles just as a machine can be driven or programmed, nature is not important in itself but can be modified to suit our needs, and that efficiency is achieved through large scale mass processes, whether they be industrial production, urban infrastructure or governance (Cook, 1990). Modernism, they argue, is



something that life has been beaten out of. Post-modernism is about planning and managing in times of uncertainty. In this phase, the Toyota production system emerged.

The main trend in the production industry has been to manufacture goods in mass production relaying on craft, machinery and automation but in the last decades the focus has shifted from transformation theory to flow – a value based view in production processes to enable the industry to cope with changing demands. This thinking of production is being related with the term “lean” and is based on the Transformation-Flow-Value (TFV) theory of production.

Another major development aided by the computer in the field of Information and Communication Technology (ICT), having made a big impact on information handling and decision making in the last decades, was Geographical Information System (GIS). Hand in hand with the growing processing power in the 1970s, software has been made that facilitates computerised drawing and developing digital terrain models. Combining these features with cartography, statistical analysis and database technology has resulted in the geographical information system. GIS is a broad concept and its functionality has changed how things are done in many disciplines by its capability of storing, retrieving and analysing vast amount of data.

The success of a project is measured as time, quality and performance and at the present many will add health and environment issues. Information plays an essential role in completing a project successfully and knowledge is said to be the most valuable asset in enterprises to day. The results of research show that the highest occurrence of the reasons for delay in scheduled activities is poor use of information – see, for example, Alarcón et al. (2008).

International construction industry has been criticised for not being able to adopt lean management principles while manufacturing industry has gain substantial profit from it. The evidence for this, presented by Levitt et al. (2007), is the flat productivity curve for construction over the last 4–5 decades, compared to a doubling of productivity over the same period for all firms in the economy. In the world, the lean philosophy has been gaining ground in the project delivery process as methods and tools supporting lean principles are investigated and implemented, but not much appreciation has been noticed in the Icelandic construction industry as recent research from Merchbrock (2009) and Kjartansdóttir (2011) has shown.

Numerous methods, tools and techniques have been devised to facilitate information use and flow in the whole project delivery process. However, they have been criticised for being fragmented and lacking interoperability as well as raising communication barriers. In the quest to implement lean construction principles, integration of ICT tools in lean production systems has proven to be beneficial as the need for communicative collaboration in the whole process of project delivery is much greater than in segregated phases of traditional delivery systems. In the search for better solutions, it would be interesting to examine the impact of GIS on lean construction; but first, a short glimpse of their development is taken.



1.1.1 Development of Lean

Howell (1999) published a report on the development of lean and here the main features of it are outlined. Lean production was developed by Toyota led by engineer Ohno. The idea emerged from two techniques used in Toyota Production System (TPS), Just in Time (JIT) and Total Quality Management (TQM). These techniques adopted by Toyota automobile production enabled pull-driven supply chain and improved value in the workflow. Ohno's main goal was to eliminate waste. The term "lean" was coined by the research team working on international automobile production to reflect both the waste reduction nature of the Toyota production system and to contrast it with craft and mass forms of production. Ohno broadened the focus on the whole process of production instead of the narrow focus of craft production, worker productivity and mass production on machinery. Ohno followed the work of Henry Ford and continued the development of flow based production management but unlike Ford he wanted to build cars to customer order. He created a paradigm for a production system: produce a car to the requirements of a specific customer, deliver it instantly, and maintain no inventories or intermediate stores.

The paradigm shift involved many changes to the old manufacturing method of Ford. Waste is defined by the performance criteria for the production system. Failure to meet the unique requirements of a client is waste, as is time beyond "instant" and inventory standing idle. This requires tight coordination between the progress of each car down the line and the arrival of parts from suppliers. Defects caused unreliable workflow and the arrival of parts assigned in that workflow would be impossible. Engineer Ohno went so far as to require workers to stop the line on receipt of a defective part or product from upstream. Ohno recognized that reducing cost or increasing speed of a single activity could inject variability into the flow overriding the improvement of that activity.

Requiring workers to stop the line decentralized decision making. He carried this further when he replaced centralized control of inventory with a simple system of cards or bins which signalled the upstream station of downstream demand. In effect, an inventory control strategy was developed which replaced central push with distributed pull. Pull was essential to reduce work in process. Less work in process tied up less working capital and decreased the cost of design changes during manufacture as only a few pieces needed to be scrapped or altered. Large inventories are required to keep production in push systems because they are unable to cope with uncertainties in the production system and also raise the cost of change. Ohno also decentralized shop floor management by making visible production system information to everyone involved with production. Transparency allowed people to make decisions in support of production system objectives and reduced the need for more senior and centralized management.

As the formations of waste in manufacturing got clearer to Ohno he moved back into the design process and out along the supply chains. To reduce the time to design and deliver a new model, the production process was concurrently designed along with the design of the car. Engineering components to meet design and production criteria were shifted to where they could best be done. New commercial contracts were developed which gave the suppliers



the incentive to continually reduce both the cost of their components and to participate in the overall improvement of the product and delivery process.

It has been shown beyond reasonable doubt that lean production methods have been a considerable success in the manufacturing industry but it is not as obvious to what extent it has benefited the construction industry. Advocators of lean thinking have applied the principles of lean manufacturing to the construction industry.

In the construction industry there has been a debate on whether or to what extent the lean ideology could be applied. Unlike manufacturing, construction is a project-based temporary production process which focuses on project delivery one at time. Advocators of lean argue that current forms of production and project management in the construction industry focus on activities or transformations and ignore flow and value considerations. The focus on activities conceals the waste generated between continuing activities by the unpredictable release of work and the arrival of required resources. The dynamic nature of the interaction of activities is the concern of lean production. In contrast some say that construction of unique and complex projects in an uncertain environment is fundamentally different from manufacturing and therefore methods for improving manufacturing production do not apply to construction.

To ease the value considerations, projects could be divided into a customer-service system which in every phase of the project an “upstream” service has a “downstream” customer. Failure to meet the customer demand is considered to be waste. Lean construction has been defined by Abdelhamid (2007) as concerned with the holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, salvaging and recycling. In view of Koskela et al. (2002), this approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs.

1.1.2 Development of Geographical Information Systems

GIS evolved from centuries of map-making and compiling registers. The earliest known map is from 1292-1225 BC drawn on parchment to show the gold mines at Coptes during the reign of Rameses II of Egypt. Later, the Greeks acquired cartographic skills and compiled the first realistic maps. They began using a rectangular coordinate system around 300 BC and about 100 years later a scholar from Greece, Eratosthenes, laid the foundation of scientific cartography. In the years to come, drivers for the development of scientific cartography were rooted in cadastral registers for taxation, military operations, utilizing resources, exploration of new land, facilitating sea travel and infrastructure development.

In 1854, John Snow depicted a cholera outbreak in London using points to represent the locations of some individual cases, possibly the earliest use of the geographic method. His study of the distribution of cholera led to the source of the disease, a contaminated water pump within the heart of the cholera outbreak area. While the basic elements of topography and theme existed previously in cartography, the John Snow map was unique, using cartographic methods not only to depict but also to analyze clusters of geographically-dependent phenomena for the first time.



The early 20th century saw the development of photo zincography, which allowed maps to be split into layers; for example, one layer for vegetation and another for water. This reduced the work of the cartographers as editing each layer theme could be adjusted to the rate of change of that theme. It was thus made possible that different kind of themes could be combined to serve the special purpose of the user.

In the early days of computing, GIS was developed on mainframe computers and evolved with the computer hardware and subsequent software development. The first generation approach was to separate spatial and attribute information within the framework of spatial data handling theory but in a second generation approach attribute data were organized into database structures. The fast growing capacity of Personal Computers (PC) facilitated the use and commercial development of GIS and thus the development of Spatial Data Infrastructure (SDI) was crucial in order to enable data and application exchange over the internet.

By the end of the 20th century, the rapid growth of various systems had been consolidated and standardized on relatively few platforms and users were beginning to explore the concept of viewing GIS data over the internet, requiring data format and transfer standards.

1.1.3 GIS and Lean Construction

GIS has made a huge impact on how many traditional activities are conducted in science and engineering and its functions to handle and analyse vast amount of data has been adopted in the construction industry to facilitate visualisation, management, automation, analyses and decision making. The potential of GIS in computer integrated construction has been investigated over the last decade. Case studies and conceptual models have been presented in order to demonstrate the use of GIS in lean construction management and project delivery. Here, in this context, it is sufficient to point to the works of Bansal et al. (2011, 2010, 2009, 2008, 2006) which integrated 3D/4D building models in health and safety planning, scheduling, site allocation, quantity takeoffs and quality control recommendations on one platform for visualization and evaluation. The potential of GIS in the construction process, they argue, lies in topography modelling of the building blocks and the construction site, and geospatial analysis.

Other studies by Khanzode et al. (2006), Gilligan and Kunz (2007), in which lean principles are linked with Virtual Design and Construction (VDC), has shown that it contributes directly to the implementation of lean construction methods. The concept of VDC can be taken to represent GIS or some aspects of it due to the similarity in underlying principles and technologies.

To relate these to the Icelandic construction industry an overview of the situation on the use of the information technology and the characteristics of the Icelandic construction industry will be presented.

1.1.4 Icelandic conditions

The fundamental characteristics of the Icelandic construction industry are that it is mainly contract driven and the contractors compete in a tendering process. Companies therefore do not freely share information or knowledge and act as islands. There are few big contractors



which specialize in big projects, leaving the small and medium companies to the rest of the market. As was seen in the financial boom in the last decade, a considerable number of contractors made houses to stock without actually reflecting the demand or customers' needs.

This fragmentation seems to characterise the execution of projects. Many small contractors with lots of small sub-contractors build the houses from drawings that had been bought without further interventions from the architect. Maybe, when changes were made to the look of the building, they were not welcomed. Often the buyer of the apartment or the house is involved in a part of the building process. It is also common that developers buy building sites on the outskirts of the cities and towns and build low cost buildings. They hire subcontractors to do the work with much disregard for the efforts of others. They just want to come in, finish their job as quickly as they can and move out. This means that the users of the buildings are at arm's length from the design and the construction process.

The mental attitude towards work in Iceland has focused on the physical outcome but reports on quality, control or management issues are often looked at as a drawback to the "real" activity. It looks as though there is a gap in understanding the benefits of the tools and techniques of ICT that could be used in construction management.

To summarize what has been stated above of the characteristics of the Icelandic construction industry, it is:

- fragmented;
- sensitive to economic fluctuations;
- activity-driven processes;
- push demand;
- division of design and construction phases.

So there is evidence of waste as defined in the TFCV theory of production such that improvements could be made. This view on the Icelandic construction industry is supported by Kjartansdóttir (2011) and Merschbrock (2009).

There is a reason to believe that these characteristics of the Icelandic construction market affect the use of information technology in a way that it is fragmented and which therefore does not communicate information effectively. However, Icelanders are quick to adopt new technology, as many examples show, and that was also in the case of GIS. In the late 1980s, GIS was adopted in Iceland and after a few years there were many dozens of GIS licences sold mostly in the public sector. This rapid progress was mainly driven by the need to convert old paper maps to digital form and the belief that this new technology would somehow correct the bad state that these mapping systems were in. In the first years of GIS implementation, the main focus was on solving technical problems. The progress was fast and some awards were won from GIS vendors and others. Iceland was in the lead of applying GIS in the world but after ten years the development stagnated and other nations took the lead. Iceland got behind mainly due to lack of collaboration of GIS technicians with other professions, thus the knowledge of the context to real world problems was missing. A higher-level approach is needed to drive progress into new fields.



1.2. Problem statement

A study from Rischmoller et al. (2006) showed that the great expectations from thirty years ago of the assimilation of the construction industry and ICT have not realized the benefits due to the lack of a framework for its application context. The focus has been too much on the core technology.

In their effort to establish a framework for applying VDC principles to the Lean Project Delivery (LPD) process, developed by Lean Construction Institute, Kanzode et al. (2006) provided a guide for their application to construction projects. These guidelines are for applying the principles of VDC during the LPD process, but it does not provide specific tools or methods to accomplish the objectives of a lean production system. Research by Sacks et al. (2010) juxtaposes Building Information Modelling (BIM) functionalities with lean construction principles and, in a related study, Kjartansdóttir (2011) explored the extent to which the Icelandic construction industry practiced lean construction technology along with BIM implementation. Although there are similarities between GIS and BIM there are also differences, providing different contexts.

In the area of lean construction, Ballard et al. (2001) proposed a guide for the design of production systems by proposing end-means hierarchies to achieve the goals of lean project-based temporary production system. Conditions for creating system control and improvement are included in system design but guidelines and techniques for applying control and making improvements are recommended for further research.

The Icelandic construction industry is facing a new challenge as construction projects have to become more environmentally oriented and more solutions have to be fit to already built surroundings imposing more complex and variable solutions. By number, most contracts are design-bid-construct arrangements where the owner contracts with an architect for a design and with a contractor to execute the construction. However, there has been a trend towards more relational contracts within the construction sector in recent years which promotes interdisciplinary collaboration. This progress is mainly driven by the size and complexity of the projects and the capabilities of the stakeholders.

To address this development it can be assumed that there will be a growing need in the Icelandic construction industry to control the flow of data and integrate the tools of ICT into the construction process to promote faster and better decision-making in the whole project delivery process. The use of applications that handle spatial information is widespread in Iceland; but a special study on how systematic it is, or to what extent it is used in construction projects, has not been made. Linking lean principles with GIS functionality could improve the project delivery process and make the Icelandic construction industry more competitive.

This review led to the main research question:

How can the Icelandic construction industry benefit from the integration of GIS with lean oriented project-based production systems?

This can be broken-down into the sub-questions:



1. Where does the functionality of GIS fit lean construction principles?
2. Where does the Icelandic construction industry stand in integrating GIS with project-based production systems compared to best practice?
3. What are the prospects for GIS adoption in the Icelandic construction industry?

1.3 Aim and objectives of the research

The aim of this research is to examine synergies between GIS and lean construction and compare the outcome to the current practice in the Icelandic construction industry to reveal its future prospects. This will be accomplished with the following objectives.

1. Identify the state-of-the-art of GIS integration in lean-oriented production systems.
2. Describe the state of the practice of GIS integration in project-based production systems in the Icelandic construction sector.
3. Identify the appreciation of the Icelandic construction sector of current and future application of GIS in the construction process with regard to the state-of-the-art.

The goal is to demonstrate how to integrate GIS in the construction process in order to improve its capability to maximize value, minimize waste and get the work done. In addition, the established framework could be used as a basis for further research.

1.4 Limitations

The domain of this thesis is the intersection of project management, temporary production system and ICT. However, it will sometimes be necessary to go beyond these limits to fully clarify the context of the concepts under examination.

The objective of this research is not to prove or disapprove something conclusively but to develop a better understanding of the given problem area by establishing a framework for the role of GIS in structuring the production process. That means it cannot be accepted or rejected conclusively, but in a way criticism can come from the respondents' attitude towards the propositions that the framework delivers.

The selection of the population in the survey was not done randomly, although the approach was to gain insights which would reflect the status and opinions of major organizations in the Icelandic construction industry covering all project delivery phases.

The propositions from the framework indicate opportunities from numbers of principles which GIS affects but are not in any other way a measurement of how well those principles are implemented, although they are supported on the grounds of theories, concepts and empirical evidence. Yin (2003) describes this as analytic generalization which can have much wider applicability than for the sample. For example, statistical generalization could be based on the framework.



In looking for relevant theories, concepts and empirical evidence, the literature review was particularly sensitive to time as an exhaustive investigation was impossible within the period allowed for the research. Peer-reviewed literature was carefully selected to cover all functions of GIS and activities in the project delivery process.

1.5 Evolution of the research and thesis outline

It all started with the question how GIS could be utilized in construction management. Soon, it was obvious that the functionalities of GIS had to be aligned with theories of communication and collaboration to handle the flow of information between various participants in construction projects. Derived from those theories, principles for designing communicative collaboration strikingly resembled those of lean production. This broadened the focus to lean construction and subsequently to project delivery process to be able to define where in the production process the functionalities of GIS would best serve the goals of such production system. Although the research process looks straightforward as depicted in figure 1, it was iterative as discoveries along the way led to revisiting previous sections.

The thesis is divided into six main chapters. In this first chapter, an overview of the research topic and its background has been presented, leading to the formulation of the research work, its limitations and outline. The second chapter explains the choice of research methods to conduct the two interrelated enquiries that the thesis presents. In the third chapter, a state-of-the-art study is conducted leading to a framework definition to analyse the interaction of GIS functionality with lean principles as portrayed by a lean production system. In the fourth chapter, the results are presented and discussed in chapter five. In the last chapter, conclusions are drawn and final remarks are made.

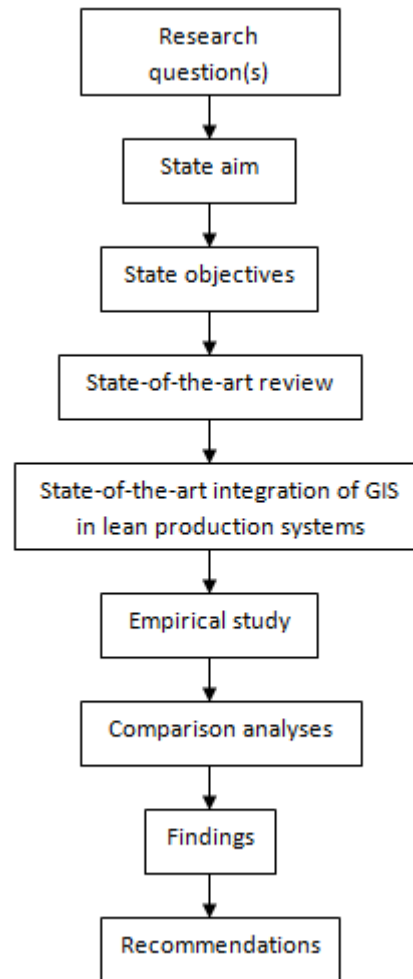


Figure 1: The research process.



2 Research methodology

In this chapter, research methodology is reviewed to find the methods that fit the purpose of the research at hand. First, types and approaches of research are identified, explaining the methods chosen in this research project. It concludes with a description of the process of the collection and analyses of data.

2.1 Types of research

The objectives of research determine the type of research and the type of design to adopt. For the purpose of research, four broad groupings have been defined.

1. Exploratory – to gain familiarity with phenomenon or to achieve new insights into it.
2. Descriptive – concerned with portraying an accurate profile of persons, events or situations.
3. Explanatory – to find causal relationships between variables.
4. Correlation – attempt to discover or establish the existence of a relationship between two or more aspects of a situation.

Most research projects can be classified in the range of descriptive vs. analytical, applied vs. pure, quantitative vs. qualitative, conceptual vs. empirical. A short explanation of the concepts follows.

The major purpose of descriptive research is the description of the state of the affairs as it exists at present. The main characteristic of this method is that the researcher has no control over the variables. In analytical research, the researcher has to use available facts or information and analyse these to make critical evaluation of the material.

Research can be situated in the range from applied to fundamental research. Applied research is aimed at finding solution for an immediate problem facing society or a business organization, whereas fundamental research is mainly concerned with generalisations and the formulation of a theory.

Quantitative research is based on the measurement of quantity or amount and is applicable to a phenomenon that can be expressed in terms of quantity. Qualitative research, on the other hand, is concerned with qualitative phenomena.

Conceptual research is aimed at investigating an abstract idea or theory to develop new concepts or reinterpret existing one, while empirical research relies on experience or observation alone.

Definitions of other types of research are variations of one or more of the above stated approaches, based on either the purpose of research, or the time required to accomplish research, on the environment, or on the basis of some other factors. Research can be one-time research or longitudinal. The former case refers to research in single time-period while the



latter involves several. Research can be set “out-in-the-field”, laboratory-based or as simulation, depending on the environment in which it is to be carried out. The research can be carried out with literature review, critical examination, summarisation, interpretation or evaluation of existing literature in order to establish current knowledge on the subject. It may be exploratory or formalised. The objective of exploratory is the development of hypotheses rather than their testing; whereas formalized research studies are those with substantial structure and with specific hypotheses to be tested. Historical research utilizes sources to study an event or ideas of the past.

