Improving Construction Planning
Through 4D Planning

Christopher James Allen

Submitted in partial fulfilment of the requirements for
the degree of Magister Scientiae in the Built Environment,
Project Management Specialisation, in
the Faculty of Engineering, Built Environment and Information Technology at
the Nelson Mandela Metropolitan University

January 2007

Supervisor: Prof. J.J. Smallwood
STATEMENT

The data used in the compilation of this treatise was collected from both primary and secondary sources. Where secondary sources have been used, reference has been made to them.

This treatise is my own work and has not previously been submitted to any other institution.

Christopher James Allen    Date
DEDICATION

I dedicate this to my late Grandfather, Harvey Crabtree, who instilled in me a passion for construction and who showed through his own hard work, dedication and passion, that no matter where you start out, these qualities can take you to the top in any chosen profession. Also, to my parents, who have provided every opportunity to allow me to exceed and instilled in me a belief that if you believe in what you are doing, you can do anything.
ACKNOWLEDGEMENTS

The path to an MSc (Built Environment) Project Management Specialisation is a long and sometimes lonely personal crusade, but there are many who contribute and provide assistance along the way. It is not possible to say thank you to them all, but I would like to mention a few.

The seeds of this research were in essence sown back in the spring of 1999 when Barry Ramsay and I formed A3D, a company desiring to use the emerging new 3D design technologies in a more advanced way, a way that could improve on the delivery processes in construction. It has been a road filled with many obstacles, at times a painful process, an extremely frustrating struggle, but through all of those nearly eight years there has been a sincere belief that the current failings in the delivery of construction projects can be improved upon through the use of new technologies, which has allowed us to succeed where others may have failed. Thank you Barry for your support throughout and continued belief that doing the right thing is for the betterment of all those involved in the construction process.

To my wife, Caroline, who has provided both moral support and motivated me when I became tardy or downhearted, thank you for providing reassurance that I was not wasting my time, and yours, in this quest to further the knowledge base and increase the dialogue for change. Also, for all the hours spent with me typing up documentation, including trying to decipher my tired and messy hand writing, my heartfelt thanks.

To my supervisor, John Smallwood, you provided the impetus and gave me the opportunity to fulfil a long held desire to further my education. It has also given me the opportunity to produce valuable research into new technologies for the better delivery of construction projects. Your valuable advice, witty sarcastic encouragement and timeous guidance, especially when the process became murky and the red mist descended, have all played an important part in the completion of this treatise.
To the construction team on the 51 Lime Street Project, and in particular the Project Director, Nick Moore and Project Planner, Adio Amusa, thank you for providing me access to information and input to maximise the potential learning and feedback from the project environment. Adio, without your personal knowledge of the construction planning process and your willingness to share that knowledge, this study could not have happened and would not have become the ground breaking research it is.

I would also like to thank Andy Butler of Stanhope for information he has provided on the implementation of 4D planning on projects carried out by their organisation, along with his continuing support of the 4D principles we enthuse. Finally, thanks also go to Prof. Nash Dawood and Sushant Sikka of the Centre for Construction Innovation and Research at the University of Teesside, for their assistance in accessing some of the data used.
ABSTRACT

Construction Planning will increasingly play a more critical role within the realm of the Built Environment. Existing practices used to plan and communicate the construction process to be undertaken are failing to deliver the desired results for construction companies and clients alike. At a time of unprecedented growth in the industry around the world, which is leading to a general skills shortage, especially in management positions, construction planners are increasingly being asked to deal with more responsibility. As with other industries, technological improvement in the tools at their disposal is one way to address the inadequacies of the present situation.

Increasingly, three dimensional design packages are being used to generate construction information which can then be used for quantities calculations, automated manufacturing processes and construction simulation. The latter forms the basis for their use in the process of planning, through new technologies being developed as virtual construction tools or 4D planning, the addition of time to the 3D model environment, but using the elements within the model as the basis for the construction programme. The benefit of using the design information to form the basis of the programme is that the interface tasks and logistical activities, as well as location related constraints, can be identified and then communicated to all levels within the construction team through a time based visual image.

The purpose of this study is therefore to establish a scientifically analysed alternative method for the creation, review and delivery of construction programmes. In order to achieve the research objectives, three methodologies have been employed. Firstly, the literature review in the fields of planning including existing methodologies and previous research of 4D related techniques has been analysed. An overview of the perceived weaknesses to current practises and proposed solution will be explored and best case scenarios outlined and further investigated. Secondly, the 51 Lime Street project provides an environment in which the proposed 4D planning techniques have been implemented and the benefits of the process can, through observation / participation methodology, be validated. Thirdly, through interview questionnaires,
with Lime St contractors and management, and e-mail questionnaires to a broader sample stratum, data on the ability of the tools, the techniques employed on 51 Lime Street and similar projects have been collated and statistically analysed to validate the reliability and relevance for future implementation.

The result of the research will provide management teams with a practical alternative to existing planning methodologies. Construction planners will have alternative technique that can further enhance their role within the project team whilst increasing their ability to communicate the team’s vision to a wider audience, making them and the project more efficient and effective in the process. It has been proposed that clients insist on the use of 3D from the commencement of the design process so that this information can be passed downstream through the construction process and onto facilities management. Planners need to be able to communicate their requirements better and the 4D planning models provide both a more inclusive way of planning alongside a better communications medium in the form of moving images. A picture tells a thousand words!

**Keywords:** Construction Planning; 4D Planning; 3D Model; Communication; Integration; Simulation
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>No.</th>
<th>Statement</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>THE PROBLEM AND ITS SETTING</td>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
<td>The Statement of the Problem</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>The Statement of the Sub-problems</td>
<td>1</td>
</tr>
<tr>
<td>1.3</td>
<td>The Hypotheses</td>
<td>2</td>
</tr>
<tr>
<td>1.4</td>
<td>The Delimitation of the Study</td>
<td>2</td>
</tr>
<tr>
<td>1.5</td>
<td>Definition of terms</td>
<td>3</td>
</tr>
<tr>
<td>1.6</td>
<td>The Abbreviations used</td>
<td>4</td>
</tr>
<tr>
<td>1.7</td>
<td>The Assumptions made</td>
<td>4</td>
</tr>
<tr>
<td>1.8</td>
<td>The Importance of the Study</td>
<td>5</td>
</tr>
</tbody>
</table>
## 2. THE REVIEW OF RELATED LITERATURE 13

### 2.1 Introduction 13

### 2.2 Integration of Project Teams 14

#### 2.2.1 Introduction 14

#### 2.2.2 Changing the Culture 16

#### 2.2.3 Benefits of Teamwork 17

### 2.3 Planning Methodologies 20

#### 2.3.1 Introduction 20

#### 2.3.2 Alternative Thinking 22

### 2.4 Construction Planning 24

#### 2.4.1 Limitations of Current Methodology 24

#### 2.4.2 Effective Planning 26

#### 2.4.3 Alternative Practices 28

#### 2.4.4 Monitoring Progress 30

#### 2.4.5 Transferring Knowledge 30

### 2.5 4D Simulation, Visualisation, Modelling and Planning 33

#### 2.5.1 Why 4D? 33

#### 2.5.2 Usability 36

#### 2.5.3 Communications Tool 37

## 3. THE SAMPLE STRATA 41

### 3.1 Introduction 41

### 3.2 The Case Study 41

### 3.3 Pilot Interview 41

### 3.4 Case Study Interview Survey 42

### 3.5 E-mail Survey 43
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>METHODOLOGY</td>
<td>44</td>
</tr>
<tr>
<td>4.1</td>
<td>Design of the survey</td>
<td>44</td>
</tr>
<tr>
<td>4.2</td>
<td>The data collection procedures</td>
<td>45</td>
</tr>
<tr>
<td>4.3</td>
<td>The Design of the Questionnaires</td>
<td>48</td>
</tr>
<tr>
<td>4.4</td>
<td>Collecting the Data</td>
<td>48</td>
</tr>
<tr>
<td>4.5</td>
<td>The Treatment of the Data</td>
<td>49</td>
</tr>
<tr>
<td>5.</td>
<td>THE CASE STUDY</td>
<td>50</td>
</tr>
<tr>
<td>5.1</td>
<td>Rationale</td>
<td>50</td>
</tr>
<tr>
<td>5.2</td>
<td>Review of Project Information</td>
<td>50</td>
</tr>
<tr>
<td>5.3</td>
<td>Observation from Projects</td>
<td>53</td>
</tr>
<tr>
<td>5.4</td>
<td>Interpretation of what was observed</td>
<td>56</td>
</tr>
<tr>
<td>5.5</td>
<td>Relevance to other projects</td>
<td>60</td>
</tr>
<tr>
<td>6.</td>
<td>THE RESULTS</td>
<td>63</td>
</tr>
<tr>
<td>6.1</td>
<td>Introduction</td>
<td>63</td>
</tr>
<tr>
<td>6.2</td>
<td>Case Study Interview Questionnaire</td>
<td>64</td>
</tr>
<tr>
<td>6.3</td>
<td>E-mail Questionnaire</td>
<td>78</td>
</tr>
<tr>
<td>7.</td>
<td>TESTING THE HYPOTHESES</td>
<td>89</td>
</tr>
<tr>
<td>7.1</td>
<td>Introduction</td>
<td>89</td>
</tr>
<tr>
<td>7.2</td>
<td>Hypothesis 1:</td>
<td>90</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Interview Survey</td>
<td>90</td>
</tr>
<tr>
<td>7.2.2</td>
<td>E-mail Survey</td>
<td>90</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Case Study</td>
<td>91</td>
</tr>
<tr>
<td>7.2.4</td>
<td>Test</td>
<td>93</td>
</tr>
</tbody>
</table>
CONTENTS OF THE STUDY

Chapter One focuses on the problem and its sub-problems along with the hypotheses that have been formulated in response to these. The parameters under which the study was undertaken are defined including the delimitations, assumptions, definitions of terms used and relevant abbreviations. The importance of the study to the construction industry with particular relevance to the planning and project management disciplines is also addressed.

In Chapter Two a review of related literature is presented. As the field of 4D planning is a relatively new area of study, literature on related technology including 4D simulation, visualisation and modelling, have also been included. In addition, related fields which focus on improving communication within the construction industry have also been reviewed to place in context the perceived failings of the current methodologies. These current methodologies are reviewed in detail alongside the existing construction planning process, its relationship to the changing project management roles and responsibilities, and other new techniques being studied and implemented in an attempt to improve on the ability to deliver projects to programme.

Chapter Three outlines the populations involved in the respective surveys and the observation / participation case study. The method used and parameters of the observation / participation case study are reviewed.

Chapter Four covers the procedures in conducting the surveys. The overall design of the survey, data collection procedures, questionnaires and the collecting and treating of the data are all explained.

In Chapter Five the information generated from the observation / participation case study is reviewed. Discussion accompanies the review and serves to interpret and elaborate on the observations.
Chapter Six focuses on the results generated from the replies and statistical analysis of project delivery data. Graphical reporting of the results accompanies the findings and provides assistance in understanding the interpretation of the results.

In Chapter Seven the three hypotheses are tested by analysing the results of the surveys, case study and statistical analysis.

Chapter Eight provides a summary of the findings, draws conclusions based on the findings with additional data provided by the reports generated from observations. Recommendations based on the study are then presented.

Chapter Nine provides closure with anecdotal evidence of the importance of understanding the present constraints and reason for change.

The references and appendices conclude this treatise.
PREFACE

The recent high profile cases of projects failing to be completed within budget or to programme, including the Wembley Stadium in London, have once again focused unwanted negative attention on the construction industry. The world’s media and politicians have taken advantage of this failure and highlighted the construction industries’ dysfunctional practices and inability to become a more integrated and information technology (IT) aware industry.

To add to this, there is an ongoing media storm, accompanied by negativity regarding South Africa’s ability to construct new stadiums in time for the 2010 World Cup. Suddenly, South Africa’s population has also focused attention upon the abilities of the construction industry and the perception has evolved that those who earn a living through construction will not be able to manage to deliver on the expectations of the Nation, and complete the Stadiums by the required deadline.