This overview of research approaches is not exhaustive but covers the set of philosophies to identify procedures, methods and techniques that have been considered for their validity and reliability in this research project.

2.2 The research approach

Appropriately chosen methods are important to guarantee creation of knowledge and the validation of effective research. They set the research in a system which makes it defensible and reproducible.

The purpose of a research project defines which approach to take, methods, tools and techniques to choose. The main intention of this research project was to identify state-of-the-art of GIS use in a lean-oriented project-based production system and the extent to which Icelandic industry is in line with it. The objective of such research is to gain familiarity with a phenomenon and see how it aligns with industry-leading organizations to reveal possible gaps against which action should be taken. Thus, the method adopted for this research project is exploratory.

There are two basic approaches to conducting research – quantitative and qualitative – depending on the type of data to be collected. As mentioned in earlier, quantitative research is based on the measurement of quantity or amount and is applicable to a phenomenon that can be expressed in terms of quantity. It is concerned with the collection of facts, and sets of facts, and the study of the relationships between those facts to produce quantified and generalizable conclusions. A qualitative approach to research is more concerned with subjective assessment of attitudes, opinions and behaviour and the researcher does not actively and purposely manipulate the phenomenon under investigation. It is suited for unstructured research as is the case for exploratory study. Also, a qualitative research approach can be used to develop the understanding required for evaluating if a variable is relevant or not to a given problem situation. The issue of generalizability arises in the qualitative approach but the research intention is to seek developmental factors rather than claim external generalization. Thus, the appropriate approach chosen for this research is qualitative.



2.3 The research design, methods, tools and techniques

This research is divided in two main, but interrelated, sections because of different methods for data acquisition. First, a thorough literature review on the state-of-the-art was established. It led to a framework which juxtaposes the functionality of GIS with lean principles in production systems stating 27 propositions. Then, from those propositions, a questionnaire on the current state and prospects of GIS usage in the Icelandic construction industry was derived in order to reveal the gap from the ideal state. The exploratory nature of the research demanded flexibility in the research design in the first section, but its results imposed a more rigid design for the second stage.

2.3.1 The state-of-the-art

The literature review is not about reading material and then showing a “thumbs up” or “thumbs down”¹. The “literature” of a literature review refers to any collection of materials on a topic, but it is not the reviewer’s opinion on the material in the context of scientific research.

Literature review has been defined to serve three main purposes as follows.

1. Map-out and establish the state-of-the-art in the subject area surrounding the topic.
2. Draw attention to the gaps in knowledge or concerns about existing understanding.
3. Support the arguments advanced by the researcher in making his or her own case for the chosen topic and research response.

A literature review was conducted to establish the state-of-the-art in the subject area. It was organized to cover relevant concepts, theories and empirical evidence which the state-of-the-art could be based upon. As this enquiry had to be flexible, it placed pressure on the time allocated for this thesis regarding which information to select; however, emphasis was placed on covering all the project delivery phases rather than the number of references.

The strategy set for the review was to use only peer-reviewed papers in journals mostly from the past two decades as developments are rapid in computer science. The focus was to identify how themes or issues connect, find out if there were emerging trends and what might be missing. Therefore, the review had an organizational pattern and combined both summary and synthesis.

2.3.2 The empirical study

The purpose of the second stage of this research project was to establish the state of current practice of GIS in the Icelandic construction industry and its acceptance on technical methods derived from propositions established by the framework as defined from the literature review. The goal was to create an understanding of GIS progress within the Icelandic construction industry.

¹ <http://college.unc.edu>



2.3.2.1 The enquiry

According to Robson (2002), there are essentially three traditional enquiry methods: experiment, survey and case study. Usually, experiments are appropriate for explanatory studies, surveys for descriptive studies and case studies for exploratory work; but in some research, a combination of those methods can be found.

The main objectives of this part of the research were to describe a situation: where does the Icelandic construction industry stand in GIS integration in the project delivery process, and what is the industry's attitude towards or experience with propositions derived from the literature review? Robson (2002) outlines the advantages of surveys as:

- a relatively simple means for studying invisible characteristics such as values and attitudes;
- capable of being adapted to collect generalizable information from almost any human population; and
- permitting large amounts of data standardization.

The main disadvantage of surveys is that respondents' characteristics or backgrounds are not always apparent to the researcher.

These justify the choice of survey method for collecting the data. Although this survey does not claim any generalization over the whole population of organizations in the Icelandic construction industry, its results could be generalized in terms of developmental factors. Not only is it suited to gathering many different kinds of information, but it can do so in a fairly quick and efficient way. This survey is classified as structured as all the respondents were asked questions in the same way. The survey approach is a mix of direct and indirect ways because respondents are asked to respond on their attitude or experience and describe a situation.

2.3.2.2 The sample

The selection of an "average" organization in the Icelandic construction industry would have been of little use for this research project as it is not likely to operate GIS or comprehend the extensive ICT usage in large construction projects. The sample was based on information-oriented sampling, as opposed to random sampling. A number of 29 organizations were selected as the subject and to be measured against the framework defined from the state-of-the-art review. Three conditions had to be met for the selection of an organization:

1. a potential GIS user;
2. leading in the industry; and
3. their aggregated operations should evenly cover all phases of project delivery.

The strategic approach was taken to search for the organisations against the three characteristics that comprise the project delivery phases in addition to choosing those organisations in LISA, an umbrella organisation of GIS users in Iceland, that are involved in



construction projects. *Frjáls verslun*² lists the 300 biggest companies in Iceland according to their turnover, from which 6 contractors, 4 engineering/consultants companies and 5 firms in the field of architecture were selected. From the list, issued by LISA (2012)³, 14 large public or semi-public organizations were selected comprising a sample of 29 as the object of this research enquiry.

2.3.2.3 The questionnaire

The questionnaire was designed to be self-completed with closed questions; apart from one exception, it was split into four parts. In the first part, information about organization size and where in the project delivery phases it operates were gathered. The second part was concerned with lean construction practice while the third was concerned with the extent of GIS current usage in the project delivery phases. In the last part, technical methods derived from the propositions established from the state-of-the-art review for implementing lean principles by GIS functionality were stated for the respondent's evaluation. The questions and instructions were presented both in Icelandic and English to ensure correct understanding of the concepts involved. The questionnaire is presented in whole in Appendix III including the covering and follow-up letters.

The questionnaire was edited in *createsurvey.com* and sent via email with a covering letter and one follow-up letter. It was open from 3-21 September 2012. Three respondents were sent a pilot version to check if the instructions were understandable and to note the time to complete the questionnaire and functionality of the survey overall.

The questionnaire was sent directly to the organization's email address with instructions in the covering letter on what expertise was necessary to answer the questions. Although the information sought was not considered to be sensitive the answers were not traceable to a name.

The responses were analysed in Excel spreadsheet and the results are presented in chapter 4.

2.4 Conclusion on research methodology

In this chapter of the thesis, research methodology has been discussed to explain the methodological framework set for this research project. It was necessary to classify the purpose of the study and to find appropriate methods for its execution, but it also serves the purpose of "validity and reliability" and lays the foundation for, hopefully, further research. Undertaking a research study also implies that it is designed to be unbiased and objective. It means the researcher does not deliberately attempt either to conceal or highlight something and draw each conclusion to the best of his or her ability.

The nature of this research is mainly explorative although it has a descriptive aspect. It is aimed at solving an immediate organization problem in the construction industry and, as such, it is applied research. In addition, it is worth mentioning its historical feature which is

² Volume 8-9, 2011

³ <http://landupplysingar.is>



intended to shed light on the context in which the two emerging technologies of GIS and lean construction are developing.



3 State-of-the-art review

In this chapter, the state-of-the-art of the research topic is mapped-out from a limited literature review. The basic theories and concepts of GIS and Lean will be provided also introducing relevant theories of communicative collaboration and data integrity for theoretical validation on the framework of the research. Project delivery will be conceptualized and its relationship with production systems will be discussed. Finally, emerging evidence of interactions of GIS and Lean will be drawn-out with all concepts leading to the opportunities in integration of GIS in Lean Production Systems.

3.1 GIS

GIS is defined as a system for capturing, storing, querying, analysing and displaying geographic data. GIS is a special class of information system, which can be divided into five components involving a computer system, GIS software, human expert, methods and the data (figure 2).



Figure 2: Components of GIS.

GIS activity can be grouped into spatial data input, attribute data management, data display, data exploration, data analysis and GIS modelling. A workflow model of GIS is depicted in figure 3.

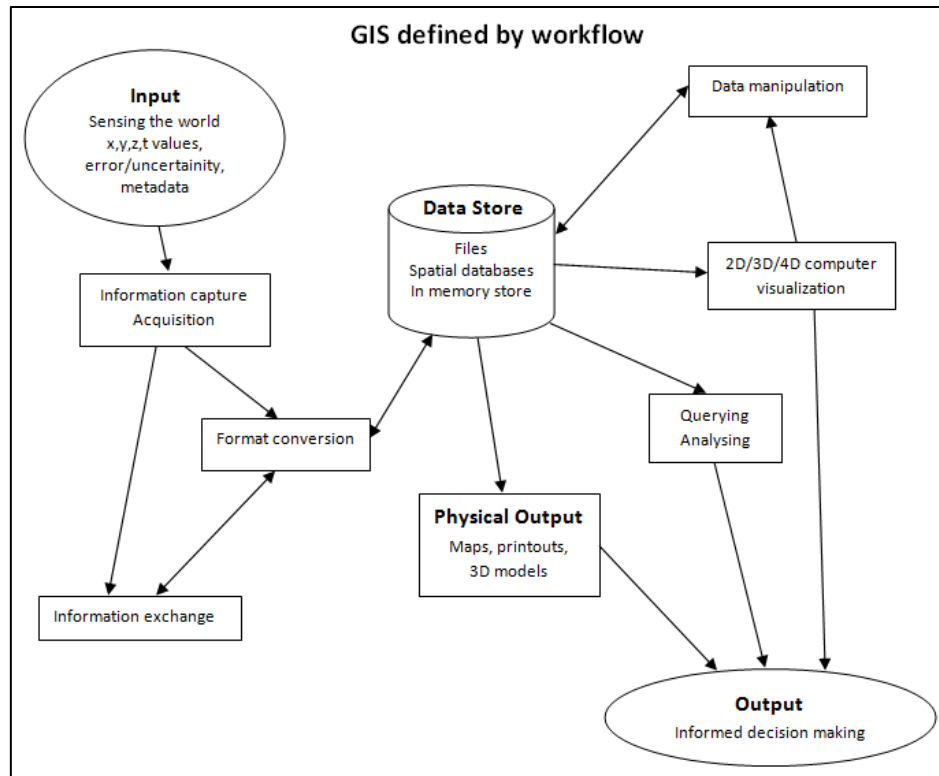


Figure 3: General workflow of GIS activities.

3.1.1 Basic concepts

Computerisation has opened-up new ways to approach documentation and decision-making. Data representing the real world can be stored and processed so that it can be presented later in simplified forms to suit specific needs. When the manipulation and presentation of data relates to geographical locations, our understanding of the real world is enhanced (see figure 4).

Since the mid-1970s, a specialised computer system has been developed to process georeferenced information in various ways. These include, from Bernhardsen (1992):

- organising parts of the information available,
- locating specific information; and
- executing computations, illustrating connections and performing analyses that were previously impossible.

The collective term for such system is GIS and it can be seen as the merging of computer aided design (CAD), spatial data handling and database technology.

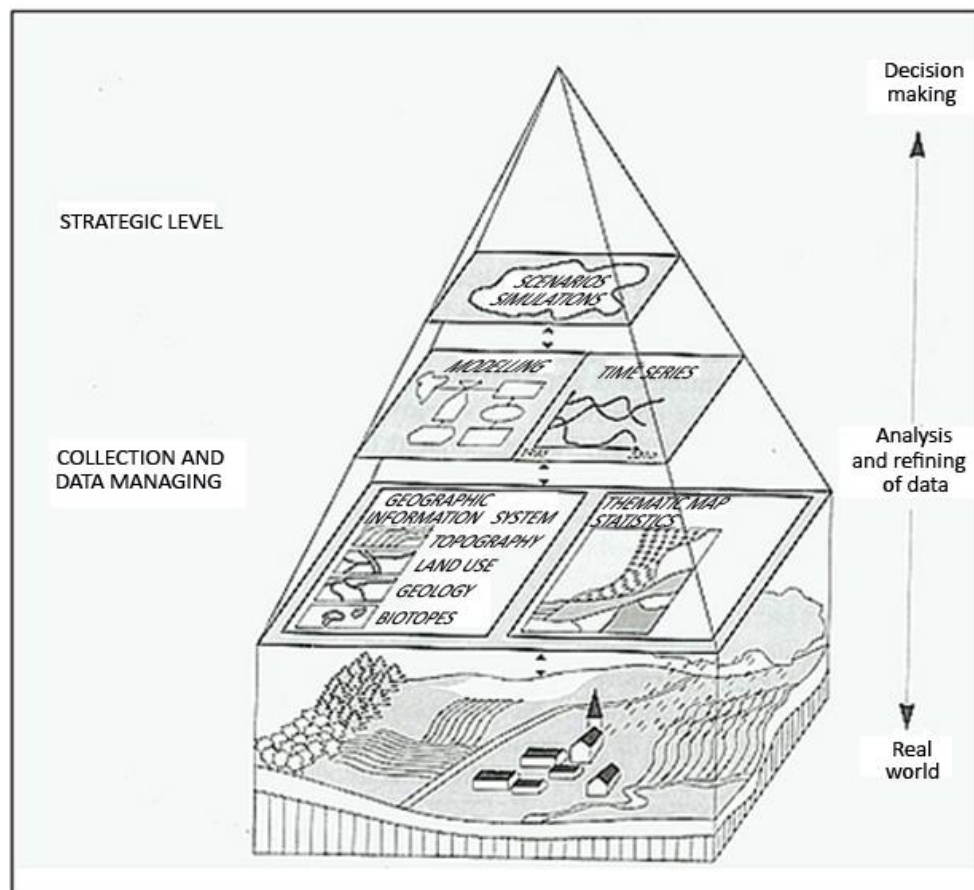


Figure 4: Decision-making pyramid.

(Simplified model of the world is brought into a computer and different techniques applied to the data lay the foundation for the “decision-making pyramid” – source: Grossman, 1983).

These systems are implemented with computer hardware and software functions for:

- acquisition and verification;
- compilation;
- storage;
- updating and changing;
- management and exchange;
- manipulation;
- retrieval and presentation; and
- analysis and combination

of geographic data, which will constitute information on the qualities of, and the relationships between, objects which are uniquely georeferenced (Bernhardsen 1992).

3.1.2 Data integrity

It is appropriate now to introduce the concept of integrity which is closely related to the functionality of GIS. In its broadest meaning, it refers to the trustworthiness of information



over its entire lifetime. A definition from Boritz (2011), in more analytical form, is appropriate for providing the context of this research:

"The representational faithfulness of information to the true state of the object that the information represents, where representational faithfulness is composed of four essential qualities or core attributes: completeness, currency/timeliness, accuracy/correctness and validity/authorization."

Use of information in a process is in accordance with how well these attributes are satisfied.

3.1.3 Spatial data handling

Spatial data handling is about displaying, processing and analysing spatial information often from a query. Many queries explicitly incorporate spatial relations to describe constraints about spatial objects to be analyzed or displayed. Spatial relations can be grouped into three different categories as follows.

1. Topological relations that are invariant under topological transformations of the reference objects (Egenhofer 1991).
2. Metric relations in terms of distances and directions (Peuquet and Ci-Xiang 1987).
3. Relations concerning the partial and total order of spatial objects (Kainz 1990) as described by prepositions such as in front of, behind, above and below (Chang et al. 1989).

In looking for formal and sound methods to describe spatial relations, Egenhofer and Franzosa (1991) introduced a framework for the definition of topological spatial relations which had immediate impact on the design and implementation of GIS because it assured completeness and offered benefits in other areas such as surveying and engineering, computer aided design and computer aided manufacturing (CAD/CAM), and robotics.

Spatial analysis is a term widely used in GIS and can be defined as a set of techniques and models that explicitly use the spatial referencing associated with each data value or object that is specified within the system under study. Spatial analysis methods need to make assumptions about or draw on data describing the spatial relationships or spatial interactions between cases. The results of any spatial analysis are not the same under re-arrangements of the spatial distribution of values or reconfiguration of the spatial structure of the system under investigation (Haining 1994). In general terms this infers that if some related object is missing or altered in computer object model it can be detected with spatial analyses and that topology and topography are at matured state in GIS.

3.1.4 Relational database

The database is another main foundation of GIS. A database comprises one or more files that are structured in a particular way by a database management system (DBMS) for storage and retrieval. Here, a file is regarded as a single collection of information that can be stored (a record). Database systems are distinguished according to the type of database management involved:

- hierarchical database systems;



- network database systems; and
- relational database systems.

Relational database management systems (RDBMS) are the most frequently used in GIS applications, primarily because of their simple and flexible structure where each piece of information needs to be stored once only.

In a RDBMS, data are stored in tables and the relationships among the data are also stored in tables. The data can be accessed or reassembled in many different ways without having to change the table forms.

The most common language to manipulate data in such a database is Structured Query Language (SQL). Relational algebra may be performed using two classes of storage and retrieval operations thus enabling formation of a new table not physically stored in the database. The system permits all objects and attributes to be related to each other, thus enabling storage of complex relationships between real world geographic objects and facts linked to them.

The structure of a RDBMS is well suited to the purpose of an “intelligent” database. Summarized from Wesley (2000) and Blaha (1988) it should:

- align with business objectives of organisations and support their organisational structure;
- contain all necessary data, which is stored once, with no unnecessary data;
- allow data structure to serve many different needs for presentation purposes;
- separate the data processing mode from the updating mode;
- define fields or the characteristics of information in a logical manner and use normalization; and
- have field dimensions that are independent and homogenous.

3.1.5 Benefits of GIS

GIS has proven its usefulness in many branches of science and engineering. Numerous of examples of integration of GIS into real world activities have been published in peer-reviewed journals, ranging from simple map representations to power system analysis tools and energy conservation programs, which have shown direct benefits in terms of time, cost and performance. An example of implicit benefit of GIS is Google Earth, a system which provides base information of locations and related facts, and with which users can integrate their own data for specific tasks.

In a research project (Bernhardsen, 1992), the gains realised by implementation of GIS in 60 agencies and organizations in Europe and the USA highlighted considerable benefits if a suitable strategy was chosen. The results where that the benefit to cost ratios may be attained dependant upon the stage of implementation:

1. Update and automation of maps = 1/1
2. With addition of internal planning and managing work = 2/1



3. With addition of sharing = 4/1

These ratios are the average for empirical observations and infer that the full potential of GIS is not achieved unless data are shared among various users. Other studies are in agreement with this result in that GIS technology enables data integration across organizations (Campbell and Masser 1991) and stimulates inter-organizational alliance (Nedovic-Budic et al. 2011).

Benefits that are typically identified as the primary drivers for data exchange include the following from Nedovic-Budic et al. (2011):

1. cost savings;
2. improved data availability; and
3. enhanced inter-organizational relationships.

Independent organizations share data which leads to savings in terms of personnel, facilities, data acquisition and maintenance costs. Data availability is improved because fragmented data gathering by many organizations is replaced with a more comprehensive library of geographic information. Data sharing is a fundamental issue of promoting greater cross-organizational communication. It is assumed that among organizations that communicate and share information, there is a stronger opportunity to develop new processes supporting business goals.

An interesting survey conducted by Nedovic-Budic et al. (2011) of data exchange patterns of 245 internal and external organizational units in the USA revealed financial motivation to be a more frequently cited reason for exchange engagement between organizations than inter-organization's units; however, the most frequent internal motivation was due to common missions or goals and saving resources.

The work of Warnecke et al. (1998) highlighted the fact that although GIS has spread out rapidly there has been general inability and even unwillingness in data sharing within and across organizational boundaries which has resulted in low levels of coordination. The problem was not typically of a technical nature, but consisted of various human or soft reasons for resisting seemingly obvious benefits of data sharing. In addition, several studies have shown that in certain circumstances, ICT in construction management has failed to provide a positive return on investment. In a study from Howard et al. (1998), benefits are found in design and administration but not in construction management *per se*.

3.1.6 Conclusion on GIS

Staggering amounts of information are involved in the project delivery process. GIS offers the advantage that it can process and manage quantities of data far beyond the capabilities of manual systems or fragmented application programs dispersed throughout the organisation and with stakeholders. Data are stored in a uniform, structured manner that facilitates data exchange and integration of ICT tools. However, underutilization and interoperability issues have been identified as problems in GIS adoption. Generally, GIS is customised to serve the operational or business objectives of firms and governmental bodies and its applications are



often not interoperable or compatible. To overcome these barriers, focus must be stretched over the SDI, where the concern should be to implement a framework of geographic data, metadata, users and tools that are interactively connected in order to use spatial data in an efficient and flexible way, as well as the redesign of processes.

3.2 Communication and Collaboration

The concepts of communication and collaboration have very broad interpretations. The central position of these concepts in this thesis, as well as their definition and role in the context of ICT tools, database technology, project delivery and project management processes, requires that they should be conceptualised.

3.2.1 Conceptualisation of communication and collaboration

The Oxford English Dictionary defines communication as: “the imparting or interchange of thoughts, opinions, or information by speech, writing or sign”. This definition shows that communication is inevitable if we want to do something for others and if others want us to do something.

The researchers Hirokawa (1982) and Terplan (1987) viewed communication, in a business context of the word, the most important tool for decision making and implementation. This view has an immense relevance when people come together to work in collaboration for a common goal. Dillenbourg (1995) noted that the target of collaboration is problem solving and defined it as: “a coordinated synchronous activity that is the result of a continued attempt to construct and maintain a shared concept of a problem or a goal to be attained”. This shows that the concept communication is firmly linked to collaboration.

The common goal for which people come together has been referred to as a project and a temporal organisation is inadvertently created for its execution (Gardiner 2005). Ngowi (2000) elaborate on this view by noting that, unlike in manufacturing industry, participants of a construction project operate in a temporal multi-disciplinary organisation in which the organisation and its associated relationships end as soon as the project is completed. In recent years, however, there has been a trend towards more integrated and lasting relationships between firms in the construction industry through multiple projects. Organisations employ various processes to achieve their goals and structured business models are developed for managers to identify the processes and activities that enable projects to be carried out effectively.

A fundamental need or model is to allow the sharing of organisational resources (Chen et al. 2003) so that they are available to the right person at the right place at the right time. Two of these models are collaboration and communication, they argue, and they pose enormous challenges to project managers. However, it has been revealed in much recent research – see, for example, Akintoye and Main (2007), Kern and Kersten (2007) and Khalfan et al. (2007) – that the development of models for collaboration and communication continue to elude project managers in construction projects. The skills of project managers are operationalized



only through communication processes as stated in the work of Pinto and Pinto (1990) wherein they recommend that project managers should master communication management.

In a multidisciplinary project delivery, a principal-agent relationship is created throughout the process. In such a relationship, the agent acts on behalf of the principal to deliver the principal's requirements. In doing so, information needs are likely to differ and may even be in conflict as both the principal and agent are striving to maximise their economic position. There is therefore a need for collaboration between these parties to achieve their goals with minimum conflict and maximum chances of success in the overall process.

3.2.2 Knowledge management

Knowledge Management (KM) can be seen as the coordinated actions that an organisation can take to obtain greatest value from the understanding of its processes. It is also the art of encouraging people to share knowledge and information relevant to the success of a project (Tenku 2008). KM functionality is to transfer quality information (necessary, relevant, correct, immediate, easy-to-understand and stimulating) between participants to maintain a shared concept of a problem or a goal to be attained.

Nowadays, the focus on the classical factors of production (land, labour and capital) has shifted to knowledge as the prime competitive resource for the new economy. From the viewpoint of Drucker (1992), knowledge is the most value adding to business operations today and that every organisation could enhance performance depending on how this knowledge is managed. Clarke (1999) and Turner (2000) claimed that traditional project management often employed a simple and passive reporting mechanism instead of dynamic teamwork. Clarke stated that most project organisations consider project management methodology as a corporate reporting tool rather than a useful system which the various parts of the organisations can use to create value through collaboration and knowledge sharing. Harigopal and Satyadas (2001) held that KM should be looked at as a discipline designed to provide strategy, process and technology as a route to increase organisational learning.

Freeze and Uday (2008) believe that ICT systems design should aim to capture tactics and build explicit knowledge as well as map-out the channels to facilitate the flow of knowledge. In their view, through the use of ICT in organisations, an integrative approach to KM should be taken that covers all potential components of knowledge and leverage those strategically aligned to project objectives.

Figure 5 illustrates the relationships between data and information and the interaction of information and knowledge to emphasise that data does not become information unless it is shared. Communication of information creates knowledge, but to facilitate communication, especially in the digital world, knowledge must be first turned into information (Ruggles 1997). The full potential of data, as in the case of tacit knowledge, is not utilized until it is communicated. For example, Harigopal and Satyadas (2001) and Koskinen (2003) view tacit knowledge as one that resides in humans. It is only subconsciously understood or applied and transferred only via observation and practice. It also is an individual's knowledge resulting from his or her perception of a given problem or solution.

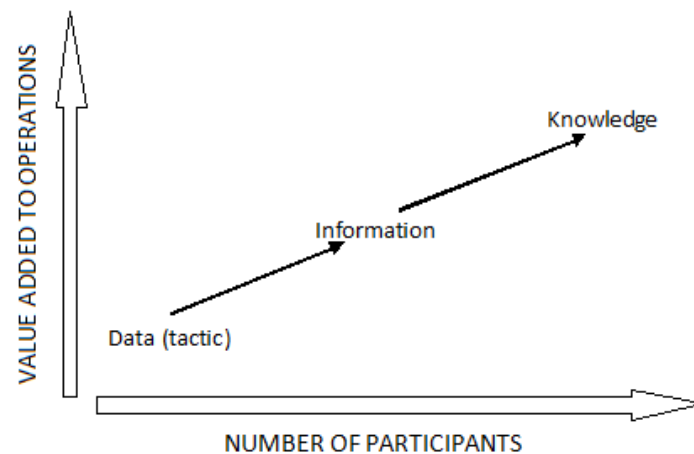


Figure 5: Knowledge building process.

(As the number of participants in communication grows more value is added to business operations. Knowledge is then transformed to manageable information to enhance communication.)

Information technology is described by Alavi and Tiwana (2003) as a “knowledge systems”, and is classified into four “knowledge processes”: creation, storage and retrieval, transfer and applications. Later, in the work of Chi and Holsapple (2005), a five-step explanation to understanding the knowledge management process was provided: knowledge identification, knowledge creation, knowledge codification, knowledge storage and knowledge diffusion and use. They argued that an effective knowledge management process would promote understanding, suppress opportunistic behaviour as well as induce commitment and trust among project stakeholders and participants. The knowledge-based view of an organisation, according to Roth (2003), implies that the creation and dissemination of knowledge should lie at the centre of the organisation’s activities.

3.2.3 Designing communicative collaboration

Growing complexity of construction processes with participants in different locations, as well as the projects, calls for integration of ICT tools in the entire delivery process of a project. Nielsen and Erdogan (2007) maintained that the base for productive and efficient communication should be on a platform that integrates visualisation techniques as well as ICT tools. All the same, recent studies by Morris and Pinto (2004) and Gardiner (2005) on project management and delivery continue to show high numbers of failure in which projects do not meet the performance intended in schedule, cost, quality or functional specifications. Analysis of these studies has revealed that communication and collaborative processes are the main factors dictating projects success or failure.

Information overloads or deficiencies may lead to undesirable consequences. Information must be manage and presented to meet the various requirements of their users. Simple permutation calculation shows that three items can be presented by 6 ways, but six items in 720 stressing the necessity for simple and logical information structure.



This conceptual framework lays down the criteria for designing communicative collaboration model to integrate into information systems. It should be aligned with the business objectives and support organizational needs, incorporate all necessary data no more, no less; it should structure data to serve many different needs of their presentation, have independent and uniform (homogenous) dimensions and use visualisation techniques. These are in line with relational database design criteria presented earlier.

3.2.4 Conclusion

From the above literature review it can be stated that it is important to choose ICT tools that best integrate all aspects of KM and leverage those that are strategically aligned to project objectives. It is also necessary to enhance communicative collaboration over the whole project delivery process to maintain a shared concept of the goals to be attained. In order to resist information islands it is necessary to improve ICT beyond a mere reporting tool and structure knowledge and communication management in a way that promotes collaboration and maintain data integrity. It will enhance teamwork and organizational learning.

3.3 Lean thinking

Lean thinking is a production philosophy, the conception of which evolved through three stages according to Plenert (1990): a set of tools, a manufacturing method and a general management philosophy. This progression is due to the characteristics of the new approach as an engineering-based innovation in contrast to science-based innovation. The practical application of the new philosophy began without any scientific, formalised bases and has diffused by means of the formations of principles and methods to implement them.

Lean thinking aims at maximising value and minimising waste setting the criteria for lean production as: unique custom product, delivered instantly, with nothing in stores. The focus is on how value is generated rather than how any one activity is managed and the delivery of a project is viewed as a production process.

Transparency is an important concept in lean thinking. It aims at making the status of the system visible at all times, so that people can make decisions locally in support of system objectives. This will enable decentralisation of decision making and promote coordination.

Simplicity is a concept understood in production process as a reduction of components or assembly steps to improve performance. To simplify processes it starts with accurate analyses of existing processes to identify potential improvements. It also involves new technological opportunities, knowledge management and change of organisational culture. Practicing simplicity can add value and reduce variability.

3.3.1 Lean construction

The theory of lean construction is that projects are temporary production systems linked to multiple enduring production systems from which the project is supplied with materials, information and resources. Every production system integrates designing and making a



product. Project management is understood in terms of design, operating and improving production systems.

The theoretical basis for lean construction is the Transformation-Flow-Value (TFV) understanding of construction. In flow-view theory, production is understood as a flow of material, labour, equipment and information. A sequence of activities consisting of moving, waiting, processing and inspecting is used to describe the production process over time. The wasteful activities between the processing of products, described as moving, waiting and inspection, are identified. These non-value adding activities are commonly referred to as waste or non-value adding work. One way of presenting the causes of waste, which originates from the types of waste defined by Ohno (1988) and one type, *not meeting value*, added by Womack and Jones (2003), is illustrated in figure 6. One component, that is missing from that picture and generates waste, is the weather or natural forces.

There is potential for cost savings by implementing flow-view thinking and, according to Sowards (2004), contractors that have already implemented lean working principles beat their estimates and work continually to beat them. Sowards also lists the priorities for construction work as understood in the flow-view theory as:

- keep work flowing so that the crews are always productive installing products;
- work has to be made ready every day and anything that is impeding the crews must be eliminated;
- reduce inventory of material and tools; and
- reduce costs.

Many tools and techniques have been developed to implement these principles in the construction process.



Figure 6: Causes of waste.

3.3.2 Lean principles in construction

Here, it is appropriate to dwell a little on the concept of lean principles and their relationship to theory and methods. Principles can be seen as a rule for choosing among solutions to a problem as depicted in figure 7.

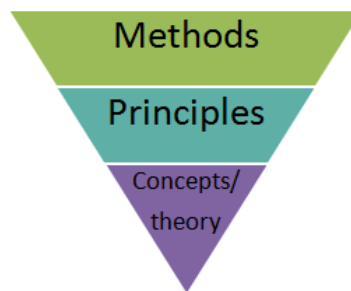


Figure 7: Principles and methods built up from theory and/or concepts.

A principle can be categorised either as descriptive or prescriptive. It has been stated that the characteristics of the new approach to manufacturing are an engineering-based innovation in contrast to a science-based innovation. Lean principles mainly deal with prescriptive outcomes of a system, the final cause of it, which guides one to take the necessary actions to obtain it.



Koskela 1992 stated a set of heuristic principles which has evolved from various subfields of the new production philosophy.

1. Reduce the share of non-value adding activities.
2. Increase output value through systematic consideration of customer requirements.
3. Reduce variability.
4. Reduce the cycle time.
5. Simplify by minimizing the number of steps, parts and linkages.
6. Increase output flexibility.
7. Increase process transparency.
8. Focus control on the complete process.
9. Build continuous improvement into the process.
10. Balance flow improvement with conversion improvement.
11. Benchmark.

In some cases the principles overlap, for example adding value to a product could increase cycle time so a balanced view is needed. Application of techniques constructed from those principles has emerged in lean construction. The best known and relevant to this research are as follows outlined from Merschbrock (2009) and Lean Construction Institute (LCI).

Last Planner System

Last Planner is a production planning system (LPS) designed to produce predictable workflow and rapid learning in programming, design, construction and commissioning of projects. It consists of five elements which involve:

1. master scheduling;
2. phase pull planning;
3. 'make the work ready' planning;
4. weekly work planning; and
5. learning and measuring.

Last Planner deals with the flow of information, work sequencing, measuring work done and a constant learning loop. This technique makes the workers accountable for the completion of individual assignments at the operational level.

LPS is aimed at implementing the 'focus control on the complete process' principle by shifting the focus on production control from reactive approach to proactive. It is a 'look ahead' approach to planning in few levels of detail, from identifying a long range of tasks to detailed decomposition of work and making it systematically ready just before execution by designing the assembly process fully before production. 'Make work ready' means that as tasks are coming up to execution all constraints for a specific task are resolved prior to its start, e.g. availability of competent staff, materials, tools, specifications and authorization. LPS is a technique seeking to systematically reduce the share of non-value adding activities in construction.



The weekly work plan is the sum of the promised tasks and is used to guide what will be done on a daily basis, and its performance is usually measured with Percentage Plan Completed (PPC). By engaging the teams actually doing the work this approach will motivate the workers and reveal lessons to be learnt from planning and design failures. The basic model of this technique is communicative collaboration.

In research by Alarcón et al. (2008), a positive regression from a number of projects was shown between the stage of the LPS elements implementation and higher PPC score. Poor use of information generated during implementation of LPS was identified as the main barrier for complete adoption of LPS elements. To overcome this barrier, use of IT tools resulted in more comprehensive implementation and thus higher PPC score.

Fail-safe for quality

This technique inserts ‘autonomation’ into the work process which gives workers authority to stop the workflow if an abnormal situation arises. It aims at preventing production of defective products, eliminates overproduction and focuses attention on understanding the problem and ensuring that it never recurs. It is a quality control process that applies the following four principles:

1. detect the abnormality;
2. stop;
3. fix or correct the immediate condition; and
4. investigate the root cause and install a countermeasure.

In lean construction, fail-safe actions can be implemented on a job site to ensure first-time quality compliance on all assignments.

One main barrier for implementing this method is that the subcontractors would not be happy if their operative stopped the work when an abnormality arises. Generally, they try to finish the work as quickly as possible and move to the next job. Incentives and transparency of the construction process could be the tools to let this principle work.

Increased visualisation

The mobility of workstations in construction is essential. Increased visualization may help the identification of workflow and create awareness of action plans on site. Visual management is aided by:

- commitment charts;
- safety signs;
- mobile signs;
- project milestones; and
- planned percentage completion charts.



These can be communicated through ICT tools as has been demonstrated by Sacks et al. (2010) as well as on the job site.

First-run studies

Description from LCI⁴: *“Trial execution of a process in order to determine the best means, methods, sequencing etc. to perform it. First-run studies are done at least a few weeks ahead of the scheduled execution of the process, while there is time to acquire different or additional prerequisites and resources. They may also be performed during design as a basis for evaluating options or designing some portion of the work.”*

The drivers in this method are these sequencing commands:

1. plan;
2. do;
3. check;
4. act.

This method is used to implement lean principle of continual improvement in construction process and can be extended to the design phase addressing buildability issues. This operation is aimed at encouraging workers to participate in a problem solving process to provide potential solutions for future activities.

Relevant lean production techniques that can be transferred into lean construction are Just-In-Time, Production Levelling and Standardization.

Just-In-Time (JIT) may be described as the process of producing and delivering products in small quantities, with short lead times to meet specific customer needs. Production levelling reduces variability and inconsistency during production and Standardization involves using stable, repeatable methods everywhere to maintain the predictability, regular timing and regular output from processes.

In lean construction, the emphasis on reliable release of work between participants in design, supply and assembly is to assure that value is delivered to the customer and that waste is reduced. Project activities are interdependent and their interactions are complex. The challenge is to translate principles for organising and managing production within manufacturing so they can be applied in construction.

3.3.3 Critical view of lean

So far methods and approaches of Lean construction have been described but this production management theory has been criticised.

In general terms of this philosophy, Green (1999) (see Howell 1999) describes it as an instrumental rationality in which the end defines the means. The production system is looked at solely from the view of creating value for the client or the owner thus not taking into account social, moral or political aspects. Lean advocates are blind followers of principles to

⁴ <http://leanconstruction.org>



reduce waste, but do not count the stress that is laid on the workers and thus its input to waste generation. He argues that thoughtfulness is seemingly in terminal retreat in the face of an imposed ideology.

Lean advocates have substantiated their arguments by referring to seemingly poor results of the construction industry compared with the great improvements in manufacturing achieved by applying lean principles. Nevertheless, it has been shown by Þorvaldsson (2008) that lack of understanding and education are the prime factors for critical path method and earned value method to fail. Thomas and Shina (2002) state that industrial engineering methods apply only to the extent that construction is like manufacturing.

Another base for criticism is that lean production comes from three different theories, transformation, flow and value, which have three different perspectives. Transformation theory implies transforming resources into goods from a functional point of view; flow theory handles the flow of resources in the whole production process from the view of identifying wasteful activities; and value theory focuses on quality and value generation from the owner's point of view. The complex interaction between these viewpoints makes it difficult to measure results from by using any one or more of the principles derived from those theories.

3.3.4 Conclusion on lean

The aim of lean thinking is perfection which is impossible to achieve. The ideal of implementation of lean applications involves using lean principles to strive for perfection through constant learning loops and benchmarking. Processes can be improved anywhere in organisations, but adoption of lean principles in an enterprise need to be considered at a strategic level.

Partial implementation of lean methods has been developed and adopted in construction industry and it has shown a good result in performance improvement. In research on over 100 projects, Alarcón et al. (2008) provided a computer system to aid the implementation of the LPS which resulted in higher percentage plan completed (PPC) score. Integration of ICT with the production process was the key factor in improving project outcomes.

Research has shown the necessity of a more holistic approach in order to realize the benefits of lean construction techniques and some argue that the full benefits will not emerge unless the processes are altered in conjunction with the implementation of the principle. The goal is to minimise waste and maximise value by improving total project performance because it is more efficient than reducing cost or increasing speed on any single activity.

3.3 Project delivery

In Iceland construction projects have mainly been executed by traditional methods; but in recent years, new management strategies have been introduced that change the way projects are delivered emphasising collaboration between stakeholders, teams and disciplines.

One aspect of this research is to ascertain to what extent Icelandic construction industry utilises GIS in the whole process of initiating, designing, constructing and operating facilities.



As has been mentioned before the Icelandic construction sector is not considered to be lean so it is appropriate to define the broad concept of project delivery (PD) and link it to the concept of lean project delivery and, consequently, to lean production systems.

3.3.1 Project delivery concept

A definition of a project delivery method is that it is a system used by an agency or owner for organizing and financing, design, construction, operations, and maintenance services for a structure or facility by entering into legal agreements with one or more entities or parties. Project delivery methods are developed on the bases of projects phases and currently three main types of contract or project delivery options exist, including design-bid-build, design-build and construction manager at risk (Bongiorni 2011). The definition of the project phases and their key activities is presented in figure 8.