The unprecedented levels of construction activity worldwide, fuelling an ever increasing race to lure the necessary talent to manage and build these projects, mean that trying to attract and retain the necessary talent is an expensive proposition. In conjunction with the decreasing number of new entrants into the sector, the industry has been left with a severe shortage of highly skilled construction professionals who have the experience and knowledge required to build these high profile projects.

By analysing and identifying a few key areas in the process, communicating that in a way that is understood by all levels of a project team, along with integrating the varied and competing agendas of the contracted specialists, the construction industry will be able to not only reduce the occurrence of delay on projects but also improve the working practices, health and safety record and most importantly, efficiency of their operations, thereby maximising the profit on projects. This will aid in funding further research and development whilst increasing the ability of organisations to attract the necessary management individuals needed to further develop their operations.
But the industry struggles with an inability to adopt new technology that would bring these much needed efficiencies to the management process and improve the use of the mass of data generated throughout the process. What this means in practice is that any attempt to deal with delays by increasing productivity within the existing workforce, will be next to impossible to achieve in the present environment. The figure below highlights the construction industry’s poor uptake of Information Technology, particularly in relation to its implementation as an alternative to existing working practices.

Figure 1: Industry Technology Adoption.
(Gallello, 2005*)

The aim of this study is therefore to provide a scientifically proven alternate method to review construction programmes in order to further enhance the ability of construction planners to deal with increasing levels of responsibility. It is also then an aim to allow these interrogated programmes to be communicated in a more explanatory manner to the legion of contractor’s whose responsibility it is to then further enhance the detail contained within the programme, using 4D planning, to improve on their ability to meet the deliverables set out in the programme. The final
objective is then to prove that by following this process greater certainty is delivered in attaining the contract programme than presently occurs through on-site monitoring of these tasks and other site based management techniques which benefit from more detailed planning methodologies.
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Heading</th>
<th>Page no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1:</td>
<td>Organisational Breakdown of Personnel Surveyed.</td>
<td>42</td>
</tr>
<tr>
<td>Table 2:</td>
<td>Breakdown of Survey Population Discipline’s.</td>
<td>43</td>
</tr>
<tr>
<td>Table 3:</td>
<td>Respondents’ exposure to planning methodology.</td>
<td>64</td>
</tr>
<tr>
<td>Table 4:</td>
<td>Types of planning methodology used and approval rate.</td>
<td>64</td>
</tr>
<tr>
<td>Table 5:</td>
<td>Extent to which planning methods communicated the project programme.</td>
<td>65</td>
</tr>
<tr>
<td>Table 6:</td>
<td>Extent to which 51 Lime Street planning methods communicated the project programme.</td>
<td>66</td>
</tr>
<tr>
<td>Table 7:</td>
<td>Respondents’ exposure to 4D Model.</td>
<td>66</td>
</tr>
<tr>
<td>Table 8:</td>
<td>Respondents’ rating of 4D planning’s ability to communicate the project programme.</td>
<td>67</td>
</tr>
<tr>
<td>Table 9:</td>
<td>Respondents’ views on need for greater levels of programme detail.</td>
<td>67</td>
</tr>
<tr>
<td>Table 10:</td>
<td>Extent to which levels of detail on 51 Lime St project compared with previous projects.</td>
<td>68</td>
</tr>
<tr>
<td>Table 11:</td>
<td>Extent to which planning performed on this project.</td>
<td>68</td>
</tr>
<tr>
<td>Table 12:</td>
<td>Respondents’ views on impact of 3D on planning detail.</td>
<td>69</td>
</tr>
<tr>
<td>Table 13:</td>
<td>Experience of detailed planning.</td>
<td>69</td>
</tr>
<tr>
<td>Table 14:</td>
<td>Extent to which 4D models may improve the ability to plan detailed aspects of the programme.</td>
<td>71</td>
</tr>
<tr>
<td>Table 15:</td>
<td>Extent to which additional detail helps communicate the project programme.</td>
<td>71</td>
</tr>
<tr>
<td>Table 16:</td>
<td>Extent to which 4D model helps communicate 3D reality required.</td>
<td>72</td>
</tr>
</tbody>
</table>
Table 17: Extent to which location based planning will improve project logistics.

Table 18: Extent to which visual communication of activity location will improve project delivery.

Table 19: Extent of 51 Lime St programme evaluation.

Table 20: Extent to which additional progress task monitoring would have on programme delivery.

Table 21: Extent to which visual communication of progress would have on programme delivery.

Table 22: Extent to which Construction is technology ‘phobic’.

Table 23: Extent of improvement in construction IT use from exposure to the use of other IT devices.

Table 24: Extent to which 4D planning models will increase with IT literacy.

Table 25: Respondents’ exposure to planning methodology.

Table 26: How 3D &4D improves communication process.

Table 27: Extent to which additional detail would help to communicate delivery programme requirements.

Table 28: Extent to which construction programme levels of detail need to increase.

Table 29: Extent to which construction programme’s need to communicate the location of tasks.

Table 30: Extent to which knowing a construction task location would aid in its completion.

Table 31: Extent to which respondents would have difficulty in communicating the location of a task without an image.

Table 32: Extent to which a 4D model would assist in the completion of a task as planned.
Table 33: Extent to which planning would be improved if a location based planning tool were used.

Table 34: Extent to which visually communicating progress against baseline would aid in programme management.

Table 35: Extent to which visual tools aid in addressing implications of process implementation.

Table 36: Use of computers by respondents.
<table>
<thead>
<tr>
<th>Figure</th>
<th>Heading</th>
<th>Page no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1:</td>
<td>Industry Technology Adoption.</td>
<td>xiv</td>
</tr>
<tr>
<td>Figure 2:</td>
<td>Use of BIM in Artra Facilities Management Software.</td>
<td>11</td>
</tr>
<tr>
<td>Figure 3:</td>
<td>Coordinated 3D services model used in 4D planning model.</td>
<td>18</td>
</tr>
<tr>
<td>Figure 4:</td>
<td>3D mechanical room model in Artra FM software.</td>
<td>19</td>
</tr>
<tr>
<td>Figure 5:</td>
<td>Communicating in 3D and 4D.</td>
<td>32</td>
</tr>
<tr>
<td>Figure 6:</td>
<td>4D planning process.</td>
<td>35</td>
</tr>
<tr>
<td>Figure 7:</td>
<td>Planning logistics graphically.</td>
<td>39</td>
</tr>
<tr>
<td>Figure 8:</td>
<td>Detailed interface planning.</td>
<td>53</td>
</tr>
<tr>
<td>Figure 9:</td>
<td>Construction Coordination.</td>
<td>55</td>
</tr>
<tr>
<td>Figure 10:</td>
<td>4D logistics planning.</td>
<td>58</td>
</tr>
<tr>
<td>Figure 11:</td>
<td>4D planning sequence models from 51 Lime St.</td>
<td>58</td>
</tr>
<tr>
<td>Figure 12:</td>
<td>Design clash detection of 4D services model.</td>
<td>59</td>
</tr>
<tr>
<td>Figure 13:</td>
<td>4D planning presentation models.</td>
<td>61</td>
</tr>
<tr>
<td>Figure 14:</td>
<td>Extent of 3D models ability to improve delivery.</td>
<td>70</td>
</tr>
<tr>
<td>Figure 15:</td>
<td>Extent to which 4D planning model would help to communicate where and when activities take place.</td>
<td>73</td>
</tr>
<tr>
<td>Figure 16:</td>
<td>Extent to which the planner on 51 Lime St had been better able to communicate the construction programme.</td>
<td>74</td>
</tr>
<tr>
<td>Figure 17:</td>
<td>Types of planning methodology used and approval rate</td>
<td>78</td>
</tr>
<tr>
<td>Figure 18:</td>
<td>Extent to which an image helps communicate project tasks to colleagues.</td>
<td>79</td>
</tr>
<tr>
<td>Figure 19:</td>
<td>Extent to which additional image tasks would aid delivery of requirements.</td>
<td>82</td>
</tr>
<tr>
<td>Figure 20:</td>
<td>Monitoring frequency.</td>
<td>85</td>
</tr>
</tbody>
</table>
Figure 21: Extent to which monitoring would be affected by having more tasks to monitor. 86

Figure 22: Extent to which 4D models helped to communicate the process implications of creating the 3D reality. 88

Figure 23: Cladding installation process. 92
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Illustration</th>
<th>Heading</th>
<th>Page no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illustration 1:</td>
<td>Delivering Client Expectation.</td>
<td>9</td>
</tr>
<tr>
<td>Illustration 2:</td>
<td>Most significant changes contributing to the project delivery process.</td>
<td>12</td>
</tr>
<tr>
<td>Illustration 3:</td>
<td>Integrated build plan process.</td>
<td>16</td>
</tr>
<tr>
<td>Illustration 4:</td>
<td>Potential savings of Lean Production in Construction.</td>
<td>22</td>
</tr>
<tr>
<td>Illustration 5:</td>
<td>Learning through repetition.</td>
<td>26</td>
</tr>
<tr>
<td>Illustration 6:</td>
<td>Alternate Construction Planning Process.</td>
<td>27</td>
</tr>
<tr>
<td>Illustration 7:</td>
<td>What should the level of detail be?</td>
<td>51</td>
</tr>
</tbody>
</table>
1. THE PROBLEM AND ITS SETTING

1.1 The Statement of the Problem

Construction personnel cannot communicate the complexity or 3D reality of a programme, nor visualise the process implications in creating that reality, resulting in late completion.

1.2 The Statement of the Sub-problems

- The first sub-problem is to investigate whether the process implications of creating 3D reality are better visualised through 4D planning.

- The second sub-problem is to investigate whether better delivery of the 3D reality can be achieved through greater evaluation of the programme using Build Plan methodology.

- The third sub-problem is to determine whether using 4D planning better communicates the complexity and 3D reality of the construction programme, assisting contract programme delivery.
1.3 The Hypotheses

- The first hypothesis is that using 4D planning models to interrogate the construction programme will highlight the process implications of creating the 3D reality.

- The second hypothesis is that using 4D Build Plan methodology will better communicate to construction personnel the reality / complexity of the programme.

- The third hypothesis is that by using the 4D Planning models to communicate the Build plan, greater certainty of contract programme delivery will occur.

1.4 The Delimitations

The research will not review the implications of the design process on certainty of contract programme delivery.

The research will not review how other planning software assists construction planners to evaluate and communicate their plan.

The study will be limited to projects exceeding £20 million (R275 million) in construction cost.

The study will not attempt to pass judgement on the abilities of the planners to create a construction programme.
1.5 Definition of Terms

4D Planning: 4D planning is an extended and deeper version of conventional planning that develops the construction programme to a higher level of detail to provide greater accuracy and less risk. [online]
(Advanced 3D Technologies Ltd., 2006)
Available from http://www.4dplanning.co.uk/services/the process.

4D Modelling: The use of 3D CAD models aligned to time, controlled and manipulated to show the building as it should appear at any stage during construction. (Fischer & Aalami, 1996: 337)

Build Planning: A process that will determine the activity and output of every trade on the construction project every day of its duration.
(BLL, 2001: 44)

Build Plan Methodology: Involves developing a detailed plan for every step of the production process. This results in the delivery of a pre-defined and agreed work output at the end of every time period, e.g. a day or a shift.
(BLL, 2001: 44)

Communication: The transfer of information from one individual to another to explain a thought process. (Makins, M. (ed), 1992: 267)

The Construction Planner: The role of the designated individual responsible for determining optimal methods, sequence and timing of construction activities and related resources for a construction project.
(Faniran & Proverbs, 2002: 159)

Contract or Master Programme: The Principal programme for a project, in particular that produced to comply with contractual requirements of the project. [online] (Bordoli, 2006) Available from: http://www.planningengineers.org/knowledge/glossary.aspx#m.
Evaluation: The review and interrogation of a proposal to achieve the most appropriate result (Makins, M. (ed), 1992: 442).