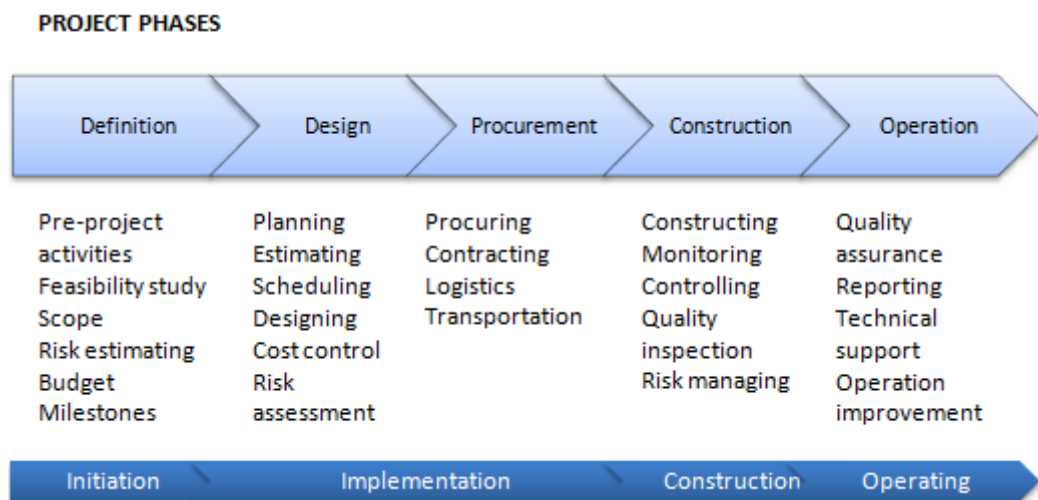


Figure 8: Project phases, relating key activities and processes.

From the American Institute of Architects (AIA) (2007) following methods are outlined. In a design-bid-build type of delivery option, the owner enters a contract with an architect for a design and with a contractor to execute the construction. In design-build type, one entity is responsible for both the design and construction with which the owner contracts. Construction manager at risk is a delivery method in which the construction manager is hired early in the process to establish an early commitment and to manage issues of schedule, cost, construction and building technology.

The target of design-bid-build method is to let the owner choose the most competitive price for the construction of the project. However, there are numerous examples of projects costing the owner much more than expected. The lack of collaboration between the designer and contractor in this process often results in problems that did not get recognized or resolved until the construction process is under way resulting in construction delays, change orders and finger pointing. The main objective of design-build method is to have one contractual



agreement to transfer risk from the owner to the design-build team and increase coordination between disciplines. This method excludes the bid part and can cause increased cost at the beginning of the project, but the intention is to cash in later because it helps to prevent some of the coordination issues that occur in the design-bid-build method. Construction manager at risk has the same contractual agreements as the design-bid-build method and the early cost commitment is like that of design-bid.

As construction projects are becoming more complex both in number of activities, disciplines involved, legal and environmental issues a new concept of Integrated Project Delivery (IPD) has emerged dealing with this variables. According to FMI and Construction Managers Association of America (2005)⁵ between 40% and 50% of all construction phases in traditional PD are running longer than planned making it likely that the project will exceed budget. This transfer of the PD concept to IPD involves adoption of new project management and delivery strategies towards more relational contracts to promote coordination of the participants from day one in the PD process.

A definition of IPD has been formulated by The American Institute of Architects and AIA California Council (2007):

“Integrated Project Delivery is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and optimize energy efficiency through all phases of design, fabrication, and construction.”

Ultimately, the goal of IPD is to make better buildings faster for less money and a way of implementation is suggested with nine principles from The American Institute of Architects & AIA California Council (2007) and Kent and Becerik-Gerber (2010):

- mutual respect and trust;
- shared risk and rewards;
- collaborative innovation and decision making;
- early involvement of key participants;
- early goal definition;
- intensified planning;
- open communication;
- organization and leadership; and
- multiparty agreement.

In work by Fish (2011), those principles are divided in two main categories – key participants and implementation – for the purpose of explanation.

⁵ <http://cmaanet.org>



AIA Californian Council (2007) stated that the most critical element for IPD success is the people involved. These individuals are involved in the project from the early stages of design through construction, building occupancy and operation. The main actors are the owner/representative, architect/designer and general contractor being commonly referred to as the *core group* which is intended to be the decision making body as well as a communication channel from the owner to the remainder of the design/construction parties. The core group is responsible for every aspect of the project from design collaboration to administrative details. Within this group of individuals is where the principles of mutual respect and trust, collaborative innovation and decision making, and open communication are absolutely critical. These principles drive the core group to work toward a set of common goals. Other groups of people need to be included early on in the project in order to harness their talents and insights to select the best solutions for the project execution. This would, in theory, reduce the errors, questions, and change orders that happen in traditional delivery methods due to lack of coordination.

The last principle, *multiparty agreement*, was added by Kent and Becerik-Gerber (2010). A multiparty agreement is one contract encompassing all concerned parties. This is different from the methods used in the previously discussed delivery methods where each entity has its own contract with each of the other concerned parties/groups. A multiparty agreement is made to create a unified group and to eliminate separate motives and separate contracts (Kent and Becerik-Gerber, 2010).

In short, the principle of shared risks and rewards will be dictated by the contract and the timeline set fourth by the core group. It is designed to create a unified core group and add more incentive for the parties to work together to create a better project for the owner. Establishing a contract between the core group members that divides loss and gains between them is though a difficult task.

Early involvement is a core concept in implementing IPD method. The principles early involvement, early goal definition, intensified planning, and organization and leadership all embody this idea. Early involvement is referring to the fact that in pure IPD all disciplines operating in the process are involved and make decisions from the project's beginning. If the goals of the project are set early on everyone will be on the same page and know what is expected of them throughout the duration of the project. Planning of the project execution will take place in the early stages of project design and collaboration. Such an intensive collaboration needs a well-structured organization and leadership.

The advantages of IPD, stated by Fish (2011), in the design phase lie in the formation of the core group and its early decisions in preparing scaled plans and specifications of the components of a project. All parties are present and involved from the earliest design phase and know what is happening throughout the project reducing the potential of conflict related to the design as well as between team players. Through shared risk and reward an "all for one and one for all" relationship is fostered. In the event that one of the core group members would need to be replaced it is more easily addressed as this organizational structure prevents information loss and other members have a general idea of what is happening.



One of the major advantages, according to the American Institute of Architects & AIA California Council (2007), during the construction phase is the ability to reduce construction time. Because of detailed planning and early communication between the contractors and design team, construction coordination and planning can begin earlier in the process. Early coordination, as has been demonstrated by DeBernard (2007)⁶, between all disciplines can reduce construction/installation conflicts, fewer requests for information as well as fewer change orders.

Fish (2011) stated that general advantage of IPD occurs from the team vested interest in the project and therefore will do what is best for the project as a whole which can result in increased profits, a better product and a good reputation for team members as individuals as well as for the team itself.

In its effort to change the delivery process, the construction industry has not seen many improvements in its processes compared to other industries. The key reason is that the construction contract has created tense relationships among the key players in the process by transferring every possible risk to another party (Bongiorni 2011). Three main issues have been identified by Fish (2011) to be critical for IPD success: contracts, insurance, and the IPD facilitator.

Guided by the principles of IPD, as outlined in above, the team focuses on trust, transparency, shared risk and reward, value-added decision making, and technology to complete a project as efficiently and effectively as possible yielding a project that is optimized to fit the owners programme, fully coordinated by early construction management (CM) involvement, executed on budget and on time, and completed without unresolved disputes and claims (Bongiorni 2011).

In the eyes of the advocates of lean construction those principles looks familiar as they address complexity and variability on the PD level with communicative collaboration and a holistic view on the construction process.

3.3.2 Lean project delivery

At this point it is time to examine the effects of Lean methodology on the PD process and how it is related to production systems. A conceptualisation from Mossman (2008)⁷ is provided:

“Lean Project Delivery (LPD) collaboratively aligns people, systems, business processes and practices so as to harness the talents and insights of all participants so that they can optimise value for the client (while creating an appropriate return for all stakeholders), reduce waste and maximise effectiveness through all phases of design, fabrication and construction. Lean projects are led by highly effective collaboration between client, lead designer and lead constructor from early in design through to project handover.”

⁶ <http://aia.org/akr/Resources/Documents/AIAP037286>

⁷ http://thechangebusiness.co.uk/TCB/Lean_Construction_files/What-is-Lean-Project-Delivery.pdf



In content there are not much difference between the definition of LPD and IPD.

Howell et al. (2008)³ stated the three linked opportunities LPD provides: impeccable coordination; project as a production system; and project as collective enterprise. They state that LPD makes available levels of performance not possible under current practice.

Impeccable coordination creates predictable workflow within and across trades and disciplines. Approaching projects as *production systems* opens the possibility of changing the structure of work in both design and construction – which does what, when, where and how. Project as a *collective enterprise* aligns financial incentives and gives the team the ability to move money across commercial boundaries, with the goal of project-wide optimization, rather than a trade-level or silo focus. The goal is to create an “all for one, one for all” mentality.

The Lean Construction Institute conducts research intended to develop knowledge of the management of project-based production systems in the construction industry. From its work, the Lean Project Delivery System™ (LPDS) was introduced. The LPDS model, illustrated in figure 9, consists of 14 modules, 11 organized in five interconnecting triad or phases extending from project definition to design to supply, assembly and use. Production control and work structuring modules extend through all phases and the post-occupancy evaluation module links the end of one project to the beginning of the next as a continuous learning loop.

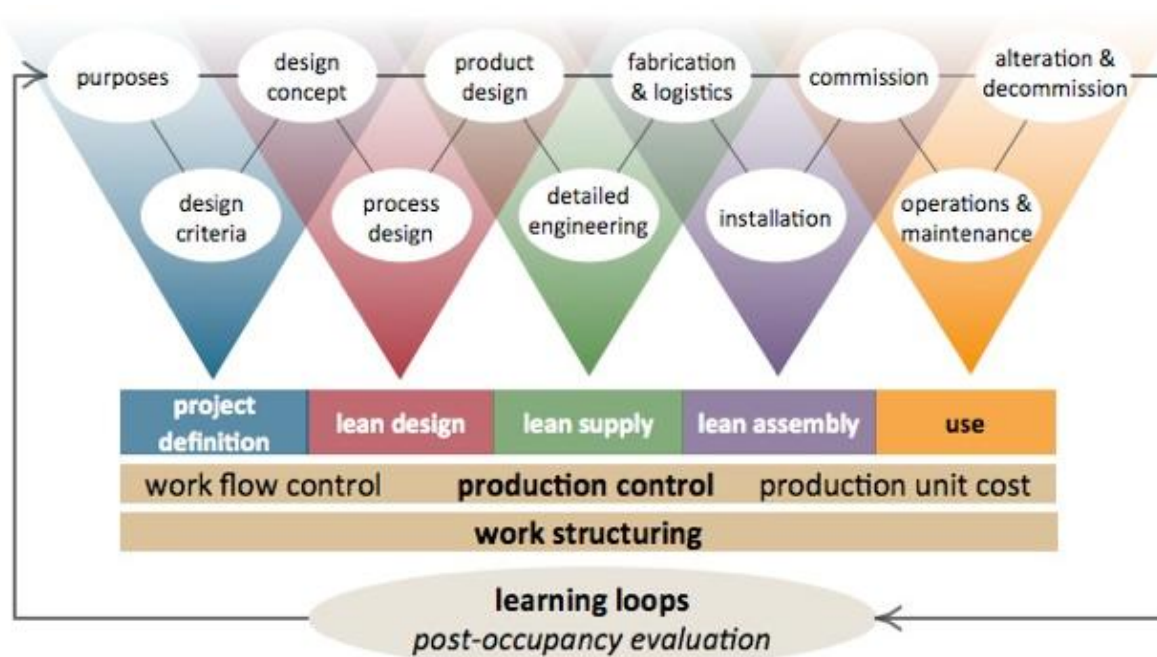


Figure 9: Lean Project Delivery System™ (Ballard 2000).

The system structures the workflow into logical, overlapping, interdependent phases with at least one module common to two phases emphasising on flow and value generation. It differs from traditional delivery systems in the definition of the project phases as sharp segregated activities.



The domain for the LPDS is defined by the intersection of projects and production systems and is defined to be project-based production systems. Some LPDS modules are considered to be applicable to some types of production systems that are not executed through projects. For example, the production control modules may be applicable to project management generally, and also to all production systems driven primarily by directives rather than by predetermined routings between process steps or machines. Especially, implemented in whole LPDS will apply to temporary production systems.

Essential features of LPDS include:

- the project is structured and managed as a value generating process;
- downstream stakeholders are involved in front end planning and design through cross functional teams;
- project control has the job of execution as opposed to reliance on after-the-fact variance detection;
- optimization efforts are focused on making workflow reliable as opposed to improving productivity;
- pull techniques are used to govern the flow of materials and information through networks of cooperating specialists;
- capacity and inventory buffers are used to absorb variability; and
- feedback loops are incorporated at every level, dedicated to rapid system adjustment i.e. learning.

Stated benefits of LPDS from Mossman (2008) and for whom are the following:

For clients

- easier to link design options to client business objectives;
- improved value and a higher quality product;
- greater potential for lower cost;
- reduced energy cost of use; and
- available for use sooner.

For designers

- less rework, minimises iteration;
- system for managing relationships, conversations and commitments;
- decisions at last responsible moment;
- easier to create high quality sustainable buildings;
- easier to design to target cost; and
- reduced design documentation time.

For constructors

- better lean designs;
- more buildable;



- logistics considered from outset;
- system for managing relationships, conversations and commitments;
- greater construction cost certainty; and
- less hassle.

Those statements are of use when looking for empirical evidence in relation to this research.

3.3.3 Conclusion

The growing complexities in executing construction projects and rapid changes in social culture and economics have created a thrust for new methods in PD process. The success of TFM theory in manufacturing has led to the adoption of principles from that theory in the construction industry. The original design of PD as a system of independent phases with well-defined decision gates has proven to generate waste and non-value activities as well as being too rigid to adjust to changes in an efficient way. The emphasis is on the interdependencies of the different phases and collaboration of teams and disciplines as well on financial agreements.

As in the IPD, the lean approach of PD is faced with the problem of serving both the customers and those who deliver the system, i.e. the producers. The latter's interests may vary greatly but the goals of production systems are the same for all partners in the delivery process.

3.5 GIS and Lean Construction

This section will concentrate on the synergies of lean construction and GIS. How has ICT, which shares similar features with GIS, been used to implement lean principles in project-based production?

In his study of two Japanese automakers, Toyota and Honda, Liker et al. (2004) concluded that Toyota achieved competitive advantages by selecting only those ICT opportunities that were needed: "those which could reinforce the business processes directly and test that it were appropriate fit to the organizational infrastructure". Also, he stated that those automakers have had a stunning success in building relationships with North American suppliers by building deep suppliers relationships. In his suppliers-partnering hierarchy, the second principle is to "share information intensively but selectively". This view emphasise the necessity of studying the application context as well as the core technology.

Although the main focus is on GIS influence on lean oriented production systems, general VCD tools are explained in this study when its functionality aligns with those of GIS. In this respect, the concept of the relevant functionality of GIS and lean principles will be drawn out to define the framework used in this research project.



3.5.1 Emerging research and empirical evidence

Animations and simulation scenarios are playing a bigger role as computer hardware gains greater processing power and more user-friendly software emerges.

In work by Haplin and Kueckmann (2002), in which they analysed processes using simulation, their results were that the concepts of lean construction can be validated using simulation as a means for testing lean concepts prior to actual field implementation. Case studies showed remarkable improvements in reducing cycle times by redesigning the processes using lean principles. The activities involved in simulation are breaking down the processes into workflow describing the sequence of the activities involved and simulating the performance of the model. The key is to redesigning the model for comparison to the way it is done in order to identify potential waste, which the simulation technique does not do directly. Simulation with GIS can incorporate all activities involved in the construction process including factors outside the produced components which influence the workflow. Using a 3D model linked to a schedule for visualisation can deliver a vast amount of information that is easy for people to understand as well as exchange their ideas with each other. Therefore, by using GIS as a platform to gather information for simulation analyses, better design of processes could be identified in a quicker way.

Work conducted by Bansal et al. (2008) utilized relational database structures and spatial data handling to link activities from the critical path method schedule to the objects on a single 4D scheduling system for a building construction depicted in figure 10. It facilitates schedule visualization and evaluation of the processes for the interior and exterior of the construction, as well as providing geographical and topological information of the construction elements and of the surroundings. The spatial data handling and the relational database structure revealed inconsistencies in sequencing and coordination of scheduled activities and objects in the building model and also between objects and non-spatial data linked to them.

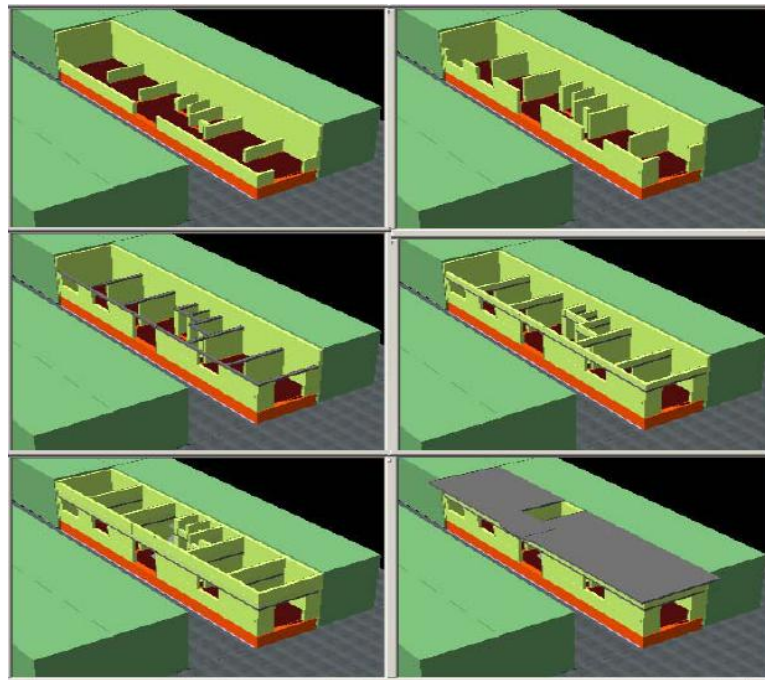


Figure 10: Animated sequence of a building construction project (from Bansal et al. 2008).

This GIS approach to visualisation and sequencing is easily extended to integrating quantity take-offs for cost estimates and work method statements for safety, continuous learning and coordination issues and quality control recommendations as Bansal (2011, 2010, 2007) has demonstrated. In the field of automation in the construction industry, the application of VDC tools has been researched. Considerable savings have been reported by contractors using 3D equipment control.

Dunston and Monty (2009), in a synthesis study, claimed that for the sake of efficiency it is desirable for transportation facilities to adopt standard practices regarding software and protocols. Moreover it should apply from defining the original topography of the land that is to be developed, through the planning and design processes and the detailed estimating process, and automate controls and inspection functions during construction. Such an approach, aimed at the horizontal and vertical control of all elements that are to be built, must work through different software and hardware platforms in order to facilitate seamless design data transmission across interfaces between entities in the project supply chain. The base platform could be GIS as it offers a mature topology and topography and is able to handle non-spatial data in a relational database. The contractor's data, using GPS equipment guidance systems on their earthmoving equipment, are easily retrieved and exchanged from GIS as well as handling monitoring data and management control of projects. This technological approach reduces data interfaces and facilitates the flow of quality information.

Related research by Dorée and Miller (2008), on the use of technology and the asphalt paving process, elaborated on the benefits that construction management as well as companies in construction could gain by reconsidering their stance towards technology. They build their arguments on the case of road construction. The goal was to extend the service life of the



asphalt layer by improving the whole process from the choice of raw materials and mix design, to monitoring the finished product. To conduct the investigation they monitored the activities involved and made an animation from the data to analyse equipments movements. With this technique the consequences of on-site operational behaviour and discontinuities was made explicit. From the data collected from the paving process they could address the important issue of reducing variability in operational behaviour and improve consistency and quality in the final product.