1.6 Abbreviations

- **BCIS**: The Royal Institute of Chartered Surveyor’s Building Cost Information Service
- **DTI**: Department of Trade and Industry (UK)
- **KPI**: Key Performance Indicators
- **NIST**: National Institute of Standards and Technology (USA)
- **NOA**: National Audit Office (UK)
- **PEO**: Planning Engineers Organisation
- **PFI**: Private Finance Initiative
- **PMBOK**: Project Management Body of Knowledge
- **PPP**: Public Private Partnerships

1.7 The Assumptions

With respect to the problem & sub-problems, the assumptions made were:

- Firstly, that there is a need for construction planners on >£20 million projects in London;
- Secondly, that construction planners need to communicate their construction programme to other personnel;
- Thirdly, that clients want greater certainty of contract programme delivery;
- Fourthly, that the projects using 4D planning are representative of similar projects not using 4D planning in trying to give clarity to contract programme delivery, and
- Lastly, those similar projects not using 4D planning are using other planning techniques and software similar to that being used on those projects using 4D planning.
1.8 The Importance of the Study

Construction planners and the role they perform are little understood both within the construction industry and the wider environment in which construction has a daily impact. The number of competent planner's available falls far short of that which is required and therefore more and more less qualified personnel are being thrust into a role as planner. These, as well as existing construction planners, are faced with ever more complex and logistically challenging projects, which need a more inclusive process that will allow them to fully understand all the interfaces between contractors and communicate this to those self same contractors, so as to attempt to improve on the current levels of contract programme delivery. In addition, this is being reviewed at a time when the pressures on the industry in London are set to increase due to the need to deliver both infrastructure and building for the 2012 Olympic Games, the majority of which will be projects in excess of £20 million (R180 million) and which cannot be delivered late!

Over the past 20-25 years the construction industries of particularly the industrialised nations have become fragmented by an incessant drive to become leaner and more focussed on a primary discipline. This streamlining has, however, come at a cost to the client, who now faces a plethora of consultants and contractors responsible for carrying out what an architect and single contractor would previously have achieved. Clients are seeking certainty in terms of cost and time from the earliest stages of a project. At present, according to the statistics referenced below, the construction industry is failing to deliver on its objectives. In addition, the Department of Trade and Industry (DTI) reports that 50% of these failing projects over-ran their contract period in 2003 (cited by Burrows, 2003: 12).

For over a decade, it has been generally agreed that there is a need for change within the UK construction industry as it is unpredictable and under achieving. (Koskela, Ballard & Howell, 2003*; Santos & Powell, 2001: 166; Construction Task Force, 1998: 9-10; Latham, 1994: vii-ix). Added to these
earlier studies is data showing that 80% of projects do not meet the three main objectives for any project: to deliver on time, budget and to the right level of quality. Quality doesn’t just mean using good materials or zero defects but “right first time, delivery on time and to budget” (Construction Task Force, 1998: 17).

It is therefore apparent that what is currently viewed as best practice, along with the technologies and processes employed to deliver those practices, are proving inadequate in addressing the increased complexity of projects and incessant market demand for shorter construction time-scales. The central message of *Rethinking Construction* (Construction Task Force, 1998: 8) was that through the application of better practices, the industry and its clients can collectively act to improve their performance. One of the targets was to improve time and cost predictability. Although this has occurred, within small pockets of the industry, driven by the Public Finance Initiative (PFI) process and other large scale government initiatives like Public-Private Partnership (PPP), it is not presently the norm. The problem is also not limited to the United Kingdom (UK).

*Rethinking Construction* (Construction Task Force, 1998: 18) also quotes studies from the UK, the United States of America (USA) and Scandinavia suggesting that up to 30% of construction is ‘rework’, that labour is used at only 40-50% of potential efficiency and at least 10% of materials are wasted. Add the effect of accidents, which account for 3-6% of total project costs and the reasons for the sad state of the industry become a lot clearer. *The Economist Magazine* study referenced by Gallello (2005*) confirms this with figures of 10% loss due to wasted materials, 30% rework in the construction process and 60% of labour effort wasted. Furthermore, this is not a failure replicated across industry in general but rather a Construction Industry phenomenon. “In North America, construction is the only non-agricultural industry that has seen a consistent decline in productivity over the past 40 years” (Graphisoft, 2004*).
This under-achievement manifests itself in the unpredictability of delivery time, budget, quality of delivered product and as a result, profitability. (Santos & Powell, 2001: 166). “profits rule…. indeed your company has turned itself inside out to satisfy shareholders….yet over the next decade it is going to have to do more, far more…. ” (Hamel, 2000: 33). Construction, as in any other industry is concerned with making profits for investors and the potential of most major organisations is therefore reflected in the share price, which for construction orientated organisations has until recently been well below the market rate. This message is driven home by the statement in *Rethinking Construction* that “The under-achievement of construction is graphically demonstrated by the City’s view of the industry as a poor investment.” (Construction Task Force, 1998: 11). In order to make construction more attractive to both investors and potential recruits, the industry needs to look to technology to improve efficiencies and working practices. As planning has a significant impact on the ability of any organisation to achieve this, the focus of there attention should be on using technology to improve the construction planning process.

However, in order to do this and still make money, organisations need to be confident in their ability to plan and deliver the shorter build programmes and lower budgets that they promise their clients, which has “made the planning function critical to achieving successful delivery of a construction project.” (Faniran & Proverbs, 2003: 159). In general, when reliable planning is not achieved, downstream activities involving the workforce tend to be poorly collaborated with the related upstream supply chains. This is where delay becomes waste, as not only is time and money lost, but also substantial man-hours, when workforces are left standing around waiting for material delivery or, when it does arrive, looking for somewhere to store it.

But how do you achieve reliable planning when the main methodology for scheduling work in construction is activity based. This does not describe the typical building construction process, which is location based. This tendency,
referred to as “separation of execution from planning” (Sriprasert and Dawood, 2003: 341) is seen as one of the major reasons for construction plans becoming obsolete, due to the inevitable impact that this separation causes to task durations. How to address this weakness in existing planning techniques is the subject of much study as can be discerned in the literature review conducted. The techniques proposed to offset this only partly address the problem as the tools are either looking at using strategy as a pull mechanism or technology from a push perspective.

The industry is extremely large and encompasses many disciplines including civil engineering, rail engineering as well as the traditional construction trades such as electrical contractors and decorators. The margins throughout the industry are extremely tight and therefore investment in new technology or research and development (R&D) into new techniques is extremely limited. One weakness of the present project initiation is that ‘seams’ exist in the information base used for decision making. This is where technology can play a role as it is perfectly suited to creating a seamless decision making environment “so that information on all divisions of an organisation, and at different levels, can be available to all decision makers.” (Bates, 1995: 3)

In addition, although every project is different in nature, it is a similar process, but that process is often not documented and as a result no two people will execute it the same way. This area of the industry, known as the knowledge base, receives little attention but has a marked impact on the ability of project teams to deliver. “Today, most knowledge is buried within individuals and not the organisation as a whole.” (Gallello, 2005*). This is symptomatic of the present culture within the construction industry whereby organisations are more focused on the present than they are on structuring their business for the longer term. The result of this lack of standard operating procedure is the inability to predict time, cost and the size of the snagging list. The same malaise affects the R&D spend and the application of IT into the industry. The same can be said for individual projects as each new project
brings a new team, each with their own knowledge. “The concept of a knowledge base allows the company to leverage the massive amount of expertise across the organisation.” (Gallello, 2005*). If the collective knowledge base could be better harnessed through a single environment, far more could be achieved with fewer resources.

It is reasonable to suggest that these informal processes by their very nature will be inefficient, ineffective and most important of all, will not deliver value for money. In order to achieve the best from off-site construction, not only does the right product need to be specified, but the build process needs to be right in the first place. The output of any process can only be as good as the input. This is why Lean Production systems from the Motor and Aircraft Industry’s have started to find favour with Construction Organisations. “Great people and average processes produce average results; great processes and average people produce great results.” Toyota Motor Corporation

Illustration 1: Delivering Client Expectation.
(Adapted from Fisher, Barlow, Garnett, Finch & Newcombe, 1997: 4-5)

If the overarching recommendation of integrated project teams was fully and enthusiastically applied the potential savings could exceed 20% of the annual spend. The savings arise from process improvement rather than margin reductions. “Why should a customer have to pay for the inefficiency and ineffectiveness of the supply chain?” (Thomas, 2005*). This is especially true, even at a time when burgeoning work order books mean that some organisations may not focus completely on what their clients want. It is apparent, however, that the various studies produced in the past decade have
made clients aware that they can do better. “Clients are becoming more
demanding and are moving away from cheapest-price tendering…. (Lane,
2002: 1), and if organisations fail to innovate they may take their business
elsewhere, which is “tantamount to murder”.

Process improvement has therefore been identified as an important strategy to
address the current unpredictability and under achievements of the UK
construction industry. IT has been identified as a key enabler (Keraminiyage,
Amaratunga & Haigh, 2005*). “Given that Darwin’s first law of business is
innovate or die.” (Wilson, 2002: 1), it might be time for the construction
consultants and/or organisations to consider investing in the use of such
technology to improve the service to their clients and improve their bottom
line. To add to this, the globalization of construction, both in the design and
construction arenas, means that organisations need to use new technology to
outperform competitors, as doing what they have done for the last 20 years is
not going to be enough to withstand what the competition is proposing to use
on projects, be it collaboration tools, parametric modelling tools or 4D
planning. The bottom-line is that without innovating, organisations will be
seen to be stagnant and clients will take their business elsewhere.

Of course, the real bottom-line in all this is money! If a new discipline /
vocation within the ranks of the construction industry can save 2 to 3 percent
as has been advocated by Dominic Gallello and Clay Freeman in ‘The New
Heroes in the Building Industry’ (2004: 3), then why would construction
organisations, or for that matter architects, not seek to employ these people
and their new technologies? This is not some whimsical idea that will
disappear in five years; on the contrary any major project will likely need one
if Tom Brady, a construction manager on the new George Lucas corporation
campus is to be believed. His experience on this project led him to include in
a recent speech “that in 5 years, every major project will employ a building
model.” (Gallello & Freeman, 2004: 3)
Instead of looking at technology as a cost, the industry should rather be looking at the technology to create value. “Clients need better value from their projects and construction companies need reasonable profits to ensure their long term future”. (Construction Task Force, 1998: 13). Value engineering is a large facet of the design process, yet costs could be reduced through use of the technology already available and through Building Information Modelling (BIM) taken on into the construction and facilities management phases, in essence a whole lifecycle cost, not just a build cost. The government in the UK has along with the General Services Administration in the United States, already reached this conclusion, with the emphasis not on cutting costs but rather on process improvements. And an essential part to achieving this is to improve on the existing planning process.

Figure 2: Use of BIM in Artra Facilities Management Software.
Source courtesy of ArtrA Ltd.

A similar mindset should occur in the private sector, but here the benefits relate to maximising the efficiency on a project, thereby enabling not only lower build costs, and therefore presumably greater profit or higher volumes of work through improved tender successes, but also completing more projects in the yearly cycle, which should in theory also translate into greater profits along with happier customers and shareholders. Furthermore, a
reflection of better project management is a thriving organisation, and the key to this is meeting project goals or programmes. Even those who own the organisations believe they need to improve. In a recent FMI / Construction Management Association of America (CMAA) survey (Doran, 2004: 2-3) of owners, in addition to confirming that key phases in the construction process take ‘20-50% longer than planned’, some of the major cost overruns were caused by a ‘Poor pre-planning process’, ‘lack of timing decisions by owners’ and ‘Excessive change orders’, all of which could be managed by using a central information portal and simple means of communication, 3D models.

Illustration 2: Most significant changes contributing to the project delivery process.
(Adapted from Doran, 2004: 19)

The combination of these two trains of thought are that by improving on the construction planning process, the industry would be able to not only become more efficient and increase its margins but also to provide better service to its clients. What is therefore critical is a construction planning process that incorporates the latest in IT advances with a more inclusive management process understood and communicated to the hordes of consultants and contractors that constitute a project team.
2. THE REVIEW OF THE RELATED LITERATURE

2.1 Introduction

There is widespread agreement that the UK construction industry is under achieving and that reforms need to occur across all sectors (Koskela et al., 2003*; Love & Li, 1998: 291; Construction Task Force, 1998: 9). What is not apparent from these studies is that the malaise that affects the industry today is the result of an incessant drive by the larger organisations to reduce the inherent risks faced by them on a daily basis, particularly from a financial standpoint, which has led them to subcontract out the risk to other organisations. In making this purely financial decision, senior management have not borne in mind that as a result there is a fundamental breakdown in the ability of all parties to work towards a common goal, coordinate their competing agendas and find a simple means of communicating that coordinated goal within one another.