Some studies have been undertaken in the field of managing geography. Workers, equipment, materials, temporary facilities, and the developing structure share the limited jobsite space during the construction period. Multiple types of spaces for different purposes on various locations are required to execute various activities at different times. Deficiencies in space planning result in a congested jobsite, loss of productivity, space conflicts, and schedule interference or delay according to Guo (2002). Traditional methods to resolve space conflicts lack features such as topography modelling and geospatial analysis which could enhance space planning. The work of Guo (2002) highlighted that space management involves three aspects of research: jobsite layout planning, path planning and space scheduling.

Different studies have suggested effective jobsite layout planning by minimizing the travel distance between various temporary facilities – see, for example, Cheng and O'Connor (1996), Li and Love (1998), and Zouein and Tommelein (1999). Path planning focuses on the path-length optimizations for construction equipment and operations (Varghese and O'Connor 1995, Lin and Haas 1996). Geospatial analyses resolve optimising problems but in space planning information on where, when and how long that space will be required on the jobsite are stored in a related file.

Bansal et al. (2011) used 4D GIS for space planning utilizing its topographic modelling, geospatial analyses and database management functions. They supports their reasons for choosing GIS for space planning over other modelling techniques because it has a matured spatial analysis tool and existing 4D CAD systems are unable to aggregate and distribute the information between spatial and non-spatial databases and have a single level of detail that hinders collaboration. Topographical features outside the constructed building are important in space planning. For example, space planning for gravity dam construction where topography plays a major role cannot be simulated without geospatial capabilities which are missing in a 4D CAD system yet are available in GIS.

Closely related to the technology described above is the location-based scheduling method which is an alternative to most common critical path method (CPM). In short, location-based scheduling based on line-of-balance technique appears to provide better characteristics to plan workflow, compared to activity-based scheduling techniques. The objectives of line-of-balance diagram are to:

- minimize variation in resource use;
- ensuring sufficient time and space between different trades;
- minimizing discontinuities in the work of trade; and



- avoiding simultaneous work of the same trade at different locations.

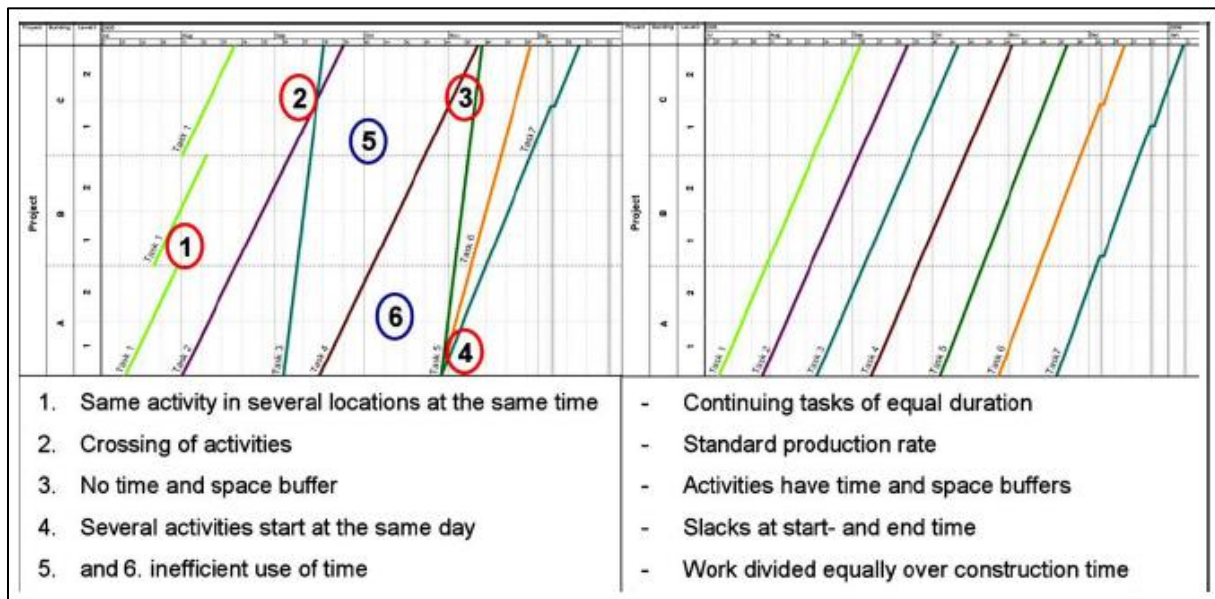


Figure 11: Examples of Line-of-Balance diagrams.

(Locations are plotted on the Y-axis and project time on the X-axis. The lines represent construction operations by crews. Left common deviation types are marked 1-6 and right is typical solutions – from Jongling and Olofsson, 2006)

Jongling and Olofsson (2006) combined 4D CAD model of a cultural centre in the city of Luleå, Sweden, with the line-of-balance technique. An example of its use is illustrated in figure 11. Their argument was that there was great potential for improving workflow on the construction site because just 15-20% of a construction worker's time is spent on direct work, approximately 45% on indirect and the remaining 35% is spent on redoing error, waiting, disruption etc. In the area of sequencing and coordination, some construction planners use CPM to integrate the product with the process. This method can lead to very detailed CPM schedules that are difficult to use and update. As a result, detailed schedules are often not updated during a construction process and thereby lose their value as an instrument to plan and control of workflow. Their results were that when the schedule was simulated in 4D a planning issues were identified that did not become apparent from the line-of-balance diagram which enabled better coordination of the workflow. They looked at it as a promising mechanism to plan for workflow although difficulties arose from lack of interoperability of the applications and methods involved. They believed that the management of workflow should include the management of different space types which were not in their model and looked at space as a resource that is related to location and a task. Suggestions on the classification of space type which could be linked to the object model are: building component space, material space, labour space, equipment space, space for temporary structures, and hazardous space. A different kind of planning is needed for each space type and its interaction varies accordingly. Another critical issue was the level of detail for space locations definition as the hierarchy of the space in the line-of-balance diagram had to be synchronised with the 4D object model. GIS tools provide the functionalities that could



address these issues as geospatial analysis are suited for analysing space conflicts and the structure of the relational database serves many levels of detail.

Until now, the main focus has been on the execution phase of the project process. Research has been conducted to demonstrate the opportunities and benefits of VDC tools, technologies and methods in the definition and design phases of PD as well. In a report from Khanzode et al. (2006), the application of principles of VDC to LPD process is demonstrated with examples. Lean design advocates the involvement of construction professionals during the design phase of the project. This approach was taken on the design work of the Camino Medical Group project which involved plumbing and fire protection during the schematic design phase to provide a feedback to the designers on the construction process and constructability. This was enabled with 3D coordination tools. In the definition phase, 3D rendering tools were utilized to create a shared vision of the building and its functioning.

In their effort of incorporating the process knowledge in the PD of Science and Engineering Quad Phase 2 project on the campus of Stanford University, 4D simulation of the project's plan was created. It allowed the project participants to evaluate the impact of the sequencing on the overall campus traffic and also on the impact to classrooms in adjacent buildings that surround the construction site. The report also demonstrated the use of 3D/4D models in seeing and planning logistics, seeing and removing constraints, testing the work sequence, and design and development details. Overall the report illustrated with examples how the VDC tools, technologies and methods can be used during all stages of the LPD system.

A paper by Kam et al. (2003) presented the findings from the design and construction of Helsinki University of Technology Auditorium Hall of the HUT-600 project in Finland using Product Model and Fourth Dimension (PM4D) approach to the project delivery. This approach involved running simultaneously with the design and construction of the HUT-600 project, an international research partnership extensively applying the product modelling approach, testing of the Industry Foundation Classes (IFC) interoperability standards, and employing an array of design, visualisation, simulation and analysis tools. Their finding was that even though this approach improved the project outcome in terms of design quality, project risk and life-cycle values, technical, cultural and business barriers were encountered. Realizing further benefits from this approach they suggested that the project participants in the HUT-600 project should have product modelling tools to support revision-handling, two-way exchanges, simpler mapping of data formats from exporting to importing applications, and more extensible and robust IFC-compliant software tools.

A paper by Richmoller et al. (2006) presented results that describe how the value generation process can be improved in the design process of industrial projects when using computer advanced visualization tools (CAVT). It provided a framework for understanding the impacts of such tools by combining production theory and lean construction principles with information technology. This framework was then used in a case study that supported their expectations. The main findings were that CAVT, in the context of the descriptions provided, led to reduction of uncertainty in the early phases of the case study project engineering and consequently during construction. It also contributed to predicting fulfilments of the goals set



to production with higher precision, designing, producing and delivering products as required by customers.

Although some investigations and experiments have been conducted throughout the field of project-based production process linking GIS with lean principles they are fragmented and lack a holistic view of the entire production process.

3.5.2 Relevant GIS functionality

In the effort to integrate GIS in temporary production systems, the key aspects of functionality are defined by the functions and capabilities that GIS provides. The fundamental technology for the functionality of GIS is computer aided design (CAD), spatial data handling and database management system. For the purpose of the research, focus is on exhibited functionality rather than core technology. Concepts of functionality are based on the framework by Khanzode et al. (2006), which apply the principles of VDC to LPD process, this literature study and, due to the similarities of GIS with building information modelling (BIM), from the research of Eastman et al. (2008) and Sacks et al. (2010).

Visualization of product objects. GIS provides the ability to render construction objects in their context with the surroundings. Using relational database capabilities to exhibit objects in several levels of detail facilitates common understanding with stakeholders.

Generation of multiple design alternatives. Designers manipulate the geometry of objects in order to fit into a built environment and the location topography as well as between the components of construction model. Spatial data handling mechanism preserves design coherence making fast and reliable evaluation of design alternatives.

Product and process modelling and visualization. These allow the project teams to understand how the facility is constructed over time and identify time-space constraints.

Use of objects spatial and non-spatial information for predictive analysis of product performance. This involves the use of a shared construction model to extract quantities for life cycle and construction cost estimates. GIS enables analyses of the functionality of the product in its environment along with construction feasibility to be undertaken.

Maintenance of information and design model integrity. Relational database structure enables storing each information once and detection of missing links between geospatial objects and non-spatial data. Geometric integrity is preserved through spatial data handling of GIS enabling automatic clash and tolerance checking.

Automated generation of drawings and documents. Integration of KM in GIS and information integrity promotes levels of detail for automation of reporting and generation of drawings. Any changes made to the model are automatically propagated to the output.



Collaboration in design and construction. GIS enables multiple editing using versioning and locking mechanism. Designers of different aspects can simultaneously view, merge or separate their design in the model. After editing, a check for conflicts is made on the parent version and resolved, promoting design consistency. Combined with the visualization of the on-going processes prerequisite of an activity can be deferred to the last responsible moment.

Generation and evaluation of construction plan alternatives. Linking a 3D object model with the construction schedule enables visualization of the construction sequence. Relating the object model with libraries of construction method recipes enables automate generation of task and modelling of dependencies, prerequisites and resource allocation. Space is considered to be a resource in this respect.

Online collaboration. GIS allows collocated and geographically distributed teams of project participants to collaborate using a shared model of product, organization and process. Handheld computers interact with the graphical object model and processes to communicate process status, deliver jobsite information to the workers, directly update progress and online requests for information.

Direct information transfer to support computer-controlled fabrication. Direct information transfer to support computer-controlled fabrication of construction components using numerically-controlled machines is already common. Additionally, business integration in construction is possible on the bases of product specifications. Topographical modelling of the jobsite in GIS and tolerance handling facilitate equipment guidance system and accurate layout for prefabrication.

Although the above concepts of GIS functionality resemble those of VDC presented by Khanzode et al. (2006) and those of BIM stated in work by Eastman et al (2008) and Sacks et al. (2010), they differ in two main respects. First, geographical information can be analysed outside as well as inside the construction area and second, levels of detail can be incorporated in the production model including factors influencing the coordination of work and flow of information in projects.

3.5.2 Relevant lean principles

In their effort to improve the production system, Ballard et al. (2001) proposed a guide for its design. In their work, production systems are understood to involve both designing and making products and are defined to be “work structuring” in LPDS. Work structuring serves the three goals of production systems: do the job, maximize value and minimize waste. For each of the latter two they proposed ends-means hierarchies intended progressively to answer the question “What should we do to achieve a goal?” moving from desired ends to actionable means. The ends-means hierarchies are presented in Appendix II. When formulating hierarchical principles, Ballard et al. (2001) used the lean approach to involve concepts of production, which consisted of flow of materials and information through networks of specialists, and the concept of production in terms of the generation of customer value.



The first goal – do the job – has traditionally been achieved by developing Work Breakdown Structure (WBS) mated with an Organization Breakdown Structure (OBS). This guide to production system design is intended to be an alternative for WBS/OBS because they propose a proactive management focus and overlapping manipulation of design and execution processes.

Work structuring is a fundamental task in production system design and extends from the global organization to the design of operations. This approach stretches the focus of project planning, which has primarily been on organisational structuring and the creation of work breakdown structures, to the entire production system and all PD phases. The proposed use of this design as a system design guide is the primary application but there are also two additional applications. One is for identifying where the gaps are in the research agenda and the other is for those implementing the concepts, processes and techniques developed in research. Measurements at lower levels may be useful, but the primary measures of production system performance are at level 2 where the purpose is to:

- deliver products that enable customers to better accomplish their purposes – customer surveys and post-occupancy evaluations;
- deliver products on time – on-time delivery rates;
- make materials and information flow – process flow analysis and project durations (cycle times);
- get more from less – productivity measurements, costs and scrap rates; and
- reduce defective products and process – percentage product defects discovered at various process stages and percentage process defects such as safety and health incidents.

Of the above, some work remains to be done on post-occupancy evaluations and on process flow analysis. Equally important is to instil the discipline of analyzing defects and failures to root causes and acting on those causes. Lastly, the hierarchy can be used as a template for construction of system models for simulating alternative designs.

Implementation of the LPDS can be a research topic in its own right although it is not the concern of this research. However, it should be pointed out that initiating change in a single element in a system will eventually bring other elements into alignment.

In a previous section, the development of PD to IPD were described and the similarities of IPD and LPD identified. Work structuring principles are based on the LPD concept so it can be reasonably assumed that in implementing those principles it inherently implements some of the IPD principles.

3.5.3 The framework of the research project

The lean principles and the features of GIS functionality are set up in a conceptual model as depicted in figure 12. This framework is for analysis of interactions between GIS functionality and lean principles. The nature of those interactions can be positive, neutral or negative.



Although level 2 of the hierarchy has been chosen in this conceptual model, this level can be cascade to include all sublevels, thus incorporating more actionable means into a study. Also, the second level is the most appropriate level to measure the performance of a production system so the framework can be used in qualitative and quantitative research. The goal of this framework is both to guide and stimulate research.

3.5.3 Conclusion on GIS and Lean

Successful integration of these two systems lies in finding synergies between their underlying principles. In applied science, this means that the emerging system has to demonstrate better performance in solving real world problems than the old one. Although a strong indication of benefits in using ICT has been detected the expectation from the construction industry has not been met as much as in manufacturing. One reason is that the construction industry is currently more fragmented than manufacturing thus imposing more complex interactions between processes and procedures in construction projects. Therefore, the framework developed here is intended to capture those elements of the project-based production system that could benefit from GIS integration.

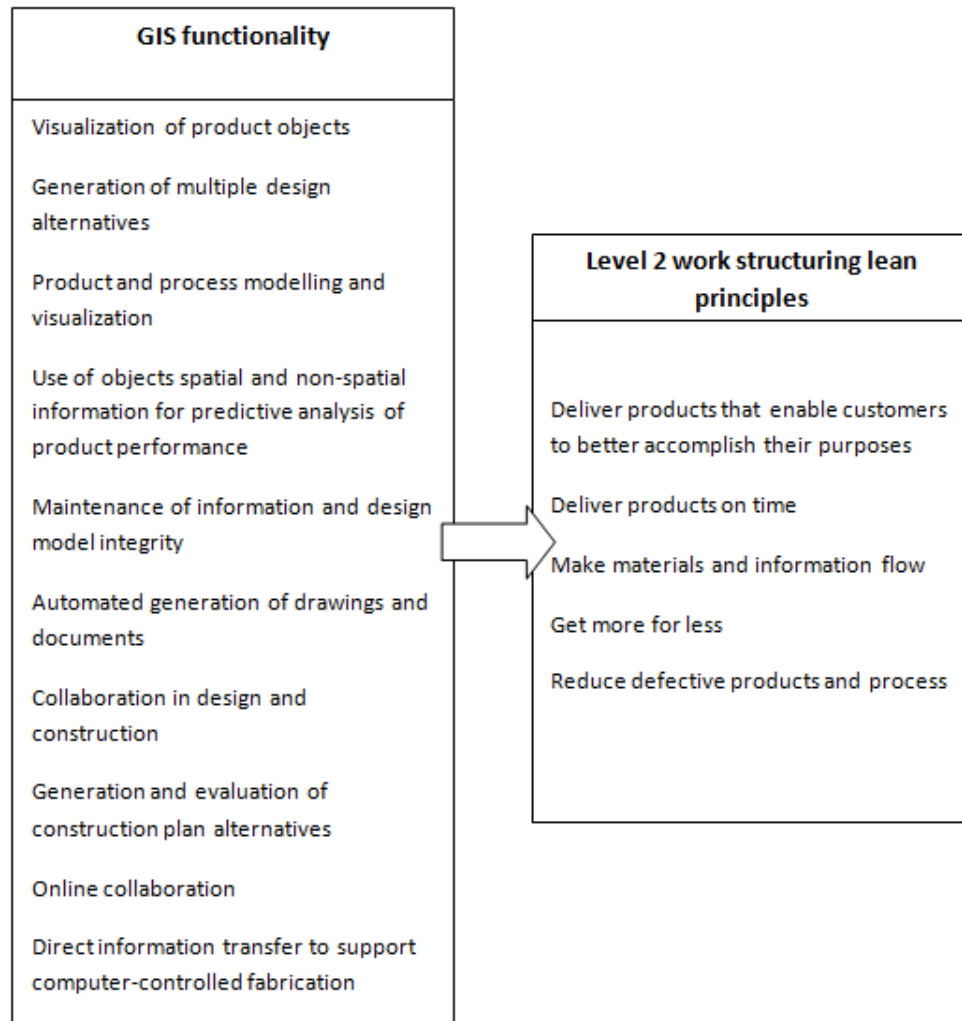


Figure 12: Conceptual model of relationships between functionality of GIS and lean principles.

3.6 Conclusion on state-of-the-art review

The main task of this research is to demonstrate how GIS can be exploited in lean oriented project-based production systems. In this literature study, GIS functionality has been aligned to relevant theories and concepts of communicative collaboration. The structure of the PD process has been established as has its relation to IPD and LPD. Lean principles for the evaluation of production systems have been identified leading to the definition of a framework intended to draw out possible interactions of lean and GIS. This literature study generates the conceptual research model with the assumption that opportunities for implementing lean principles can be uniquely determined from the functionality of GIS and lean work structuring principles.

The next steps in this research project are using the framework to propose possible positive interactions and seek empirical evidence to describe the current state and future prospects measured against the state-of-the-art.



4 Results

This chapter present the data collected for this research and its analysis. The research has two interrelated stages. First, propositions for integration of GIS in lean production system will be stated and, second, data from a questionnaire on the current state and future prospects of GIS in the Icelandic construction industry will be presented and analysed.

4.2 Integration of GIS in production system

From the conceptual model of relationships defined for this research project, 27 propositions on how GIS should be integrated in temporary project-based production systems are stated. The propositions are based on inductive reasoning supported by the literature study earlier in the thesis. The way those propositions were structured was by identifying the positive impact of the features of GIS functionality on level 2 ends-means hierarchies by cascading all the actionable means, below that level, to identify positive interaction. The basic method to derive the proposition was to state if “x, y, z, ...” functionalities were used to implement a, b, c, ... principles. The propositions were based on theories, concepts and empirical evidence and their relevant references are listed for each of them. The references are not exhaustive but are intended to direct further research. The propositions are stated according to the hierarchical guidance proposed in the work structuring hierarchy from Ballard et al. (2001) – maximize value before minimize waste – and are demonstrated in Appendix I.

The propositions provided are not deemed to be proven by direct empirical evidence; they are, however, supported by other research. Instead, they are candidates for verification or contradiction through measurements in future research such as the one which follows here.

4.3 Empirical data

The data gathered with the survey was divided into four parts. In the first part, information about organization size and where in the project delivery phases it operates were gathered. The second part was concerned with lean practices while the third part was concerned with the current extent of GIS usage in the project delivery phases. In the last part, propositions derived from the state-of-the-art review for implementing lean principles by GIS functionality were stated respondents’ evaluation. The survey was sent to 29 companies/organizations of which 12 responded, giving a 41% response rate. The results are presented shortly.

4.3.1 General information

In this first part of the questionnaire, general information on the number of employees and in what project phases their company/organization operated was sought.

In the first question, the respondent was asked to mark one of four size categories: one with less than ten, one between ten and 20, three between 21 to 50 and seven with more than 50



employees. To be able to submit the questionnaire this question was required to be answered. Their relative distribution is shown in figure 13.

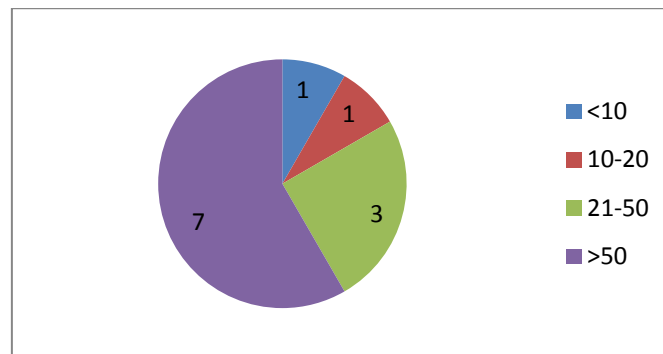


Figure 13: Number of organizations in each category in terms of number of employees.

The main purpose of this enquiry was to confirm that the organizations involved were of medium or large size with regard to what may be expected in Iceland, taking into account the number of companies and size of the local market. According to the list of organizations that were contacted, it is very doubtful that any of them had fewer than 10 people employed but the reason could be that the respondent mistakenly referred to his or her department size. However, the result showed the vast majority of medium or large size organizations responding to the questionnaire.

The objective of the second question was to establish the phases of project delivery process in which the responding company/organization operated. The respondent was asked to select one or more of five phases in which his or her company operated. This question was obligatory. The results are depicted in figure 14 and show fairly evenly distributed operations over all project phases.

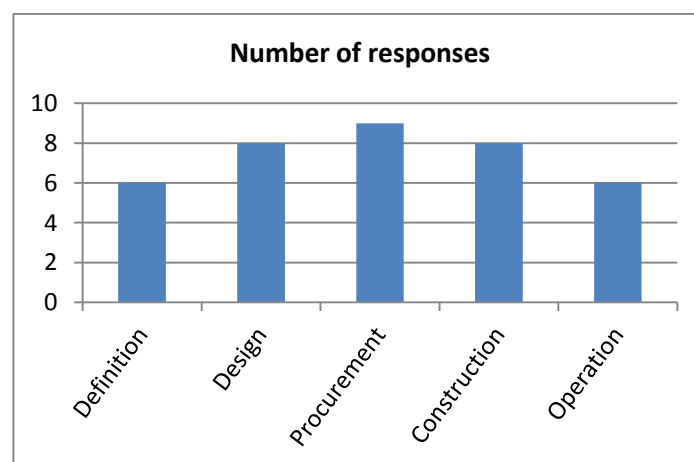


Figure 14: Distribution of responses on project's phases.



4.3.2 Information on Lean practice

In this part two questions were asked about lean practice in the responding company/organization. The first required respondent to indicate if the company/organization practiced lean construction management techniques and, if yes, the respondent was asked to identify which of the six techniques mentioned were used. Also, the respondent had the opportunity to describe one other technique that was not mentioned.

Only two respondents confirmed to be practising lean construction management techniques in their organizations. They marked two defined techniques and one response was “other” but it was not described further. The techniques stated and the techniques in use are depicted in figure 15. As was expected not much evidence on lean construction practice was established.

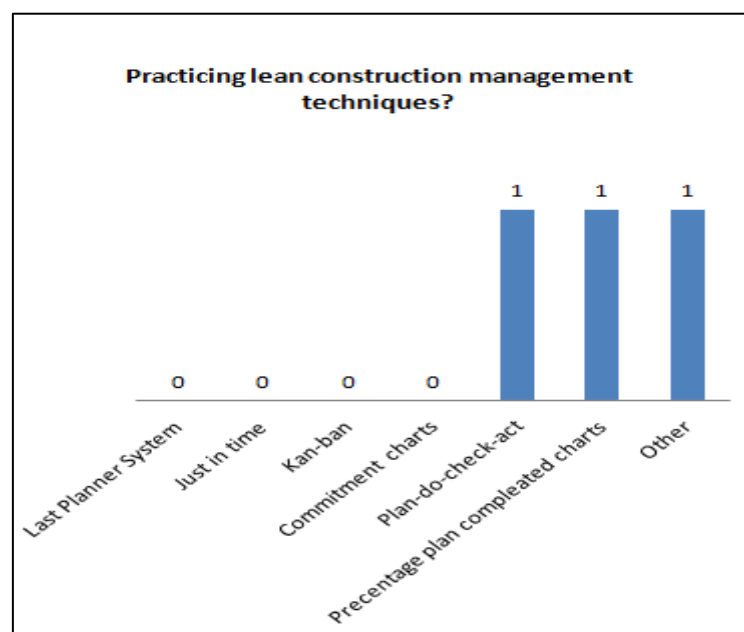


Figure 15: Use of lean construction management technique.

4.3.3 Information on GIS practice

In the third part of the questionnaire, information was gathered on whether or not the respondent company/organization used GIS in the project process and, if so, to what extent. Its purpose was to reveal the current role of GIS in delivering projects.

First, the respondent was asked if his or her company/organization used GIS in delivering projects (required). It was stated that it was irrelevant whether GIS operated within or external to the organization. Eight organizations claimed to be using GIS and four did not use it. Comparing the data on GIS users' and non-users' organizations with the data about project phases revealed that GIS is to be found more often in the definition and construction phases (figure 16).

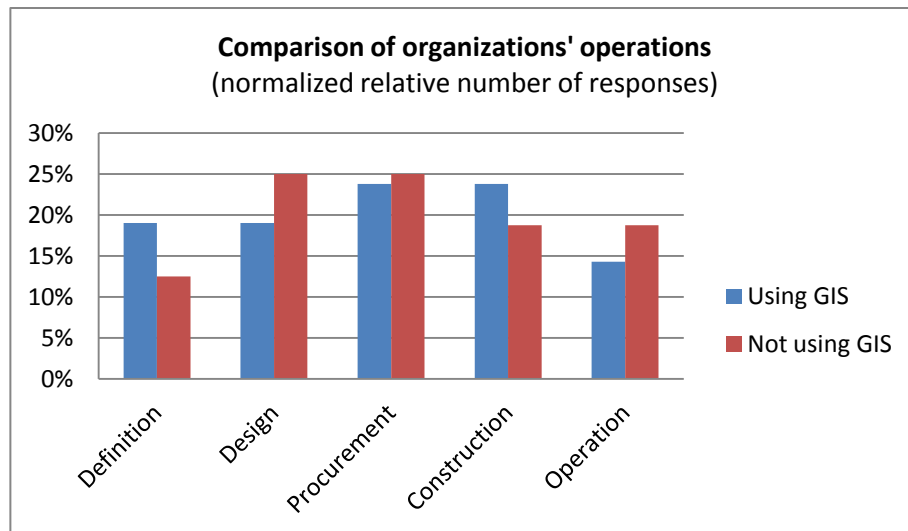


Figure 16: Relative distribution of operations of GIS and non-GIS users.

By comparing the number of GIS users in each category to the number of employees it was shown that the smallest organizations did not use GIS, while all medium organizations used GIS and four of the largest organizations. Second, if the company/organisation was using GIS, the respondent was asked to indicate to what extent it was used in the company/organization projects, rated on a five point scale from never to always, in 21 defined activities covering all project phases. The results are shown in figure 17.

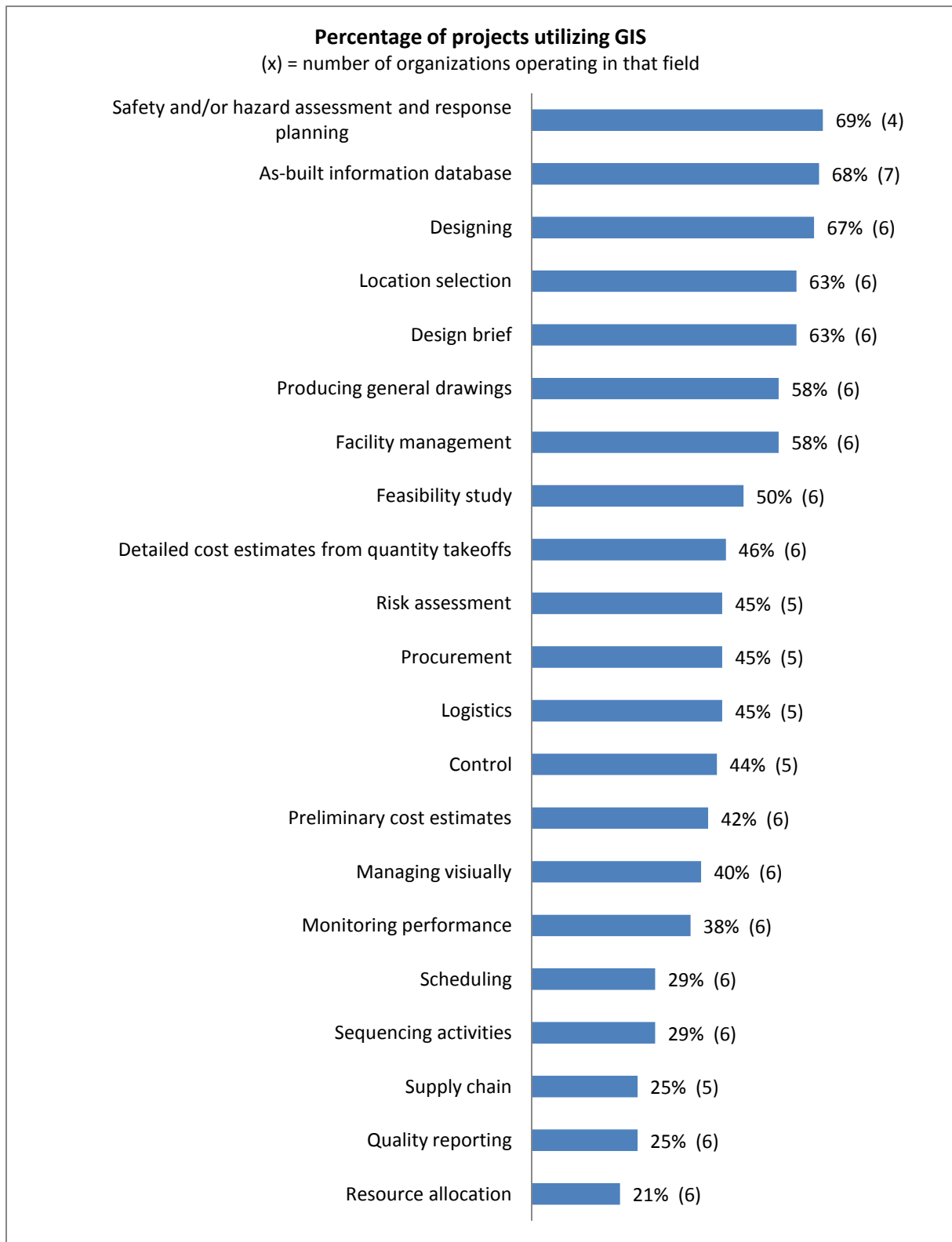


Figure 17: Relative number of projects utilizing GIS in relevant activity.

The results show that GIS is utilized in all activities stated but it would be interesting to sort the activities by phases in the project. In table 1, this is shown and the mean of projects utilizing GIS has been calculated.



Definition		Design		Procurement		Construction		Operation	
Activity	% of projects	Activity	% of projects	Activity	% of projects	Activity	% of projects	Activity	% of projects
Location selection	63	Safety	69	Procurement	45	Control	44	As-built database	68
Disign brief	63	Design	67	Logistics	45	Visual management	40	Facility management	58
Feasibility study	50	General drawings	58	Supply chain	25	Monitoring	38		
Risk assessm.	45	Cost estimate	46			Sequncing	29		
Preliminari cost estim.	42	Schedule	29			Quality reporting	25		
						Resource allocation	21		
Mean use	52.6		53.8		38.3		32.8		63.0

Table 1: Activities grouped by phase.

The table demonstrate that GIS was most frequently used at the early stage of the project delivery and facility operation but less in the procurement and construction phases.

4.3.4 Information on future prospects

The last part of the questionnaire was aimed at establishing company/organization acceptance on the technical methods derived from the propositions and identifies the most common barriers for implementing the stated techniques. Its purpose was to measure the respondent's awareness of each technique in terms whether or not it was practiced in the organization. It concludes with an enquiry into current and future prospects of 4D building models.

First, the respondent was asked to mark on a five point scale how strongly he or she agreed if his or her company/organization had or could gain from implementing each of the 17 stated techniques in, either one or both, better product and lower cost of projects. If the technique mentioned was not relevant to his or her organization's operation it could be checked. All respondents were required to respond on those statements. The respondent's answers are summarized in figure 18.

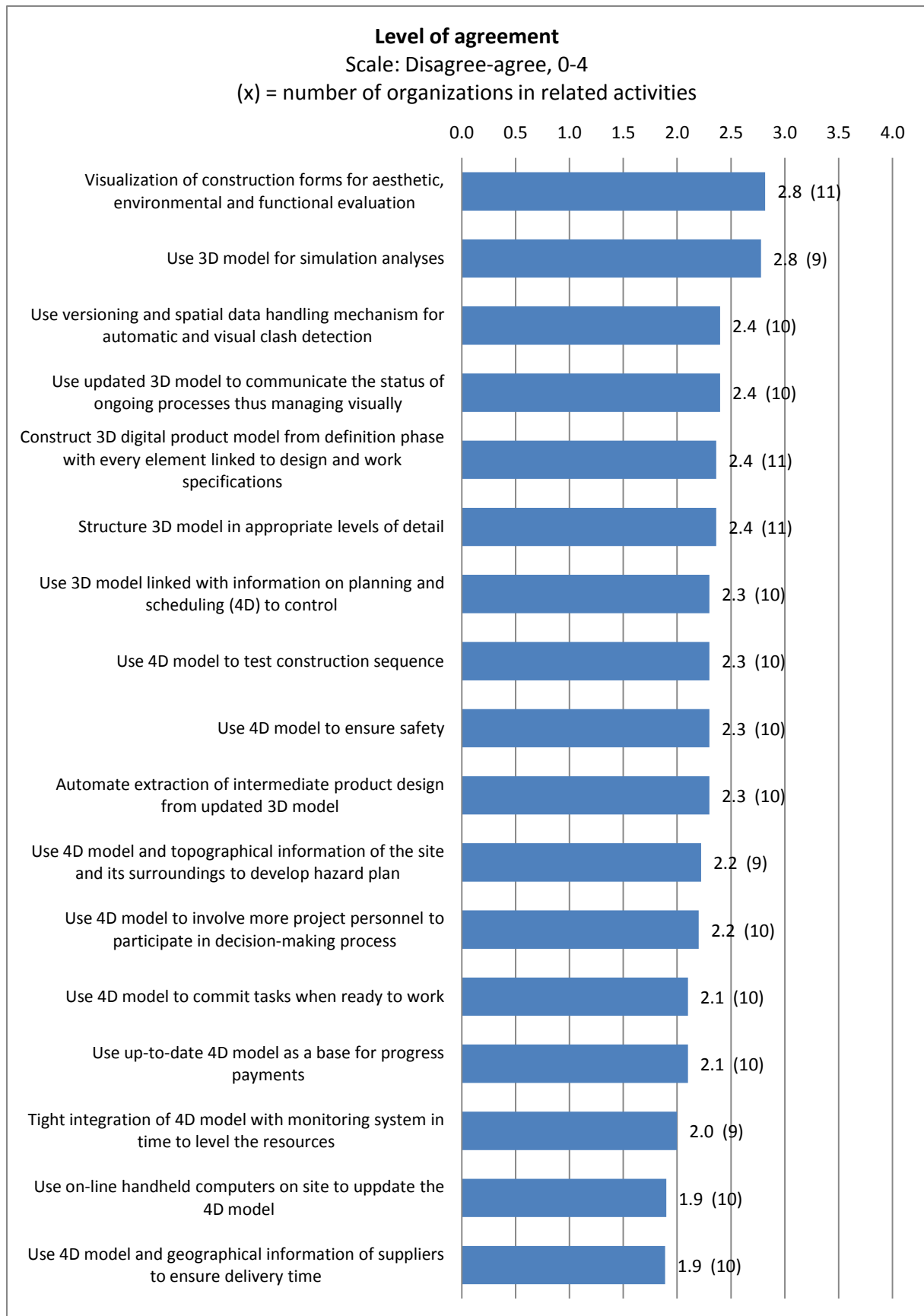


Figure 18: Respondents level of agreement on methods functionality in respect to reducing cost or better products.



A large majority of the techniques was reckoned by the respondents to at least improve the project's performance, lower cost or both. It was easily detected from the summation, sorting from highest to lowest, that respondents favoured 3D building models more than 4D.

Investigating the variety of the level of agreement between size categories revealed the information depicted in figure 19.

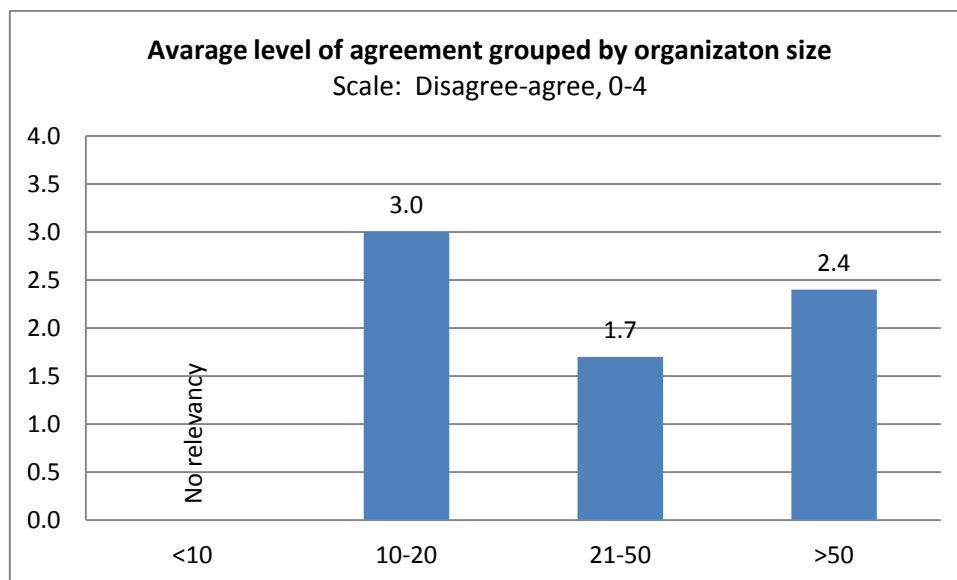


Figure 19: The average level of agreement on stated technical methods grouped by number of employees.

The sample is small in the first two categories with one organization in each; however, there are three in the third and seven in fourth. Statistical inferences cannot be drawn from the first two, although some assumptions can be made from the others.

Second, the respondent was asked to mark one or more pre-defined options which she or he considered to be the most dominant factors for implementing the technology specified in the preceding question. The answer to this question was required and the result is shown in figure 20. Analysing the data revealed that there was no conclusive indication of any correlation between the size of the organization and most cited reasons for not implementing state-of-the-art technology.