Therefore, the literature review has focussed on how we presently communicate our goals on construction projects as well as the current thinking on re-integration of teams within a splintered subcontracting environment. In considering the relevant literature to review, it has to be borne in mind that 4D Planning as a process and Build Planning, in particular, are little studied and have therefore been reviewed as a lesser part of 4D.

The literature review therefore encompasses four areas:

- Integration of Project Teams;
- Planning Methodologies;
- Construction Planning, and
- 4D (Simulation, Visualisation, Modelling and Planning).
2.2 Integration of Project Teams

2.2.1 Introduction

The focus of this study is on a planning methodology that through the use of visual tools creates a process that focuses on coordinating the multitude of players on a project into a single harmonious team. The reason for this is the fragmented nature of the construction industry in the 21st Century. Ideally there should be direct single responsibility and integrated construction groups carrying out the bulk of the UK’s construction workload (Harding, 2005: 39). Both Sir Michael Latham’s report, Constructing the Team (1994: 62), as well as the Construction Task Force’s Rethinking Construction report (1998: 7), recommended integration but only ended up agreeing to partnering. This is totally at odds to the National Audit Office’s (NAO) report (2005: 1) recommendation that full integration of the team is best for the client. Further studies about this requirement revealed that the fragmentation and confrontational relationships are the major inhibitors for performance improvement initiatives (Love & Li, 1998: 291).

The debate over integrated teams has been ongoing for more than a decade. In a 1995 article Gary Bates makes the point that the “weakness in the present project initiation is that ‘seams’ exist in the information base used for decision making.” During the last decade IT has made this process easier through the likes of the PDF format documents, yet knowledge-based tools are only infrequently used. He continues and says it would help to “disseminate experience and expertise developed in earlier projects to new ones”. (Bates, 1995: 3)

Recommendations in the Constructing the Team final report (Latham, 1994: 11), point out that the intention is to benefit clients through improvements in “the industry’s performance and teamwork and thereby achieve better value for money”. It has already noted that clients are not getting what they ask for and that there are already a number of initiatives in place from previous reports, including off-site prefabrication, which could be more widely
implemented. However, the above will only be achievable though “effective teamwork by designers, contractors, subcontractors and manufacturers.”

In 1998’s *Rethinking Construction* (Construction Task Force, 1998: 7) both a positive and negative view of fragmentation were expressed. In particular it is recognised “that the fragmentation of the UK construction industry inhibits performance improvement” whilst “the extensive use of subcontracting has prevented the continuity of teams that is essential to efficient working.” Unfortunately, the status quo is unlikely to change in the short to medium term as studies have repeatedly shown “the industry typically dealing with the project process as a series of sequential and largely separate operations”, which leads them to deal with individual organisations, further perpetuating the subcontractor culture. The focus of attention should therefore be to shift away from this culture as increasing efficiencies and quality are fundamental to achieving better delivery of projects. This is further backed up by ‘other studies’ which “all suggest that there are significant inefficiencies in the construction process and that there is potential for a much more systematised and integrated project process.” (Construction Task Force, 1998) It is essential that the available resources are maximised “in order that the ‘skills of all the participants’ are brought to bare on ‘delivering value to the client.’”

Integration is therefore related to achieving existing goals, increasing productivity, reducing waste, meeting budget and time constraints. How to be more productive or achieve more with the same resources is a major pre-occupation of chief executives, whatever industry they operate in. Construction is no exception (Parry, 2005: 38). But unfortunately “the complexity of project processes, the lack of information management experience at project management level, together with the fragmented and adversarial nature of the industry” (Winch & Kelsey, 2003: 4) inhibit the ability of the industry to become more integrated.
2.2.2 Changing the Culture

The change from a vertically integrated to subcontractor style industry and the resultant transfer of risk across a greater number of organisations has already been mentioned. However, other risks are created, mainly for the client, as no one party is responsible for coordination across all consultants and contractors. Unfortunately, when things do go wrong, it inevitably leads to a blame culture, which will likely get passed onto the smaller links in the chain that have more to lose. They are therefore more likely to increase their cost and request extra time, to reduce the risk to them from a financial and time penalty perspective. In order to eliminate this type of culture, which harms the client most with inflated prices and extended construction periods, construction has to be viewed “as an integrated flow, rather than a collection of independent tasks.” (Poppendieck, 2003: 5).

Illustration 3: Integrated build plan process.
(Bovis Lend Lease, 2001*)

The industry has been short on strategic collaborative thinking for a long time due to its fragmented and adversarial nature. In order for organisations to compete in an open market environment, where design companies are seeking to wrestle back management control or construction organisations are looking to take on board design responsibility, smart organisations will look to
innovation to increase the connection between the fragmented entities and “make sense of the pieces of the puzzle.” (Greenway Consulting, 2004: 3) One of the catalysts for change may be the clients’ desire to get their projects completed even quicker than is presently happening. “Speed to market is forcing new fields of collaboration, including advanced design-build models … and teaming models.” (Greenway Consulting, 2004: 2) This change to the way information is produced and evaluated also means a shift towards partnering, as well as design and build projects, to improve communication and reduce rework.

In a study carried out by Sarshar, Haigh, Finnemore, Aouad, Barrett, Baldry and Sexton (2000: 241), they report that the construction industry has had few recognised methodologies or frameworks on which to base a process improvement initiative. However, process management, from a technological standpoint, has been identified as a key enabler in achieving this. Quoting from a recent study, which addressed the information management systems within the Architectural, Engineering and Construction (AEC) industries, Keller, Scherer, Menzel, Theling, Vanderhaeghen and Loos (2006: 449) focus on the complexity of construction projects and point out that “General conditions have become even more complicated by shortened construction times and limited budgets.” However, through use of IT and other communications technology which support “cross-disciplinary, collaborative work” it will provide “an opportunity of strategic importance” and a platform which focuses on “collaboration instead of confrontation.”

### 2.2.3 Benefits of Teamwork

When teams do work together on a series of projects they learn skills to enhance the product and foster relationships with the supply chain, further enhancing the delivery process. This is the key premise of integrated project teams. If they are to do this, they need tools which will assist them to communicate on the same level, which is best achieved through visual means and on a single software platform. “One of the primary goals of computer
integrated construction (CIC) is to simplify the methods for handling information generated throughout the lifecycle of a project.” (Rankin and Froese, 2002: 1) Much development has occurred in this field over the past couple of years and new systems are emerging, particularly on the design side, to enable this to occur.

One of the areas in which collaborative thinking will be extremely beneficial to the industry is in the interoperability of project information. This is borne out in a recent study, the National Institute of Standards and Technology (NIST) report in the US, which put the cost of non-interoperability at an estimated $15.8 billion (R110 billion) annually, and the construction phase contributed up to 25% of this amount. By using applications that are more integrated, either a single platform or single working process e.g. Building Information Modelling (BIM), substantial savings can be achieved which are sorely needed in an industry that makes on average around 2% profit. “Our use of technology is now viewed as strategic to growth” says Patrick Thompson, Chief Information Officer (CIO) of Shaw Group. He succeeded in reducing costs by $60 million (R420 million) (Silver, 2005*).

Although this may mean a fundamental shift in the way that teams currently operate and could sideline architects from the process completely, the use of
an integrated model makes a lot of economic sense for a client and is beneficial for the contractors as well. The present arrangement places undue risk on them due to the poor levels of information available when pricing and unrealistic working arrangements forced upon them by consultants, including Project Managers, driving the process. However, the biggest factor is the reduction in both design and construct costs, and an improvement in delivery time through prefabrication and better planning due to improved communication. “The gains realised are the classics sought by the industry: faster, better, cheaper – and safer – construction,” (Sawyer, 2005b: 28)

Another facet to knowledge is the transference of information from the design phase into the construction phase and finally into the facilities management phase. At present, these phases of a building lifecycle are very poorly interconnected, which means that not only does waste occur in the construction process, but it also occurs from the beginning of the design phase, which means there is a continuous waste of money. “The ability to support and manage data across the entire building lifecycle … increases the value of the design above that of visualizing a building’s appearance” (Laiserin, 2002: 2).

![Figure 4: 3D mechanical room model in Artra FM software.](source-courtesy-of-ArtrA-Ltd)

By using the database structure embedded in these models, downstream benefits can be achieved for estimating, procurement, logistics, Health & Safety (H&S) and Facilities Management (FM). It also allows some of the
new planning methodologies and technologies to be incorporated into the process, further improving on the value of money deliverables. Although there are still some restrictions in terms of information transfer between parties, it still provides a platform on which other fundamental changes to working practice can be based. “The team understands the building as a whole and that is better for the project.” (Baxter, 2006: 1).

In order to reduce risk, the two main contributors need to be addressed, “incorrect information caused by ineffective synchronization of all data…and inaccurate assumptions generated by the variability of conditions during actual construction.” (Gallello, 2006: 10). The more integrated the design and construction process is, the more likely these two elements will have been reduced to lesser inhibitors of a more efficient process, due in part to the working relationships formed, communication improvements employed and a single source of information to build from being created.

2.3 Planning Methodologies

2.3.1 Introduction

Sriprasert and Dawood (2003: 342-343) have identified seven major technique groups in construction planning, which they have classified through reviewing and analysing literature. These groups are:

- Critical Path Method (CPM);
- Line of Balance Method (LOB);
- Simulation Method;
- Knowledge based expert system and artificial intelligent method (KBES and AI);
- Visualisation Method (4D and VR);
- Critical Chain Scheduling (TOC theory), and
- Last Planner Method (LPM).

This in-depth study also focuses on how these techniques have been used referencing numerous previous studies including Ballard’s research (2000*)
into the Last Planner Method focusing on production control involving the use of short-term planning at crew level. Attention is also given to Line of Balance with its basis in finding the required resources for each stage or operation so as to prevent the following stages from being interfered with, thus allowing the target output to be achieved. (Harris & McCaffer, 2000: 88) This is countenanced by Steyns’ investigation (2001: 364) into Critical Chain Scheduling with particular reference to Parkinson’s Law and the negative effect of human behaviour in calculating duration, which has obvious implications within a construction planning environment and its extended use of float.

To add to these, there are the new style amendments to existing techniques including resource-activity CPM developed by Lu and Li (2003: 413) and Computer-Assisted Construction Planning (CACP) as proposed by Rankin and Froese (2002: 258-260). This study goes on to comment that at present there is “no universal planning system that can remedy the typical problem of separation of execution from planning” in the construction industry. However, they do propose their Multi-Constraint information management and visualisation system as a possible solution to this situation.

What underlies all these concepts are principles from outside construction including the Project Management Body of Knowledge (PMBOK), which has borrowed it’s principles from traditional management techniques, but breaks down a project into smaller deliverables that can then be completed individually (Project Management Institute, 2000: 11). Theory of Constraints is a management philosophy that focuses on constraint as being anything that limits it from achieving higher performance when reviewed against the original goal of the project (Goldratt, 1990: 4) whilst Lean Construction, a concept derived from Toyota’s Lean Production system, has as it’s primary goal the understanding of the physics of production at the task level. Having achieved this, it looks to the design of support systems to minimise the combined effects of dependence and variation between activities, especially
on complex, uncertain and quick projects. (Howell, 1999: 2-5). Lean Thinking describes the core principles underlying this system and it is these principles that have now become part of Planning Methodology. This then ties into many aspects of the procurement process as the required product or design is only pulled from upstream steps when required ‘which leads to just in time delivery.’ As the removal of ‘wasted time and effort represents the biggest opportunity of performance improvement’, planning in this way can be an extremely useful process in the day-to-day running of construction projects.

Illustration 4: Potential savings of Lean Production in Construction
(Bovis Lend Lease, 2001*)

2.3.2 Alternative Thinking
There are deficiencies in many of the processes due to the differences experienced between industries. In addition, the constantly evolving nature of products means that new challenges are being set to deal with the added complexities posed as a result of this. An example of this is the Work Breakdown Structure (WBS) method which forms the basis for many modern planning techniques. Its focus on ‘sub-optimized thinking’ means that too many tasks need to be managed at any one time, which leads to fewer tasks getting attention and inevitably areas needing attention being under planned. By focusing more on the interface between elements, the tasks themselves
can then be managed on a more hands-on basis, according to the outline programme created at a higher level.

New research is being conducted on a regular basis to try deal with the identified shortcomings in the existing methodologies. More practical methods based on CPM have recently been proposed including the resource-activity critical-path method (RACPM). This, along with previously noted new methodologies endeavour to include for resources as part of any algorithmic calculations instead of the current situation of only focusing on activity length and path relationship. “The existing methods for resource-loading CPM have failed to address and clarify the ‘resource critical’ issue brought up about 40 years ago.” (Lu & Li, 2003: 413). In order to try to minimise this, alternative methodologies such as Critical Chain Method (CCM), focus on maintaining the mean, rather than specifically defining an exact duration, thereby removing the failure factor from any calculation. In addition, it also allows those who have control to manage delivery in such a way that they may actually benefit from completing sooner rather than just in time. The latest of these ideas is known as DRAG, ‘Devaux’s Removed Activity Gauge’, which focuses on how much we can shorten the critical path activity before some other path becomes the critical path. This has some major implications for delay on projects and also for shortening schedules through focus on the critical path.

What is apparent from these various studies is that the techniques that are presently being used to manage the design, planning and construction processes of a building facility, ‘abstract the process to produce a Gantt chart or CPM schedule’ (Haupt, Webb & Smallwood, 2004: 2 citing McKinney, Kim, Fischer & Howard, 1996). When reviewing the planning methodologies presently used, it is pertinent to note that the dominant way is ‘activity-based scheduling’ based on techniques such as, Generalised Activity Networks and Critical Chain Method (CPMPERT) (Graphisoft, 2004: 1). This is fine when dealing with a manufacturing or static environment as the men and materials
component can remain in a single location for each activity planned. However, relative to a construction environment, not only is each project in a different location geographically, but so is each activity, even if it is the same GPS location i.e. second versus fourth floor. A more comprehensive tool is preferable. This tool needs to simulate and visualise construction activity sequences as part of an interactive experience (Haupt et al., 2004: 2).

A more relevant process would be 'location based scheduling’ as this “deal very effectively with the need to schedule the precise location of the work crew … and takes into account site constraints.” (Graphisoft, 2004: 1) However, to be able to do this requires the ability to see where the activity is taking place, in the same three dimensional environment in which it occurs.

2.4 Construction Planning

2.4.1 Limitations of current methodology

Developing the construction plan is a critical task in the management of a construction project (Hendrikson, 2000*). As previously mentioned in the review of Planning Methodologies, the construction planner has a host of techniques that can be employed in the quest to plan and manage the delivery of the construction process. In fact “the capability to execute a project may well be a function of the planning system employed.” (Central Unit on Procurement, 1995: 6). However, as the statistics quoted earlier in this review of the literature suggest, the methods presently employed do not satisfactorily achieve the desired results.

Why is it that after nearly fifty years of planning as a specific genre, invariably planned outcomes are not realised? There has over a number of years been concern regarding the level of planning occurring on construction projects with the studies conducted by Laufer since the 1980’s making particular reference to this. His 1987 paper makes reference to the following areas as needing to be resolved before planning can be more effective:
- Scheduling is overemphasized, resources and methods planning are neglected;
- Planners lack formal training or experience in construction methods;
- There is an over-emphasis on CPM and PERT methods;
- There is a deficiency in information gathering methods, and
- Planning the planning phase and evaluation of it are non-existent.

All of these are still relevant today, twenty years on, and as other literature has made note of, we are still not learning from past experience. In Construction Methods and Planning (Illingworth, 2000: 5-6), attention is drawn to the need for ‘competent and experienced personnel’ being required for effective construction plan generation, especially in relation to the two main processes: ‘understanding what has to be built’ and then planning the best way to go about doing that whilst maximising the return on investment in men, materials and time.

Evidence cited in Heesom and Mahdjoubi (2004: 171) suggests that there is a shortage of skills in the area of construction planning, with the number of planners having the ability or knowledge to effectively plan construction projects decreasing. Much of this has been confirmed in follow up studies including those conducted by Winch and Kelsey (2003: 7-8), and what many of them reiterate is that much of the problem lies with the construction industry structure, i.e. planners lack practical site experience because they are only involved in the early stages, and the information they are being asked to work with, be it as master planners, or as a contractor planner, is woeful and inadequate. Those tasked with the responsibility are in the main new to the role, and therefore lack the necessary experience at that level to be proficient at it. This is a result of the extremely steep promotion curves brought about by high volumes of work and a shrinking workforce.
Illustration 5: Learning through repetition.

(Bordoli, 2005*)

In their investigations Winch and Kelsey note the planners received “large amounts of information that was not relevant to their role and…the quality of much of the information was poor.” To further exacerbate the situation, as the feedback process from projects is not happening regularly, the problems occurring on one project are being replicated over and over again. This is partly due to the workload issues of all the main parties involved, but also because no formal review process exists in most companies to interrogate the planning and implementation of projects. To add to this, it is commonly the case when a new project commences that through “past experience, typical activities specific to the project are identified and added, until a list is compiled covering all the requirements.” (CUP, 1995: 3)

2.4.2 Effective Planning

“Effective planning is one of the most important aspects of a construction project and influences the success of a project.” (Chevallier & Russell, 1998). What is apparent in the literature is that effective planning cannot occur without experienced schedulers and that “even experienced professionals often find developing realistic and practical schedules … a challenge.” (Fischer & Aalami, 1996: 337). The question has also been asked about how much planning is effective and is it wise to employ a large amount of
resource to the process when the results appear to be so poor! What is apparent is that “Efficient allocation of resources…should be undertaken on a value adding and cost effective basis.” (Faniran, Love & Li, 1999: 311) However, in order that a schedule is useful to those making decisions, it has to be presented at an ‘appropriate level of abstraction or detail’.

(Bovis Lend Lease, 2001*)

Scheduling is however, only a small part of the construction planning process. Alshawi and Hassan (1999: 198) point out that for construction planning to function as a control and decision-making tool it has to be ‘integrated’ with other disciplines such as design, estimating, site layout planning and material purchasing. There are limitations in the scope of what planning can achieve due to the increased complexity of projects and “as the scope of the project schedule grows and the complexity of the design increases, process schedule review often becomes a formidable task.” (Songer, Diekmann & Karet, 2001: 1) When we add the dimension of design to the equation, planners are left in a situation of having to make assumptions based on experience, which little of them have sufficient of, or go on what
would be termed a ‘gut feel’. If they had an ability to take the design information as it changes and feed it into the planning process in a way that would highlight the impact of those changes, the process would start to become a whole lot easier. Add the ability to use that self same information as a communications tool and planners may start to change the way they process a project.

Planners and site managers are required to simulate various construction processes in order to build the project. This simulation can either be done intuitively by the planner using 2D mark-up drawings or by using computer based simulation techniques, such as ‘discrete event simulations methodologies’. However, when projects enter the construction phase, management find themselves having to make decisions that may have other more profound monetary or labour consequences, in a time and pressure sensitive environment. “Making fast decisions is easy, any fool can do that. Making good decisions fast is what's hard.” (Sawyer, 2005a*) And that is the crux of the issue with planning programmes in that they don’t allow management a simple way to quickly analyse and then communicate to project staff a revision in the sequence of works. A good proportion of these decisions are therefore made on the basis of experience and intuition, without the support tools such as those available for the sequencing of tasks. The move to a fast track construction mind-set exacerbates the current limitations of the planning process and when added to management’s desire to meet client expectations it is invariably found that “the planning function is critical to achieving successful delivery of a construction project” (Faniran & Proverbs, 2002: 159).

2.4.3 Alternative Practices

The Lean Enterprise Web Information System (LEWIS) has been developed in line with the principles of lean construction, to reduce the “delays and rework caused by informal and unclear instructions.” (Christiansson, Dawood & Svidt, 2002: 3). This coincides with the philosophies of 4D promoters, and
it is therefore seen as bridging the gap between simple web based document management systems and fourth dimension models as a decision support system. However, the process is more about ‘endorsing production-oriented culture’ and workforce information at the point of execution, whilst also forming a single repository and ‘tools to capture and process construction site information.’ (Sriprasert & Dawood, 2003: 350).

Implementing ‘lean’ techniques into the construction industry is a challenge, but it is finding favour with more and more construction organisations as they strive to reduce the identified bottlenecks on site. However, to realise this requires a clear vision amongst the whole team of what needs to occur where and when, especially as it works on the principle of ‘pull’, such that materials are only available when they are required. How to achieve this is best summed up by the following government funded project report “The key was to change the way in which construction works were planned. A 4D model of the project … was developed as a working tool … to identify contingency options when project delays were experienced and to control delivery and storage of materials” (Wilson, 2002: 1).

One of the reasons provided for implementing ‘lean’ techniques is that studies have shown that trying to plan large levels of detail early in the process only leads to a greater probability that the project targets will not be met. In Faniran and Proverbs’ 2003 study, which followed up two previous studies of a similar nature, they confirm that these occur “due to the increasing number of planning loops that occur as planners plan and re-plan minute project details.” In addition, this large amount of detailed planning cannot be easily communicated to those on site who have to try and implement it. Reams of paper would be required and the walls of a project site office are needed to be able to show this level of detail using traditional Gantt chart techniques. To add to this, trying to monitor this level of detail and the relationships that are present between tasks becomes a full time occupation. At present, this is one of the fundamental areas where projects
fail, as the inability to monitor a large number of tasks leads to the late identification of problems.

2.4.4 Monitoring Progress

An equally important facet, therefore, is that the programme as agreed by the various parties is in fact followed and that as a result, when tracking the progress by regularly monitoring activity on site, the financial aspects of the project are also managed. “The final vital piece of the jigsaw is regular reporting of progress” (CUP, 1995: 6). Current practises in this regard are at best average and at worst non-existent. In Her Majesty’s Treasury guidelines on work projects, they make particular reference to the premise that the ‘entire planning process should be considered in the context of risk management’, which includes the aspect of time delay, as this may have a negative impact on delivery and therefore budget. There are a number of techniques already in place to achieve this and the planning software packages all come with the ability to run Critical Path analysis and the more sophisticated Planned Progress Monitoring graphs. However, without actual progress data, no amount of computing power will be able to forecast completion, cash-flow, labour or resource situations.

2.4.5 Transferring Knowledge

However, the critical aspect of the construction planning process is that of communication, both during the programme creation and its subsequent implementation. Those at the ‘coal face’, the foremen, superintendents, and construction managers, those who have to implement these highly complex programmes have lost faith in the process that creates them. “They are plagued constantly by the two biggest forms of construction waste - people waiting for materials and work waiting for people.” (Poppendieck, 2003: 1). By putting in place a framework programme that is explained and communicated to all, it allows for the detailed planning to be done with those whom it most impacts.
It is also vital that as part of the construction planning process, that those activities that could impact on the programme be addressed. To this effect, “the use of computer modelling to test the performance of the end-product……..and especially minimise the problems of construction on site” tie in with the need to “pre-plan the manufacture, construction and commissioning.” (Construction Task Force, 1998: 23). In *Rethinking Construction* the overriding message is that “IT is an essential part of improving the efficiency of construction.” A number of alternatives have been researched including a new generic construction process modelling method (GEPM), which uses object-oriented principles, and has borrowed features, such as activity task and temporal dependency, from methods like the Integrated Definition for Function Modelling (IDEFO) and scheduling.