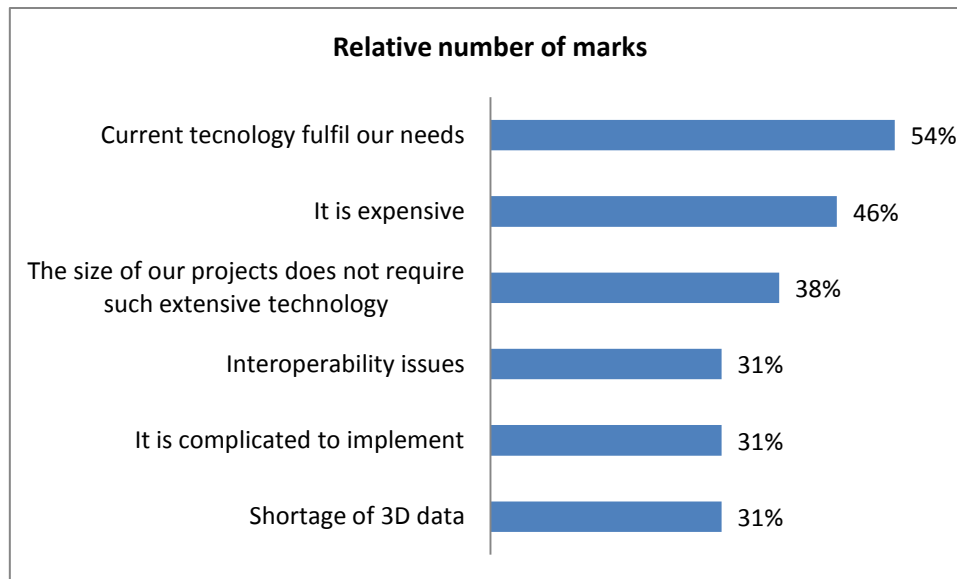


Figure 20: The relative number of incidents of most dominant factors to implementing these techniques.

Third, the respondent was asked if his or her company/organization used 4D computer models. The purpose was to find out if there were any currently in use. This answer was required. No incident of 4D use was found. The last question dealt with how likely the respondent thought that his or her company/organization would adopt this technique over the next three years. The results are depicted in figure 21.

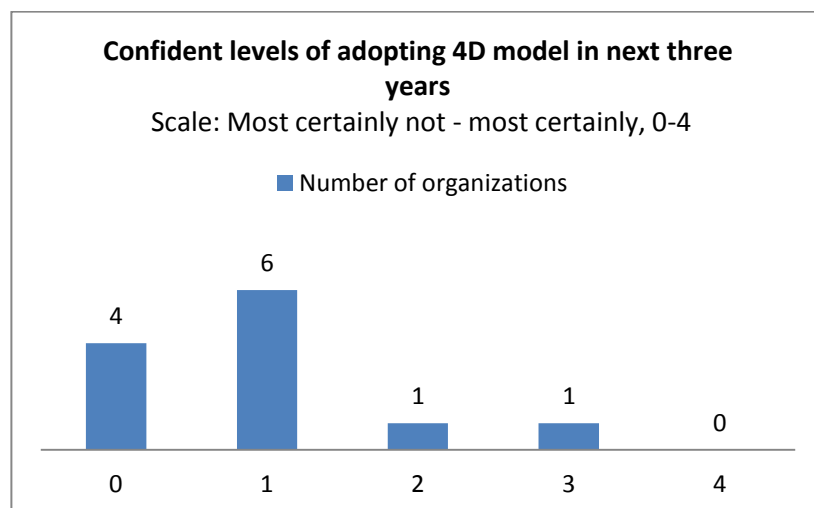


Figure 21: Level of confidence for adopting 4D construction object model over the next three years.

The results, illustrated in figure 22, comparing the size of the organizations to the level of confidence in 4D production models being implemented in the next three years support the logical assumption that the use of 4D models favours large organizations.

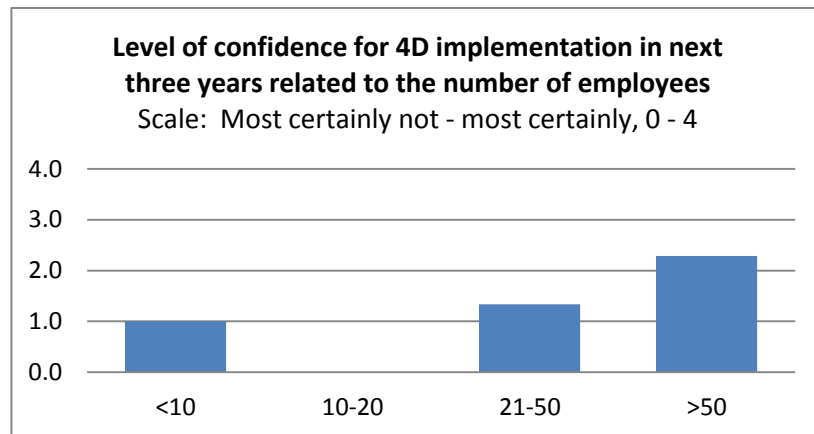


Figure 22: Level of confidence related to number of employees.

4.4 Conclusion

The transformation of the 27 propositions to 17 technical methods, for respondents to evaluate, is mainly due to their overlapping nature. The same technique can implement principles relevant to two or more propositions. This overlap is inherited from the TVF production theory as it looks at the production system from three different perspectives as has been explained earlier. Questions were as short and as clear as possible, yet cover all aspects of the production system where GIS functionalities could be exploited.

In general, the results show that the distribution of the respondents operations in project delivery and the size of the organizations fairly met the criteria set for the design of the questionnaire, thus reflecting the opinions of the leading organizations in the Icelandic construction industry. Although the sample is small – 29 organizations – they account for more than 90% of the Icelandic construction market.

Statistical analysis of the data is of little use. They are largely indicators or descriptors of opinions and the current status of the organizations participating in the enquiry. Another limitation inherent in the questionnaire design was not to explicitly investigate the extent of 3D use as that would have complicated the design which could have resulted in a lower response rate and extra time. However, its design is implicitly meant to draw out a fairly accurate picture on this matter.

The questionnaire is presented in whole in Appendix III including the covering and follow up letters.



5 Discussion

In this chapter, the results of this research will be discussed to highlight the relationships among observed facts and demonstrate their significance.

5.1 The propositions

When reviewing the propositions, their application does not simply lie in maximizing value and minimizing waste with GIS functionality, but also reveals the organizational and managerial context. These can enhance the management focus and the understanding of what may be needed to realize positive interaction when implementing lean and GIS. Most of the propositions are aimed at supporting the principle of “deliver products that enable customers to better accomplish their purposes”. In this respect, it should be kept in mind that in the guide that Ballard proposes, minimizing waste is subordinate to maximizing value in work structuring. However, their concentration in that field are in line with the results found by Rischmoller et al. (2006) and Khanzode et al. (2006) in that the best opportunities for VDC principles to support the ideal of lean construction lie in their integration early in the production process.

It has been stated earlier that the application of the information technology (IT) has sometimes not returned the benefits that were expected. Koskela and Kazi (2003) investigated the cause thereof and came to the conclusion that realizing IT benefits was, in general, dependent on the compatible realignment of business processes, thus imposing the need for fundamental understanding of the inherent properties of construction. In this current context of GIS and lean construction, it is proposed that in order to make changes in the production process it should be coherently based on GIS tools, process changes and lean construction principles, not only on the implementation of core technology.

5.2 Empirical information

By reviewing empirical data, gathered from the leading Icelandic companies in the construction industry, some statements regarding the status and progress of the implementation of GIS in projects, and VDC technology in general, can be made.

The results regarding lean practices confirm the scarce use of lean construction management techniques in the Icelandic construction industry. Nonetheless, the literature study shows that GIS has demonstrated its usefulness in achieving the goals of the techniques used in lean construction management such as LPS, JIT, kanban and plan-do-check-act. The two organisations practicing lean construction techniques are using plan-do-check-act and percentage plan completed charts but they also use GIS so there could be grounds for further integration.

The results regarding GIS practice have demonstrated some use of it in all activities defined in the research, but seldom is it used in all the organization's projects. GIS users operate rather



more than non-GIS users in the definition and construction phases which could reflect the notion of Bansal et al. (2008) that GIS editing tools at present are not mature enough. Nevertheless, in regard to the number of projects, the extent of GIS use is significantly more common in activities relating to the definition, design and operation phases than in procurement and construction. This discrepancy implies that GIS is not well integrated into construction processes and that this pattern is reflecting the traditional design-bid-construct method of project delivery in Iceland which imposes a barrier to the sharing of information. The overall results on the current state of GIS usage in production systems demonstrate the fragmented use of GIS. In thirteen activities, GIS was never used, but in eight it was always used. This reveals considerable underutilization of GIS among GIS users in the industry and lack of a holistic view of GIS integration in production systems.

Reviewing the information on future prospects of GIS, and in some sense VDC, raises some issues to contemplate. Although a large majority of the techniques was reckoned to improve the performance of production processes, the data imply some hesitancy on the part of those implementing the techniques. This is a contradiction which would be interesting to look at more closely, although it could be rooted in the lack of a conceptual framework for the integration of VDC tools in production systems.

It is reasonable to assume that the Icelandic construction industry is in the phase of moving from 2D to 3D in implementing VDC tools. This assumption is based on research into BIM at the implementation stage by Kjartansdottir (2011) and also from the data gathered for this research. Looking at the number of responses relative to the most dominant factors for implementing the stated techniques (figure 20), one can note that 3D tools are not much used in the respondents' organisations. If that were the case it would have raised the last three dominant factors and lowered the top three because respondents would have less reason to contemplate the top three issues. Respondents opinions favoured more the techniques relating to 3D modelling than 4D, and organizational or business factors raised more implementation barriers than technical. That can be inferred because the different nature of the origins of the pre-defined factors. This view is also supported by the level of confidence respondents have on how likely it is that the organization will implement 4D modes over the next three years. Nevertheless, the data show positive correlation between the size of the organization and the level of confidence.

5.3 Other considerations

Apart from aspects of lean construction, the propositions have been used to conceptualize 17 techniques or methods of which each can be implemented; however, the organizations are not systematically practising lean methods in construction.

Regarding validity and reliability of this research it is worth mentioning that the technique “visualization of construction forms for aesthetic, environmental and functional evaluation”, which is based on the definition of “visualization of product objects” functionality of GIS, has the highest level of agreement (figure 18). This is in line with the research by Sacks et al.



(2010) which showed that the highest concentration of unique interactions of lean principles and BIM functionality was the “aesthetic and functional evaluation” benefits of BIM. Another point that is the average level of agreement of 2.3 (see figure 18) implicitly supports the propositions by recognising the positive interaction between lean and GIS. When looked at, the relationships between the size of the organization and how much respondents favour technical methods, it indicates agreement on the techniques as the organization gets bigger (see figure 19).



6 Conclusions

In this final chapter, the key findings obtained in this research are summarized. How and where the objectives were met and further research are outlined.

6.1 Final conclusions

This research project set out to explore the role of GIS in the construction industry and how it could be related to the TVF theory of production. The goal was to answer the research question: how can the Icelandic construction industry benefit from the integration of GIS in lean oriented project-based production systems?

The thesis started with a literature study aimed at describing the historical background of the two emerging technologies, GIS and lean, and to demonstrate in what context to real world problems these developed. The problem situation was described both external to, and within, Iceland to formulate the problem statement leading to the objectives of the research. The research methodology was reviewed to explain the framework set for the research. It proceeded with identifying state-of-the-art of the research topic which was mapped-out from the literature review. The theories and concepts of the research topic were aligned and empirical evidence linking lean principles with GIS functionalities reviewed.

It was found from the literature review that a holistic approach to GIS implementation in production systems was lacking. A framework was established in the effort to evaluate how GIS affects production systems. Although the framework was inspired from the work of Sacks et al. (2010), it is different in two ways, providing different contexts. First, functionality incorporates elements that cover both the production model and its surroundings, and can provide many levels of detail. Second, the lean principles used include a ends-means hierarchy to guide production system design, as provided by Ballard et al. (2001).

The framework juxtaposes the hierarchy with the functionality of GIS. To begin with it was used to identify 27 propositions for the implementation of lean hierarchical principles with GIS functionality from the state-of-the-art review to achieve the goals of a production system. Those propositions were then used as a basis for the empirical enquiry, a survey, of the current state and future prospects GIS usage of the Icelandic construction industry. From the propositions, 17 technological methods were derived covering all activities in PD process, which GIS could exploit, for respondents to evaluate.

In order to gather information on current state and future prospects of GIS in the construction industry, a questionnaire was sent out to 29 leading organizations in the industry which gave a response rate of 41%. The questionnaire was divided into four parts.

In the first part, general information on organization size measured by the number of employees was gathered. The finding was that most of the respondents' organizations were of a medium or large size according to the nature and size of the Icelandic market and operated fairly evenly in all project phases. The second part on lean construction practice revealed



scarce use of lean construction tools. The results from the third part on the current usage of GIS within the organizations showed some use of it in all defined activities in the PD phases. The key findings imply that its capabilities are underutilized and that its use is fragmented.

The questionnaire concludes with gathering information on future prospects of GIS or VCD tools with similar functionality. The key finding was that a large majority of the stated techniques was reckoned to improve performance of projects in respondents' organizations; nevertheless, some hesitancy in implementing these techniques was detected. In the process of moving from 2D technology to 4D, some use of 3D was detected. Overall, the industry is on the move from 2D to 3D and seems unlikely, on average, to be using 4D models three years hence, although a positive correlation was observed between the size of the company and level of confidence.

6.2 Objectives accomplishment

Three objectives were set for this study. The first was to identify the state-of-the-art integration of GIS in lean-oriented production systems. This was accomplished with a literature review of concepts, theories and secondary empirical evidence relating to the research topic in chapter 3. From that study a framework to evaluate interactions between lean principles and GIS functionality was defined to identify the state-of-the-art propositions on GIS integration in lean production system, and was put forth in section 4.1.

The second objective was to describe the state of current practice of GIS integration in project-based production systems in the Icelandic construction industry. This was done by identifying the key activities in PD phases in section 3.3.1 to structure a framework for the questions on the extent of GIS use in the Icelandic construction industry, which constitutes the third part of the questionnaire and is discussed in section 5.2.

The third objective was to identify the appreciation of the Icelandic construction industry of current and future application of GIS in the PD process with regard to the state-of-the-art. In the fourth part of the questionnaire, technical method statements, derived from the state-of-the-art propositions, were put forth (section 4.3.4) to measure the degree of acceptance that these methods benefit the industry. Furthermore, the most dominant factors for implementation of the stated technology, current and future use of 4D construction models, were sought. These were discussed in section 5.2.

6.3 Contribution

The framework provided can be used to conduct quantitative as well as qualitative research i.e. deliver products that enable customers to better accomplish their purposes and can be measured with customer surveys and post-occupancy evaluations.

The application of the propositions is not only to identify positive interactions between GIS and lean construction, but also to provide an organizational and managerial context that could enhance the focus of management and comprehension on what is needed to realize the



benefits of ICT on the enterprise level. As those propositions are closely related to the principles of IPD it could set the base for alternative contractual methods in PD and promote the sharing of information. The derived technological methods can serve as a guide for an incremental or holistic implementation approach, not only GIS principles but VDC tools in general, in production systems from which benefits could be measured.

The empirical results revealed underutilization and fragmented usage of GIS in organizations practising lean construction as well as those that did not. This thesis not only provides this status information but also a means to deal with it.

On its evolutionary road to utilizing 4D building models, the Icelandic construction industry is in the phase of a fragmented use of ICT in conjunction with 2D building models though there is some sign of 3D. This thesis is intended to stimulate this progress as it explains where the opportunities are in GIS integration in project-based production systems and what barriers have to be overcome. One of the consequences of this technology in the near future is to make the traditional WBS obsolete as design and production go hand in hand.

6.4 Further research

This thesis presented propositions for the integration of GIS in production to increase its capacity from the perspective of TVF theory. The next step could be evaluation of success when in place with empirical research to prove or disapprove the propositions, i.e. before and after measurement.

Conducting this research project raised a number of subjects to contemplate. One basic matter is the level of detail. The literature study revealed difficulties in that area and there is no systematic approach available yet on how to synchronise the levels of detail in a 4D object model with the operation of trades and organizational structure.

6.5 Final thoughts

ICT has left little untouched relating to execution of the daily activities of humans. In the field of production, lean thinking has provided a new approach to construction projects. It would be interesting to try to predict how those technologies will develop together. One can say that GIS deals with imitating real world objects, their locations and facts linked to them and that a lean system deals with eliminating wrong moves, unnecessary parts and raises the prospect of a reliable outcome from production. Tying those features together means automation. We have seen a large increase in the use of robots in manufacturing but not so much in construction. In manufacturing, the activities are stationary but the artefact is moving which is in total contradiction with construction as the artefact is stationary but activities are moving. Using GIS as the “brain” in the manufacturing process makes activities independent of location. The brain could be producing everywhere in the world. Its task in the morning would be to take a look at yesterday, optimize the day and starting the machines. The possibilities of



using GIS in solving problems facing such production are endless but which of them are realistic is the everyday question.

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Appendices

Appendix I

The propositions

Propositions about GIS integration with lean oriented project-based production system

Maximize value

Deliver products that enable customers to better accomplish their purposes:

1. Early generation of 3D shared conceptual model with project specifications and cost data in its topographical surroundings to evaluate processes and organization, and communicate stakeholder demands and customer needs, align stakeholder interests (Khanzode et al, 2006; Eastman et al, 2008).
2. With appropriate levels of detail using relational database KM functionality to transfer pertinent information enhance cross-functional team organizations (Bansal et al, 2008; Khanzode et al, 2008).
3. External and internal collaboration is achieved by versioning simultaneous designs from multiple modellers and by merging clashes are detected and resolved, increasing positive iteration (Kam et al., 2003; Khanzode et al, 2008).
4. Visualization of construction form for aesthetic, environmental and functional evaluation, in its topographical surroundings promotes collaborative direction to value generation. The topographical constraints of the constructed objects and the influence of natural forces as well as the interaction between the building components is modelled and analysed thus facilitate planned business operation and tradeoffs (Kam et al., 2003; Bansal, 2008; Eastman et al, 2008).
5. Rapid generation of alternative designs is put in context of its surroundings enables an optimal choice (Bansal, 2011; Dunston and Monty, 2009).
6. Interaction of environmental aspects and building objects are evaluated in terms of capital cost and operational cost for all life cycle stages (Kam et al., 2003).
7. Modelling building objects in 4D visual systems from early stage in increasing level of details stretch the focus of control over the complete system (Rischmoller et al. 2006; Bansal et al, 2008; Alarcón et al, 2008).
8. Integrating fragmented tools and methods in existing production processes on one platform reduces the number of parts and linkage in the IT system (Dunston and Monty, 2009; Dorée and Miller, 2008; Bansal et al, 2008).
9. From early stage of the project delivery 4D animation of the work schedule and visualization of ongoing processes enhance transparency for all stakeholders and team members during the whole production system process (Kam et al., 2003; Khanzode et al, 2006).
10. 3D systems with topology and data verification handling mechanism ease the decision making on flawless prefabrication (Kam et al., 2003, Khanzode et al, 2006).

11. Activity sequencing by linking construction objects with the schedule in 4D models and monitoring progress near in time will enable an effective clash detection mechanism and coordination of flow of work and material (Bansal, 2008; Kam et al., 2003, Khanzode et al, 2006).

Deliver products in time/Reduce cycle time variation:

12. Integrating monitoring system near time of install rapid detection of production deficiency is enabled. Linking 4D construction model with spatial and non-spatial information on logistic, work method statements and safety procedures promotes preventive control and minimize risk of production disruption (Bansal, 2011; Golparvar-Fard et al, 2009).
13. Terrain model of the construction site are connected with the out side infrastructure and the constructed objects facilitate more realistic evacuation or mitigation plans for imposed hazards (Bansal, 2011).

Minimize waste

Reduce defective products:

14. Transportation time is included in the choice of supplier and recorded with other relevant information of its performance, increasing on-time delivery (Liker and Choi, 2004).
15. Rapid extraction and communication of designs in connection with as-built information near the time of assembly improve the quality of intermediate products and design constructability (Kam et al., 2003).
16. Tightly integrate monitoring system near time of assembly with quality assurance and use as a base for payment (Golparvar-Fard et al, 2009).
17. Eventually as-built model is used to demonstrate system and facility functionality and capacity (Zhang et al, 2009; Eastman et al, 2008).