Computer Assisted Construction Planning (CACP) is an application “that provides a comprehensive description of project planning information for initially populating and effectively managing a project database.” (Rankin & Froese, 2002: 11). As part of a more integrated framework using other new technologies, CACP is a way of dealing with the shortage in skilled professionals to carry out the planning process. This has resulted in the use of 3D CAD models and animations, with studies showing that there are benefits to this proposed methodology “the quality of the schedule, is dramatically improved when the scheduler has access to a 3D design representation.” (Songer, Dickmann, Rasheed & Hays, 2001: 206). In addition, it provides a way to transfer knowledge from those who have it to those who do not, whilst “supporting more detailed construction planning.” Emerging research efforts are currently focussed on providing project planners and managers with computer-based advisory tools to visualise the construction plan in a 4-dimensional, that is 3D computer model and the time component, environment (Heesom & Mahdjoubi, 2004: 172).

It is also imperative that what is communicated incorporates all relevant activities whilst remaining unambiguous and understandable. By engaging
with the team, the collective knowledge of the individuals involved can be then incorporated for presentation to others up or downstream from that environment, allowing projects to remain on course even when problems are encountered. It will also highlight constraints that may not be initially apparent when creating the initial programme especially in respect of logistical activities and site environment restrictions.

**Figure 5: Communicating in 3D and 4D.**
Source courtesy of A3D.

Being able to involve those from outside the project team environment becomes a fundamental aspect to this and using visual means to communicate information to non-construction minded individuals has proven extremely useful on a wide variety of projects. As Jack Demsey of the US Coast Guard made reference to when discussing proposals on a project: “The ability to communicate the concept in quick, intuitive means really turned the tide.” (Sawyer, 2005a*) It also allows alternatives to be put forward more quickly and ‘what if’ scenarios to be conducted in more depth prior to work commencing on site. How this information is extracted and presented depends on the end user, but in the main most commentators agree that combining the programme with a 3D model would appear to provide the most accomplished solution: “Virtual planning helps everyone understand at the speed of thought” (Sawyer, 2005a*).
With the ageing workforce and shortages in key personnel, the industry is looking to technology to help. Add to this the skills crisis already evident in many building trades, means “management processes will be critical in any drive for productivity improvement.” (Parry, 2005: 38). In all the methodologies referenced, the fundamentals of the process do not differ; planners still need to involve all team members in the process. Ownership of the programme is essential if the project is to be successful and therefore it is imperative that the planner meets with and gains feedback from those actually doing the work. Therefore, it is also a highly useful to have as a way of communicating with people who do not understand a Gantt chart or WBS environment, but do understand images. A hallmark of good planning centres on communication of the plan to those who have to implement it (Soloman, 2005: 1). Now more and more firms are turning to visualisation tools to make that possible (Sawyer, 2005a*).

2.5 4D (Planning; Simulation; Visualisation or Modelling)

2.5.1 Why 4D?

As has already been noted in the previous section, there are already a number of techniques in use, so why further complicate the process. As referenced in the introduction to the literature review, the ability of pictures or images to communicate far in excess of what a list of words can achieve has long been recognised. In fact, there are many benefits to having an animated construction schedule, not least that it “can be played repeatedly, slowed down or stopped at any time to assess the accuracy of the schedule.” (Songer et al., 2001: 1). Even as a training tool for inexperienced planners, the ability to visualize the construction process is seen as a way of addressing the severe shortage of trained Planning Engineers.

Since the mid-nineties much work has been undertaken to demonstrate that creating a 3D model over time assists in the planning process. In addition, further experiments have shown evidence of the practical advantages, as the programmes created through the 4D process are “more complete and
accurate, safer and less crowded and had better work flow.” (Songer et al., 2001: 9). Using the Design and Integration (DALI) tool on the MidCity Place project in London was seen as a way to assist in reducing waste costs associated with the project (Pearson, 2001: 51). It has the potential for presenting ideas to clients in order to promote collaborative working (Fischer, 2001: 1) and to assist in the problems associated with site logistics and site layout (Zhang, Anson & Wang, 2000). Heesom and Mahdjoubi (2004: 172) quoting their 2002 study also point to its use in improving site logistics, such as defining the ‘work execution space’, whilst the ability to analyse the construction schedule to assess the ability of construction personnel to execute their designated tasks has also been much researched (Sawyer, 2005a*; Sawyer, 2006*).

Quoting from the 1994 report by Michael Latham, he says that an exciting new development is ‘Knowledge Based Engineering’, which was developed for use in the manufacturing of aeroplanes and cars. He goes on to enthuse about how it can assist clients to “clearly understand the likely outcome of projects at design state” and that additional fees for this service would be “repaid many times over if it ensures a well planned project.” Those comments were made over a decade ago, so why is it being discussed as a possible rather than implemented technology? ‘4D is not a new phenomenon’ which begs the question why it hasn’t already found favour. It was first conceived as an idea “back in 1986-87 when Bechtel collaborated with Hitachi Ltd. to develop the Construction CAE / 4D Planner software.” (Rischmoller & Alarcón, 2002: 1).

The industry is not falling over backwards for the new products as they are not necessarily what the industry presently needs. “In the real world, 4D isn’t a priority even for customers who have bought a solution” says Rich Rowland of Lockwood Greene Engineering. As a result, the use of 4D visualisation software is presently limited to large scale projects or projects with high risk factors, where the additional costs can be offset against the
greater potential risk of failure (Goldstein, 2001*). At the EMCOR group, CIO Joe Puglisi said he balances new technology needs and costs “by requiring users to provide data that the new acquisition will reduce costs and create new business” (Silver, 2005*). A lot of resistance to the 4D process is because of the need to add an additional process, the 3D modelling. However, as the design packages become more parametric based e.g. Revit & ArchiCAD, so designers have the tools to produce models that “go beyond serving the design information needs of architects and their clients” (Laiserin, 2002: 1) and start to form part of the construction process the “C” in AEC.

Figure 6: 4D planning process.
Source courtesy of A3D.

However, for those clients who are looking for something a little outside the comfort zone, 4D has already proved to be of benefit “We are looking for ways to build better cheaper and faster” says Andy Butler of Stanhope. They have tried to drive down construction time on previous projects with limited success. “The answer was to pilot a new computer simulation tool called DALI that would allow the building construction process to be modelled in 3D” (Pearson, 2001: 48). At Heathrow Terminal 5 the information in the 3D models created by the design team has been used for construction and ultimately will be used for operation and maintenance (Lane, 2005: 59). The large multi-dimensional firms can use internal budgets and economies of scale to create their own in-house systems. Large AEC firms such as Parsons Brinkerhoff have been using in-house resources to plan and manage mega
projects in real-time using custom built, time dependant solutions. The 4D model is used at the monthly meeting Knutson has with subcontractors “looking at it, it gets people to understand how the structure goes together.” (Goldstein, 2001*)

2.5.2 Usability

Among many of the research papers on 4D there is a propensity to focus more on the technology in use rather than the needs of end users for the product. This research has noted from experience of the systems that the 4D software is another tool in the planners armoury and is in itself not a solution to the planning malaise that currently affect projects, and what it is general touted as achieving. As more software options become available and the major 3D CAD software suppliers make this a priority in their business model e.g. Graphisoft’s Virtual Construction Solution, so the cost and therefore value add of using this technology will become more commonplace. “Autodesk has hired a 4D construction simulation expert” (Newton, 2005*). Furthermore, the continuing alignment of the various software systems including the ability to export from most CAD packages to the DWF file format and likewise XML in planning software makes integration of various different models and programmes more feasible than has been the case previously, and which has formed a barrier to entry into the 4D world.

Interest in construction simulation / visualisation has been growing rapidly due to a number of commercially available 4D platforms already in use including Bentley Systems Schedule Simulator, Navisworks’ Timeliner and Graphisoft’s Constructor, which all work from the perspective of a complete design model which is then taken into a separate software system and where it is linked with a project programme to reflect this visually. A3D’s PAL system is different in that the model environment is used to generate the programme, with any changes in the programme then automatically reflected when linked back to the model in the 4D viewer environment. This means that models can be generated in any software platform and planners can
continue to use the systems they presently rely on to create the initial programmes. As the system has been rigorously tested on over 40 projects, it also has encompassed many of planners’ requirements as opposed to being design based or requiring specialist software skills to run. The system has been kept simple to allow many of the existing tools in both CAD and the Project Planning software packages, including the methodologies referenced earlier, to be used to their maximum potential, whilst the 4D planning & coordination is the domain of the PAL interface user.

2.5.3 Communications Tool

Amongst planners there has been some scepticism of the new technology with web forums conducting in depth discussions on the merits of 4D. The biggest constraints appear to be money and a lack of understanding of how the technology physically works. This is partly due to some systems having a separate programming interface rather than using the power of the existing planning software. Should these hurdles be overcome the general consensus is that it is a great communication tool which graphical improves on methods currently used. It also provides an added dimension to what has previously been available as the 3D models are more representative of the site environment than the current use of 2D diagrams to plan logistical layouts, which in the 3D world we live in is a logical assumption to make. However, it will never be a substitute for good planners, although it may help to create good planners especially if those with experience can transfer that through the use of these models.

It has already been mentioned that there is a critical shortage of experienced construction professionals, which is felt particularly in the planning disciplines, where experience has previously been the only measure used to facilitate planning. However, the use of 4D has been shown to be extremely useful in educating inexperienced planners, allowing them to meet the required levels of delivery. “a comparison between the quality of experienced vs. inexperienced schedulers indicates … that by simplifying the
comprehension of the design with 3D CAD and walk-through, even the inexperienced scheduler was able to create a quality schedule.” (Songer et al., 2001b: 206). Also by linking 3D drawings to a project schedule, all project stakeholders from the owner to tiling subcontractor, can see how the project is supposed to progress (Goldstein, 2001*). In its guidance to clients, the HM Treasury makes reference to the ability of those who are in essence funding a project to be able to “interpret programmes prepared by project advisors without being experts in the field.” However, they follow on to say that the methods currently in use, namely a bar chart and network planning do not meet all the requirements due in part to ‘difficulty in showing the complex interdependence of activities’ and distortion by giving ‘undue weight to some activities.’

The main value from 4D is therefore derived from using it proactively to visualise the construction sequence. By visually reviewing the project programme from the outset, the process implications of the construction can be highlighted so even when the model is not in use, those implications are known. This then will allow greater interaction at an earlier stage with those who presently don’t become involved until much later in the process, which only leads to design re-work once their collective input has been garnered following tender submission. This is more in line with the proposals fostered in the collaboration reports over the past decade which have focused on partnering arrangements as opposed the open tender process which is presently the norm.

One of the tools being proposed to allow this to happen is immersive virtual reality technology or CAVE™ as it has been dubbed. This technology is used to “view three-dimensional stereo images and simulations in actual one-to-one scale.” (Whisker, Baratta, Yerrapathruni, Messner, Shaw, Warren & Rotthoff, 2003: 2). The premise behind the use of this technology is that 4D models can be input into a format more relevant to the site environment and therefore issues identified on a higher level model, possibly on a desktop
computer, can be worked through with those responsible for constructing the area in question, prior to going on site to do it, in essence a rehearsal of the real installation. This has found favour in particularly the Nuclear Industry, where the costs of mistakes are greatly exaggerated and therefore the value of using such technology can be validated.

Another advantage for planners is that aspects of the project relating to activities such as tower cranes and temporary works in excavation areas, which may be shown on programme and located on a 2D graphic, but are not included in the design information, can be better understood by being modelled in 3D and added to the 4D. An example of this may be the date a tower crane support bracket is added or removed. This can have severe implications for cladding or services installation on that floor and may require specialist engineering design details. In addition, if the crane is relocated due to site logistical constraints, the impact on related design or construction activities will be more visible than using existing planning processes. Communicating similar information to clients, other team members or even the general public, then forms part and parcel of a process already completed, rather than requiring additional time and cost to be expended in doing this through other visual and non-visual means.

The most important aspect of using 4D is that it adds value to the process, saves time, and money. Presently a study is being undertaken by Sushant...
Sikka and Prof. Nash Dawood at the Centre for Construction Innovation and Research at the University of Teesside, to try to identify ways of quantifying the value through KPI’s related specifically to the use of 4D models in the planning process. Previous studies have made mention of the unquantifiable benefit generated from 4D in its many guises. “Where 4D technology has been embraced, direct savings and an increase in productivity has been seen” (Heesom & Mahdjoubi, 2004: 179). 4D technology enables planners to predict potential problems at the construction stage, which could have considerable cost and time implications. The Centre for Integrated Facility Engineering (CIFE) confirmed with hard data that 4D modelling at the appropriate stages in the construction process results in significant building efficiencies and cost savings (Silver, 2005*).
3. THE SAMPLE STRATA

3.1 Introduction

The study was conducted in two parts, an observation / participation case study and a survey. The survey was conducted amongst two sample strata, preceded by a pilot interview process to formulate the questionnaires.

3.2 The Case Study

The observation / participation case study was conducted on the 51 Lime Street project in London, England. The project comprised a 29 storey and adjacent 10 storey office building, including 2 basement levels, on a large central city site surrounded by narrow lanes and adjacent to the award winning Lloyds of London Insurance Headquarters designed by Sir Richard Rogers.

As the client and construction manager had already agreed to include 4D planning and coordination alongside the more traditional planning processes, and as the designated individual assigned to oversee the implementation of the technology, the researcher had unfettered access to study the use of and participate in meetings aimed at maximising the potential benefits that could be accrued to the project.

3.3 Pilot Interview

A population of four London based construction professionals was selected to interview in order to formulate questions to be used in the follow up surveys. The population was selected on the basis of their different spheres of responsibility, namely planning, project management and project development, their good knowledge of IT and high level usage thereof. All had varying levels of 4D experience but their most compelling attribute was a commitment to the use of technology to improve on the industries ability to deliver projects.
3.4 Case Study Interview Survey

This was limited to the population of construction personnel involved in the 51 Lime Street project. Those surveyed were derived from all occupations and represented the majority of organisations employed on the project. A breakdown of the number of personnel surveyed is contained in Table 1.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Number surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Manager; Architect; Structural Engineer; curtain walling; BMU; lightweight roof cladding; toilet fit-out; brick and blockwork; general metalwork</td>
<td>1</td>
</tr>
<tr>
<td>Sub and super-structure concrete; ductwork; shop fronts / doors; BMS; drylining; sprinklers; mechanical services; lifts; insulation / fire-stopping</td>
<td>2</td>
</tr>
<tr>
<td>Management consultant; electrical services</td>
<td>3</td>
</tr>
<tr>
<td>Structural steelwork</td>
<td>5</td>
</tr>
<tr>
<td>Construction Manager</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 1: Organisational Breakdown of Personnel Surveyed

The population varied considerably in its demographic nature due in part to:

- Type of work performed;
- Level of responsibility;
- Previous exposure to technology;
- Construction experience, and
- Education.

The limited nature of the project population and its ‘education’ in or exposure to other new technologies may give an element of bias.
The case study survey was intended to provide direct feedback from a live project environment to enable other data received on the project to be placed in context. It also provided a cross reference to the data received in the more expansive e-mail distributed questionnaire.

3.5 E-mail Survey

The population was comprised of 91 construction industry individuals who were familiar with 3D and 4D technology, although they had not necessarily used or been exposed directly to the technology. They were drawn from a wide range of disciplines (Table 2).

<table>
<thead>
<tr>
<th>Discipline</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Director</td>
<td>26</td>
</tr>
<tr>
<td>Project Manager</td>
<td>22</td>
</tr>
<tr>
<td>Planner</td>
<td>9</td>
</tr>
<tr>
<td>Cost Consultant</td>
<td>6</td>
</tr>
<tr>
<td>Architect</td>
<td>5</td>
</tr>
<tr>
<td>Project Engineer</td>
<td>5</td>
</tr>
<tr>
<td>Financier</td>
<td>3</td>
</tr>
<tr>
<td>Logistics Manager</td>
<td>3</td>
</tr>
<tr>
<td>Software Creator</td>
<td>3</td>
</tr>
<tr>
<td>Academic</td>
<td>2</td>
</tr>
<tr>
<td>Project Supervisor</td>
<td>2</td>
</tr>
<tr>
<td>Structural Engineer</td>
<td>2</td>
</tr>
<tr>
<td>Management Consultant</td>
<td>1</td>
</tr>
<tr>
<td>Project Coordinator</td>
<td>1</td>
</tr>
<tr>
<td>Reporter</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: Breakdown of Survey Population Discipline’s

The geographic location of the individuals surveyed included the entire United Kingdom and Canada, with all participants falling within the parameters outlined in the delimitations of the study.
4. METHODOLOGY

4.1 Design of the study

The methodology adopted in this study was the mixed-method approach (Sydenstricker-Neto, 1997*) which entails a combination of both quantitative and qualitative research. Although this dichotomy of methodologies is sometimes seen as not being best suited to producing pure research, to this researcher it was the most appropriate way to establish a benchmark against which further studies can be conducted.

The qualitative aspect relied on the observation participation method (OPM). This strategy addressed an opportunity to understand the realities of implementing new technology into a live project and provided a platform against which the latter quantitative research could be assessed. The author of this survey started to work on the case study as a 4D planning consultant during the initial demolition of the existing site structures. The project planner had requested the use of the technology as he had previous experience of using it on other projects. The client had also previously used the technology and agreed that it would be of benefit in the context of the construction management contract on the project.

The 51 Lime Street project therefore afforded the ideal environment in which to test the perceived capabilities of 4D planning and the processes involved in its implementation. The researcher had opportunity to review what others had not previously seen, access to and involvement in the planning process which would involve use of 3D and 4D technology. Regular feedback from project participants provided insight into the perceived positive and negative aspects of the process, whilst internal review by the construction planner and management provided user input into study reports. The observations would provide corroborative research material to test the first and second hypotheses.
A descriptive quantitative research approach was adopted to provide an alternative viewpoint in the study. Two techniques, correlational research and survey research (Leedy & Ormrod, 2005: 180-185), were used to provide the most comprehensive coverage against which to review the hypotheses.

The correlational research was formulated to provide data that could be used to test the third hypotheses. The project information was selected based on the use of 4D during all or part of each project chosen. This was compared against traditionally planned construction projects to give a statistical measure for the two hypotheses being tested.

The survey research technique included the use of questionnaires and conducting of interviews. The body of data collected in this way constituted the major primary data, which was required to test the hypotheses.

The survey was conducted in two phases. The first was a pilot interview conducted to develop guidelines for optimum ‘Phase 2’ questionnaires.

The questions for Stage 1 of the Phase 2 questionnaire were selected to reflect the proposed interview nature and relationship to the 51 Lime Street case study.

The questions for Stage 2 of the Phase 2 questionnaire were formulated based on the management demographic of the survey population and their exposure to 3D and 4D technologies rather than knowledge of the technology.

The data collected in both surveys was used to test all three hypotheses.

### 4.2 The data collection procedures

The primary data used in this study was acquired from interview questionnaires and analysis of the information generated on the case study of 51 Lime Street.
For the pilot interview, four construction professionals were interviewed using a series of questions derived from the initial survey of the literature and observations on the case study.

The Phase 2 - Stage 1 survey interviewees were all contacted via a covering letter as presented in the form of Appendix A, e-mailed to management and contractors involved in the 4D planning process on the 51 Lime Street project. It requested their attendance at two interview sessions to be conducted in the project office on the 5th and 10th October 2006. Most respondents requested access to the questionnaires prior to the proposed interview in order to limit time spent with the interviewee. The initial interview session was therefore cancelled and a second e-mail sent with the questionnaire attached for review, as presented in the form of Appendix B. The respondents were also provided with an option to conduct the interview telephonically. Meetings were held with three respondents during the second appointment time and telephone conversations, outlining the basis of the questionnaires, were held with a further three respondents. Due to the slow response, possibly precipitated by changes in the management structure on site, respondents were provided with a third option to answer the questionnaire in their own leisure and to return this electronically. Although the response was slightly better, in general the response rate was disappointing.

The Phase 2 – Stage 2 e-mail questionnaire, as presented in the form of Appendix C, was forwarded under a covering letter dated 19th October 2006, as presented in the form of Appendix D. Participants were requested to complete the attached questionnaire and return it electronically, or alternatively, forward a written confirmation via facsimile to the offices of the respondent. 21 of the 91 participants responded, which equates to a response rate of 23.1%, which is satisfactory especially as a number of senior management delegated responsibility for answers to other members of staff who had already been sent questionnaires as part of the survey.
The correlation research data was obtained from A3D and in the case of the case study from the project planner. The data from all projects was collated by Teesside University as part of its use in a separate study presently being conducted to determine the value of 4D to the UK construction industry. The benchmark against which the data could be compared was provided by the ‘Guide to Building Construction Duration’ published by the BCIS in 2004. The BCIS is a division of The Royal Institution of Chartered Surveyors (RICS) based in London, UK.

The secondary data used in this study was obtained from various international publications including, inter alia, articles from respected journals and proceedings of conferences, books, brochures, magazines and Government Publications, as well as the World Wide Web, with the latter providing the most of information. The search engines of Google, Yahoo, MSN and the Electronic Journal of IT in Construction were extensively used to locate relevant literature on the Internet. It should be noted that a large proportion of the documents found on the Internet do not contain page numbers and this makes it extremely difficult for researchers to compile an informative reference list, as is standard practice using hard copy publications.

The search for the information commenced in the author’s collection of information, continued in the library of the Nelson Mandela Metropolitan University and then the British Library. In these institutions, use was made of the following databases:

- EBSCO;
- Nexus;
- The Nelson Mandela Metropolitan University’s own database;
- FirstSearch, and
- The British Library’s own database.

Once these resources had been exhausted, use of the Internet was made along with references provided by colleagues and fellow researchers.
4.3 The Design of the Questionnaires

Pilot Interview
As the questionnaire was intended to provide an informed opinion of the current perceived inadequacies of the construction planning process, only biographic and perception questions were included.

Phase 2 – Stage 1: Interview Survey
This included four biographic questions to enable the drawing of inferences, five process implication questions, six build plan methodology, and eight communication related questions reflecting the hypotheses. A further eight perception related questions were included to determine interviewee bias.

Phase 2 – Stage 2: E-mail Survey
This included four biographic, nine process implication, four build plan methodology and two communication related questions reflecting the hypotheses. A further six perception related questions were included to provide inference.

4.4 Collecting the Data

Pilot Interview
The four professionals identified arranged to be interviewed in their individual capacities in London. Interviews were undertaken on a one-to-one basis.

Phase 2 – Stage 1: Interview Survey
The project director was sent a letter on the 17th July 2006 requesting the survey be conducted amongst all the project participants, to which he agreed. As has been noted, the population was mainly located on site at 51 Lime Street and therefore interviews were arranged to be conducted on the 10th October at the management offices located 5 minutes from site. When this initial interview process failed to illicit the anticipated response, informal interviews were conducted at the desks of respondents located in the site
accommodation unit. Additional interviews were then conducted telephonically and finally those who could not find the appropriate time to be interviewed replied to the questionnaire via e-mail. Two reminder e-mails were sent on the 14th November and 9th December following the issuing of the questionnaires by email on the 24th October.

**Phase 2 – Stage 2: E-mail Survey**

On the 19th October 2006, 91 questionnaires incorporating 25 questions were e-mailed, with a covering letter requesting that completed questionnaires be returned via e-mail or facsimile by the 3rd November 2006. Follow up e-mails were sent on 14th November and 4th December 2006 (see Appendices E and F), with the return date extended initially to the 26th November, and then finally the 9th December, in order to maximise the number of returns. By the 10th December, 21 of the questionnaires, which equates to a response rate of 23.1%, had been returned.

**4.5 The Treatment of the Data**

As the pilot interview entailed the gathering of data to be used to formulate the interview and e-mail questionnaires, it was structured to be processed manually.

The questionnaires that originated from the pilot interview and case study were coded and then the data was processed using Microsoft Excel and presented as reflected in Chapter 6.
5. THE CASE STUDY

5.1 Rationale

The 51 Lime Street project is a 44,000 m² office development comprising a 29 storey and adjoining 10 storey building on a prime site opposite the famous Lloyd's of London building. The challenging site with narrow surrounding streets and adjacent working office buildings, coupled with a fast track build programme that looked to maximise the pre-let status of the project, meant a need from the project team to employ ‘outside the box’ techniques to maintain the project delivery targets. As part of the strategy, the client procured the services of A3D, a 4D Planning and Coordination consultant who have seven years of experience in the implementation of 4D on commercial projects.