Make materials and information flow:

18. With workflow modelling simulations, location-based scheduling and location analysis for space allocation, work is structured for flow (Jongeling and Olofsson, 2007; Halpin and Kueckmann, 2002; Bansal, 2007).
19. With 3D object model linked to schedule, the design model is simulated in connection with as-built model as close to real time as possible, the progress is visualized in look ahead window to systematically get tasks ready for work. It enables assessment of plan reliability and balance load to capacity (Seppänen et al, 2007; Golparvar-Fard et al, 2009).
20. Merging objects with identical tasks reduce the risk of overload the same trade in different locations (Bansal, 2011).
21. Location allocation planning optimises the travel distance between various temporary facilities and in relation with scheduled tasks appropriate size and location of inventories is analysed in the model thus reduce process batches (Bansal, 2011).

22. Animation of the construction process along with the progression of as built model enable workers to mark where and when resources are needed. This is integrated with VM system (Sacks et al. 2009; Tezel et al, 2010).
23. Use on-line update mechanism on site to ensure quality (Lee, 2005; Golparvar-Fard et al, 2009).

Get more for less.

24. Implement KM with animation of the construction process related to relevant non-spatial data in appropriate levels of detail accessible to all teams. It stimulates positive communication and development of common understanding of the organizational operations and processes thus develop skill and facilitate constant learning (Wu and Kuo, 2010; Tenku, 2008).
25. With the design model and as-built model on one platform facilitates overlapping design of artefacts and work processes. It enables shifting tasks where they can best be done (Kam et al., 2003).
26. Use spatial data handling to assess the dimensional consequence of change in design on the remaining objects will result in reduced material scrap (Kam et al., 2003);
27. Maintain data and design model integrity by storing each piece of information once. It reduces the cost of using information and preserve integrity between model and outputs (Sacks et al, 2010).

Appendix II

The hierarchy

Ends-means hierarchy for lean production

Goal: Maximize Value = Level 1				
Level 2	Level 3	Level 4	Level 5	Level 6
Deliver products that enable customers to better accomplish their purposes	Structure work for value generation	Align stakeholder interests		
		Organize in cross functional teams		
		Increase positive iteration		
	Understand, critique, and expand customer purposes	Use a collaborative project definition process		
		Use a set based strategy in design		
		Design for all life cycle stages		
		Inspect against purposes		
	Increase system control (ability to realize purposes)	Focus control on the complete system		
		Simplify the system (reduce the number of parts and linkages)		
		Increase system transparency		
		Use Last Planner system of production control		
		Reduce variability, including latent product defects		
Deliver products on time/Reduce cycle time variation	Minimize production disruptions	Increase system control		
		Reduce variability		
	Respond rapidly to production disruptions	Use the Last Planner system of production control		

Goal: Minimize waste= Level 1				
Reduce defective products	Improve supplier quality and on-time delivery	Reduce the number of suppliers and engage them in pursuit of the lean ideal		
		Actively learn with suppliers from project to project		
		Require evidence of product compliance from suppliers		
	Improve the quality of intermediate products within the production process, either design or construction	Improve design constructability		

		Use in-process inspection		
		Pay after inspection/quality assurance		
		Use commissioning processes ¹¹ to demonstrate system and facility functionality and capacity		
Make materials and information flow/reduce cycle times	Structure work for flow	type, size, and locate buffers to absorb variability and match the value of time vs cost for this customer		
		Make throughput=demand rate (avoid overproduction [waste] and underproduction [loss of value])	Match bottleneck capacity to demand rate	
			Pull materials and information through the production system	
		Structure work in continuous flow processes when feasible	Balance processing times of the production units	
			Use multiskilled workers to smooth workflow between production units	
		Layout for flow		
		Simplify site installation to final assembly and commissioning		
		Minimize negative iteration in design	Use the Design Structure Matrix (DSM) ¹³ to eliminate avoidable iteration	
			Use strategies for reducing negative iteration at team assignment level	Accelerate iteration through team sessions
				Design to the upper end of interval estimates; e.g., loads
				Shift overdesign where estimates can best be made or overdesign can be done at least cost
	Control work for flow	Use the Last Planner system of production control	Try to make only assignments with the following quality characteristics: definition, soundness, sequence, size, learning	
			Measure plan	

			reliability	
			Identify and act on root causes of plan failure	
			Explode scheduled tasks as they enter the project lookahead window (typically 3-12 weeks)	
			Analyze lookahead tasks for constraints and act to remove those constraints	
			Allow lookahead tasks to maintain their scheduled dates only if they can be made ready in time	
			Balance load and capacity by retarding/advancing scheduled tasks and/or reducing/increasing resources	
	Reduce inventories (time spent waiting in queues)	Reduce variability (a primary reason for inventories)	Underload resources	
			Identify and act on causes of variability	
		Reduce transfer batch sizes (get stuff out of queues asap)		
		Reduce setup times (a 'cost' that constrains inventory reduction)		
		Pull matls and information through the production system ¹²		
	Reduce inspection time	Make inspection unnecessary or automatic; aka, pokayoke		
		Incorporate inspection in processing time		
	Reduce processing times	Reduce process batches		
		Redesign products to require less processing time		
		Apply technology that reduces processing time		
	Reduce rework time	Do in-process inspection		
		Identify and act on causes of defective work		
	Reduce time materials and information spend being moved and not processed	Reduce 'distances' over which materials and information are to be moved		
		Increase movement		

		speed		
		Reduce the number of moves; e.g., strive for 'one touch' matl hdlg on site		
Get more from less	Increase resource productivity, aka realized capacity (but subordinate to value and flow)	Increase resource utilization	Match load and capacity (have sufficient load to utilize available capacity)	
			Reduce system variability (allows greater utilization for a given throughput rate)	
		Increase resource fruitfulness	Develop skills	
			Improve design for fabrication and installation	
			Assign tasks where they can best be done; e.g., shift detailed eng. to suppliers	
		Assign tasks where they can best be done; e.g., shift detailed eng. to suppliers		
	Reduce the cost of acquiring resources, materials, and information	Reduce transaction costs		
		Reduce purchase prices		
	Reduce the cost of using materials and information	Reduce material scrap		
		Reduce unneeded work space		
		Reduce 'emissions'		

Appendix III:

The questionnaire, the covering and follow up letters

Covering letter

Ágæti viðtakandi hjá xxxxxx.

Ég er að vinna að meistaraverkefni í meistaranámi hjá Háskólanum í Reykjavík.

Meistaranámið heitir Framkvæmdastjórnun og er kennt við verkfræðideild.

Meðfylgjandi könnun er hluti meistaraverkefnisins. Tilgangur hennar er að kanna núverandi notkun og framtíðarviðhorf varðandi hagnýtingu upplýsingatækninnar, byggða á virkni landupplýsingakerfa, hjá fyrirtækjum og stofnunum sem sýsla við mannvirkjagerð. Með þátttöku í könnun þessari gefst fyrirtækjum og stofnunum kostur á að varpa ljósi á stöðu notkunar landupplýsingakerfa í dag og lýsa afstöðu til aðferða sem hafa eða gætu orðið þeim til hagsbóta í framtíðinni.

Heppilegast er að svarandi /svarendur hafi þekkingu á verkefnadrifnum framleiðslukerfum í bland við upplýsingakerfi, svo sem yfirmenn mannvirkjaframkvæmda, hönnunar- eða verkefnastjórnendur.

Könnunin er nafnlaus og því órekjanleg til einstakra fyrirtækja eða stofanana. Hún er sett fram bæði á ensku og íslensku með það í huga að svarendur skilji betur viðfangsefnið.

Það tekur um 10 mínútur að svara könnuninni. Takið eftir leiðbeiningum þegar spurningunum er svarað.

Vinsamlegast smellið á eftirfarandi hlekk til þess að opna könnunina:

<http://www.createsurvey.com/s/Enko5v/>

Rannsóknin er opin til og með 14. september 2012 og verður síðan kynnt seinna í haust 2012 hjá HR ásamt meistararitgerðinni í heild.

Follow up letter

Þar sem þetta efni varðar ekki svo mörg fyrirtæki/stofnanir er hver svörun afskaplega mikilvæg áreiðanleika rannsóknarinnar. Ég hef því framlengt frestinn til 21. september í þeirri von að fleiri sjái sér fært að svara henni. Þeim sem þegar hafa svarað þakka ég fyrir.

Ágæti viðtakandi hjá Recipient's Name,

Ég er að vinna að meistaraverkefni í meistaranámi hjá Háskólanum í Reykjavík.

Meistaranámið heitir Framkvæmdastjórnun og er kennt við verkfræðideild.

Meðfylgjandi könnun er hluti meistaraverkefnisins. Tilgangur hennar er að kanna núverandi notkun og framtíðarviðhorf varðandi hagnýtingu upplýsingatækninnar, byggða á virkni landupplýsingakerfa, hjá fyrirtækjum og stofnunum sem sýsla við mannvirkjagerð. Með þátttöku í könnun þessari gefst fyrirtækjum og stofnunum kostur á að varpa ljósi á stöðu

notkunar landupplýsingakerfa í dag og lýsa afstöðu til hugmynda sem hafa eða gætu orðið þeim til hagsbóta í framtíðinni.

Heppilegast er að svarandi /svarendur hafi þekkingu á verkefnadrifnum framleiðslukerfum í bland við upplýsingakerfi, svo sem yfirmenn mannvirkjaframkvæmda, hönnunar- eða verkefnastjórnendur.

Könnunin er nafnlaus og því órekjanleg til einstakra fyrirtækja eða stofanana. Hún er sett fram bæði á ensku og íslensku með það í huga að svarendur skilji betur viðfangsefnið.

Það tekur um 10 mínútur að svara könnuninni. Takið eftir leiðbeiningum þegar spurningunum er svarað.

Vinsamlegast smellið á eftirfarandi hlekk til þess að opna könnunina:

<http://www.createsurvey.com/s/pRN3pn/>

Rannsóknin er opin til og með 21. september 2012 og verður síðan kynnt seinna í haust 2012 hjá HR ásamt meistararitgerðinni í heild.

Með von um jákvæð viðbrögð,

Ásgeir Sveinsson
Netfang: asgeirs11@ru.is
Sími: 859 9525

The questionnaire

Online survey powered by CreateSurvey

Núverandi hlutverk landupplýsingakerfa (LUK) í framleiðslukerfum íslenskra mannvirkjaframkvæmda og framtíðarhorfur. (The current role of Geographical Information Systems (GIS) in production systems in Icelandic construction sector and its future prospects.)

***Hluti I: Almennar upplýsingar um þitt fyrirtæki/stofnun. (General information about your company/organization.)**

Hver er fjöldi fastra starfsmanna í þínu fyrirtæki/stofnun? (What is the number of employees in your organization?)

- ☐ Færri en 10 (Fewer than 10)
☐ 10-20
☐ 21-50
☐ Fleiri en 50 (More than 50)

*** Hvar í ferli verkefnis stafar þitt fyrirtæki/stofnun? (In what phases of project delivery process does your organization operate?)**
(Hægt að haka við fleiri en einn kost) (Possible to check more than one box)

- ☐ Skilgreiningu verkefnis. (Project definition phase.)
☐ Hönnunarbætti verkefnis. (Project design phase.)
☐ Öflun aðfanga verkefnis. (Project procurement phase.)
☐ Framkvæmd verkefnis. (Project construction phase.)
☐ Starfrækslu verkefnis. (Project operation phase.)

***Hluti II: Upplýsingar um notkun aðferða "lean construction" í þínu fyrirtæki/stofnun. (Information about lean construction practice in your company/organization.)**

Notar þitt fyrirtæki/stofnun verkfæri "sparneytnihugsunar" (e. lean thinking) við mannvirkjagerð? (Does your company/organization use lean construction tools?)

- ☐ Já (Yes)
☐ Nei (No)

Ef **já** þá hvaða verkfæri? (If **yes** then what tools?)

- ☐ Last Planner System.
☐ Just in time.
☐ Kan-ban.
☐ Skuldbindingarskjal. (Commitment charts.)
☐ Skipuleggja-gera-athuga-aðhafast. (Plan-do-check-act.)
☐ Hlutfall áætlunar lokið skjal. (Percentage plan completed charts.)
☐ Annað, vinsamlegast tilgreinið: (Other, please specify:)

***Hluti III: Upplýsingar um notkun LUK við úrlausn verkefna í þínu fyrirtæki/stofnun. (Information on GIS usage in projects in your company/organization.)**

Notar þitt fyrirtæki/stofnun LUK við að koma verkefnum til skila? Does your company/organization use GIS in delivering projects?

Ekki skiptir máli hvort LUK sé rekið af þínu fyrirtæki/stofnun aðeins að það sé nýtt við starfsemina.

- ☐ Já (Yes)
☒ Nei (No)

Ef **já** þá: Í hvaða þáttum verkefnisferilsins og í hve miklum mæli? (If **yes** then: where in the project delivery process and to what extent?)

(Veldu hlutfall þeirra verkefna þar sem LUK er beitt frá aldrei til alltaf en óviðkomandi ef þitt fyrirtæki/stofnun starfar ekki á því sviði.) (Choose in how many of your projects GIS are used from newer to always or not relevant if your company does not work in that field)











































	Óviðkomandi (Not relevant)	Aldrei (Never)	2	3	4	Alltaf (Always)
Við staðarval verkefnis. (In location selection for a project.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við hagkvæmnigreiningu verkefnis. (In feasibility study for a project.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við frumhönnun verkefnis. (In a project's design brief.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við áhættumat verkefnis. (In a project's risk assessment.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við frumáætlun kostnaðar verkefnis. (In preliminary cost estimates.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við hönnun. (In designing.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við gerð aðaluppdráttar. (Producing general drawings.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við gerð nákvæmar kostnaðaráætlunar byggða á magntölum úr LUK. (In detailed cost estimates from quantity takeoffs.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við gerð tímasetninga. (In scheduling.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við ráðstöfun aðfanga. (In resource allocation.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við skráningu framvindu verkefnis. (In monitoring project performance.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við stýringu verkefnis. (In project control.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við gerð öryggis- og/eða hættumats og viðbragðsáætlunar. (In safety and/or hazard assessment and response planning.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við öflun aðfanga. (In procurement.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Í samskiptum við birgja verkefis. (In project supply chain.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við skipulag aðdrátta. (In logistics.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við röðun verkþátta. (In sequencing activities.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við sjónræna stjórnun t.d. með táknnum um gang verkþátta á verkstöðum. (In managing visually.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sem reyndargagnagrunn mannvirkis. (As an as-built information database.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við gerð gæðaskýrslna. (For quality reporting.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Við rekstur mannvirkis. (In facility management.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Hluti IV: Spurningar varðandi innleiðingu sparneytnisreglna með virkni LUK. (Questions about methods for implementing lean principles by GIS functionality .)

Hve sammála ert þú því að eftirfarandi aðferðir munu eða hafa haft (ef aðferðin er þegar í notkun), í þínu fyrirtæki/stofnun, jákvæð áhrif, annað hvort eða bæði, á frammistöðu og kostnað verkefna. (How strongly do you agree that subsequent methods will or has (if they are already in place) either or both result in better product or lower cost of a project in your company/organization?)

	Óviðkomandi (Not relevant)	Ósammála (Disagree)	Frekar ósammála (Rather disagree)	Hlutlaus (Neutral)	Frekar sammála (Rather agree)	Sammála (Agree)
* Byggja þrívítt tölvutækt (3D) módel af framkvæmdinni strax frá byrjun verkefnis þar sem hver eining er vensluð hönnunar- og verkfyrirmælum. (Construct 3D digital product model from definition phase with every element linked to design and work specifications.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
* Byggja upp tölvutækt þrívíddarmódel í nokkrum stigum upplausnar (nákvæmni). (Structure 3D model in appropriate levels of details.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

* Nota útgáfustýringu og vélræna meðhöldun rúmgerðra eininga við sjónræna og sjálfvirka árekstraleit hönnunarhluta. (Use versioning and spatial data handling mechanism for automatic and visual clash detection.)						
* Sjónsköpun byggingarforma og umhverfis þeirra í tölvugerðu líkani fyrir mat á fagurfræði, umhverfisáhrifum og notagildi. (Visualization of construction forms for aesthetic, environmental and functional evaluation.)						
* Nota tölvutækt þrívíddarmódel fyrir greiningu á hermum. (Use 3D model for simulation analyses.)						
* Nota tölvutækt þrívíddarmódel venslað skipulagi og tímaáætlunum verkhluta (4D) við eftirlit. (Use 3D model linked with information on planning and scheduling (4D) to control.)						
* Nota 4D módel, í nokkrum stigum upplausnar, til að auðvelda fleirum þáttöku í ákvarðanatökuferlinu. (Use 4D model to involve more project personnel to participate in decision-making process.)						
* Nota 4D módel til að skuldbinda (úthluta) verkþætti þegar ferlið er reiðubúið. (Use 4D model to commit tasks when ready to work.)						
* Nota 4D módel til að prófa röðun framkvæmda mannvirkjahluta. (Use 4D model to test construction sequence.)						

* Nota 4D módel til að tryggja öryggi. (Use 4D model to ensure safety.)	☉	☉	☉	☉	☉	☉
* Nota 4D módel mannvirkis og staðfræðilegar upplýsingar byggingarstaðar til að þróa viðbragðsáætlanir gegn vá. (Use 4D model and topographical information of the site and its surroundings to develop hazard plan.)	☉	☉	☉	☉	☉	☉
* Nota 4D módel og landfræðilegar upplýsingar um birgja (flutningstími) til að tryggja afhendingartíma. (Use 4D model and geographical information of suppliers to ensure delivery time.)	☉	☉	☉	☉	☉	☉
* Senda birgjum sjálfvirkir hönnun og verklýsingar á framleiðslueiningum úr uppfærðu 3D gagnamódeli. (Automate extraction of intermediate product design from updated 3D model.)	☉	☉	☉	☉	☉	☉
* Nota uppfært 4D módel sem grunn fyrir áfangagreiðslum. (Use up-to-date 4D model as a base for progress payments.)	☉	☉	☉	☉	☉	☉
* Öflun reyndargagna með eftirlitskerfi sem næst rauntíma til að jafna flæði aðfanga. (Tight integration of 4D model with monitoring system in time to level the resources.)	☉	☉	☉	☉	☉	☉
* Nota uppfært 3D módel til að miðla upplýsingum um gang verkferla og þannig stýra sjónrænt. (Use updated 3D model to communicate the status of ongoing processes thus managing visually.)	☉	☉	☉	☉	☉	☉

* Nota beintengdar handtölvur á verkstað til að uppfæra 4D módelið. (Use on-line handheld computers on site to update the 4D model.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
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* Hver af eftirtöldum atriðum finnst þér helst hindra innleiðingu ofangreindrar tækni í þínu fyrirtæki/stofnun? (Which of the following do you consider to be the most dominant factors for implementing the technology specified above in your company/organization?)

Möguleiki að haka við fleiri en eitt. (Possible to choose more than one.)

☐ Núverandi tækni uppfyllir þarfir okkar. (Current technology fulfil our needs.)

☐ Stærð verkefna okkar gefur ekki tilefni til svo umfangsmikillar tækni. (The size of our projects does not require such extensive technology.)

☐ Erfiðleikar við samhæfni samskiptastaðla. (Interoperability issues.)

☐ Innleiðing er flókin. (It is complicated to implement.)

☐ Tæknin er kostnaðarsöm. (It is expensive.)

☐ Skortur á tölvutækum þrívíddargögnum. (Shortage of 3D data.)

*Notar þitt fyrirtæki fjórvítt tölvumódel. (Does your company/organization use 4D computer model.)

☐ Já (Yes)

☐ Nei (No)

Ef **nei** þá: (If **no** then:)

Veldu á kvarðanum frá einum (líklega ekki) til fimm (mjög líklega).

	Líklega ekki (Most certainly not)	2	3	4	Mjög líklega (Most certainly)
Hversu líklegt telur þú að þitt fyrirtæki/stofnun muni nýta sér 4D tölvutæk módel á næstu þremur árum? (How likely do you think your company/organization will utilize 4D computer model in next three years?)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>