The researchers’ role as the 4D Planning Manager on the project allowed unfettered access to all aspects of the planning. Coupled with a project team, including knowledgeable planner, who were open to maximising the potential of new technology, this provided a not to be missed opportunity to further the industry’s knowledge on the potential of 4D in the project environment. In particular, the especially large and complicated site where the full scope, from site wide logistical planning down to detailed daily sequencing of basement work space usage could be reviewed first hand, would be of immense benefit to those currently reviewing options for the technology on similar projects.

5.2 Review of Project Information

As the 4D consultant, the researcher’s role was to work in conjunction with the Construction Planner to produce a ‘vision’ programme in the 4D environment. Starting with the design information as it existed at Tender Stage, the project was modelled in 3D before the information was transferred into the 4D environment using the Master Programme provided by the Construction Planner as the template from which to work. It should be noted
that this programme was expanded exponentially to include not only the construction activities in more detail but also a host of logistical tasks as well. By using the design information, some of it already in the 3D environment in the form of the concrete core model and some services, all aspects required for scheduling tasks are included.

Illustration 7: What should the level of detail be?  
(Amended from Bordoli, 2005*)

This vision programme is not a contractually binding programme, but rather a more in depth programme created with the relevant contractor, taking into consideration all interface issues with other contractor programmes. However, it relates to the desired master programme time parameters as defined by the construction management team. Once the base 4D construction models had been completed, an iterative process commenced which would lead to the creation of build plans. These would be followed by each contractor for the duration of the project. Working with the Construction Planner, the researcher was able to study the process followed and participate in the creation of ‘vision’ programmes for all the works packages. It is this process, which is believed to have the greatest benefit to project teams, from the 4D planning and co-ordination technology, as being able to visually interrogate and run multiple scenarios almost at the touch of a button, saves much time and effort before getting to site. In addition, doing this two to three months prior to the work commencing, means contractors have time to
make changes to personnel, and provides construction managers an opportunity to find additional resources, or get design’s changed before they have a direct impact on meeting programme delivery dates.

Once these vision programmes had been created, the researcher was an observer in the implementation, monitoring and amendment of these programmes. The majority of this activity occurred in the management offices of the 51 Lime Street project at Lovat Lane, EC2, with a number of these sessions conducted in a meeting room with the model projected onto a smart board. This was to allow the participants to interrogate and make amendments in a ‘live’ environment, thereby seeing immediately the impact of their decisions on other contractors and the overall project programme duration. In addition presentation meetings were held in the site induction room also using an overhead projector or at desks of management staff using a laptop or desktop computer. The main individual driving the process for the Project Team was Adio Amusa, the Construction Planner for the project, who was then responsible for using the 4D model as part of his reporting process at meetings with the Project Management team and the Client. He also had to present the model to the eventual occupiers of the building, the leading insurer, Willis Group.

The research goal was to demonstrate the ability of the 4D planning and coordination model to assist the Construction Planner in better communicating the proposed programme to all involved in the process whilst also improving the delivery time period of the project through greater interrogation of the programme. This was to be achieved by increasing the number of tasks and therefore interfaces between contractors and reducing the overall build time as a result of this. In addition the use of 3D modelling throughout the process was to be investigated for additional benefits in design coordination and clash detection, as well as Facilities Management benefit through the lifecycle of the project.
5.3 **Observation from Projects**

With access to all areas of the project, the researcher was able to observe the interaction between the Construction Planner and each of the individual contractor planning managers, the negotiating and bartering that form an integral part of a planner’s responsibility and the importance of being able to fully communicate the construction team’s vision for the project and get contractors to agree to work to the same plan.

The contract programme was initially converted into the 4D model and so was studied intently, with the major interface points of particular interest. All relevant 2D drawing information, or where available 3D information, was dissected into its component parts and individual processes interrogated with contractors to understand the weaknesses and areas needing greatest management input. Construction scopes were also reviewed so as to understand particular aspects of the process and produce the most relevant 4D planning model to be monitored. This did not mean last planner type programming, as that is too detailed to be effective in the 4D Model and was left to the site teams to manage. However, the vision those decisions were based on came from the build plan model as the main interfaces between contractors had already been addressed at management level.

![Detailed interface planning](image)

**Figure 8: Detailed interface planning.**
Source courtesy of A3D.
The researcher was able to observe the reaction from contractors to changes forced upon them by design or circumstance and also their ability to use the model to explain why they needed additional time to complete some specific area of work or reason to shift other contractor dates in order to reduce the overall programme through a more integrated team process. This also included ways to maximise the use of logistical equipment and also to review design issues affecting the construction process and ways to resolve this without affecting the programme duration, even if meant it may have an impact on overall budget costs. The researcher attended meetings where use was made of the model to discuss with the contractor why they were not prepared to work in a certain way, the restrictions imposed in terms of logistics and health and safety (H&S) in their working area and the reasoning for the work rate they had given in their initial planning presentation. It was, therefore, possible to amend the sequence of proposed works to better reflect their constraints or those of other contractors working in a similar area, and amend the whole working arrangement to take cognizance of delays occurring elsewhere on site. The construction programme was reviewed in terms of the location the work was being carried out in and proposed alternate sequences, possibly requiring additional resources, achieving the requirements set out by the Construction Managers, but which did not affect the contractors cost base. All this was done with the ‘vision’ programme in mind and not the original contract programme.

Once the programme baseline had been set, the responsibility for monitoring progress against programme was passed to the contractor and the model became the reporting environment for all levels of management and a tool to enable educated discussions to take place within a management meeting with contractors. I observed unknown constraints being discovered through the visual sequence of activities including H&S restrictions being highlighted by simply seeing two activities occurring in close proximity at the same time. It graphically demonstrated the need to have large pieces of plant on site at an earlier date in order to be able to get them into the basement and asked
questions about where that equipment would be stored before being installed. The restrictions of the site environment, including non-construction related clash, were visually highlighted in a three-dimensional perspective by the model and led to time being saved when the accommodation units were relocated in order to enable the façade panels to be installed.

**Figure 9: Construction Coordination.**
Source courtesy of A3D.

Most importantly, the awareness of progress, when measured against the baseline and the ability to communicate that visually in a fast and effective manner, without the need for reams of paper and a word being spoken, was extremely beneficial in resolving meetings quickly and getting teams to concentrate on real issues. More importantly, an issue was dealt with immediately without a follow up meeting needing to be agreed and instead of persons having to go away and review information for questions to be answered at the next meeting. This was as true for design issues as it was for planning issues, but as they are inextricably linked this was of no surprise to the researcher. As a participative researcher, I was rewarding to observe the model environment being used to coordinate multiple contractors working within a single environment, so that the most efficient working sequence could be achieved, benefiting all of them in the process. Although there were a number of issues that could not be resolved and not all contractors were convinced of the benefit that could be derived from fully committing to the process, in the main the technology was well received and would be of benefit when used again.
5.4 Interpretation of what was observed

It is apparent from being involved in the planning process that one of the major areas that is not currently dealt with in any detail is the interface between contractors and their logistical requirements. When the initial 4D model of the project was created, those areas needing most attention were the ones related to logistics, including:

- The tower cranes in terms of their position and the effect this would have on a number of contractor programmes;
- Extension dates for masts, which means the cranes are not in use, and
- Final removal, which impacted on the completion of the external fabric of the building and numerous internal areas due to slab infills.

Other equipment including piling rigs, vehicle delivery loading areas and the site accommodation in terms of its size, location and interference with daily operations, all had to be reviewed in context with multiple contractor activities.

Figure 10: 4D logistics planning.

Source courtesy of A3D and Mace.

Once the detailed build plan programming commenced with contractors, the researcher became aware that the interface point such as the handover of a work zone by a contractor or the coordination of the designed installation
sequence had not been visualised and a lot of assumptions had been made based on previous experience. Although the process on each project is obviously similar, the constraints are not and it was very apparent that this is where the greatest delays occur i.e. lay down areas interfering with another activity, be it a pile being driven or moving a piece of equipment around a floor slab. Other examples were access routes for vehicles being blocked by equipment or a contractor being prevented from working due to H&S issues created as a result of contractors using equipment above the workforce.

It was also noticeable that the use of the 3D and 4D models made the contractors aware of these restrictions and depending on the attitude of the users to the use of the technology this was viewed as either a positive or negative benefit to resolve the restrictions. Management’s attitude was fairly similar to that of contractors, which was somewhat surprising, especially from experience of these situations on previous projects. Knowing well in advance of a problem that needed an alternate solution, and having a tool that would assist in resolving that situation, would have been much better received by the whole team, including the client, than being made aware of it only weeks before and having to provide a short term solution, which tends to lead to further subsequent problems which then need further management input. It is, however, also the opinion of the researcher, that should the technology be used again with similar team members, then they would in the main make better use of it and gain more out of it than was achieved on this project, simply because the potential benefits took time to percolate down from the Construction Planner to the Project Managers, Construction Managers and Contractor Managers. The potential benefit of communicating issues to one another using the model was not fully utilised until late in the process and by then, it had lost a lot of its potential to benefit and change the course of operations, than would have been the case if used earlier.

Although the planning was still a long iterative process, due in part to the constantly changing design, more was achieved in review meetings by having
the visual imagery available and providing an alternative sequence by inputting the proposed amendments immediately. Also, being able to see the coordinated sequence occur visually i.e. see the sequence play out on screen, without having to follow the relationship theory inherent in a linked bar chart environment, was especially beneficial bearing in mind the complexity of major projects such as this. In addition, more problems were identified during review sessions, and not necessarily programme related issues, through the visual medium of the model. This is not necessarily a fault of the design process as these are mainly elements added during construction and then removed upon completion of the relevant task, i.e. temporary design construct restrictions.

![Figure 11: 4D planning sequence models from 51 Lime St.](source-courtesy-of-a3d)

However, the ability to carry out design coordination and clash detection as part of the planning process has enormous benefits for all areas of the process, including the design. Here again, when the issues were raised early enough in the process, changes could be made in terms of value engineering on the design side and construction process on the planning side that would benefit project delivery and cost reduction in equal measures. However, as the 4D planner role is still very new to most individuals involved in the review process, respecting the individual carrying out the role and their
professional integrity, is the biggest challenge to making this a more beneficial input into the process. This is manifest in an inferred resistance to the use of the model environment from members of the construction management team and also contractor management teams. This may be a resistance to a ‘big brother’ type scenario where every decision is interrogated because it becomes very visible especially when monitoring of the build plan occurs. It may also be a perceived undermining of the role of an individual within the team environment especially if the individuals concerned are not confident in their own ability and feel their position is threatened as a result. By using the technology on a more regular basis, the benefits of interrogating one’s own decisions will become more apparent and a lot of these hostilities would subside. However, the system does not allow any individual to hide and is ruthless in exposing deficiencies, so particular attention needs to be paid by management to educating users, as it can be used in a negative way to undermine a project.

![Figure 12: Design clash detection of 4D services model.](image)
Source courtesy of PSI Software and A3D

The benefits of working in the 3D environment have been well documented by other researchers, but these benefits have once again been reaffirmed on this project. Although improvement in the use of the model to check design coordination i.e. automated clash detection, is an area that still needs greater
attention, the overall ability to communicate the spatial constraints and constructability issues in the third dimension are of immense benefit to all members of the team. Therefore, greater pressure needs to be placed on the design teams to work in this manner from the start as it would have a positive impact on the planning process and costing process.

It was noticeable on this project that when the consultants and contractors undertook their designs in 3D, the coordination aspect of the designs became a more integrated process simply because each designer had to work alongside another to get their element of the design signed off, as opposed to each one submitting their design for sign off individually, and a lead designer coordinating the completed packages. Also, by using this data in the planning phase, and from there as an as built reference for the facilities management team, additional value add is created in the process which offsets any additional cost incurred. The ability to use these self same models to communicate with the client and eventual building tenant, in a simple and uncomplicated fashion, provides a project management team with a tool which instils a perceived confidence in their ability to deliver. Even better, this can be done without having to expend additional resources in its creation.

5.5 Relevance to other projects

How can what has been observed and participated in be transferred across to other similar and also completely different projects? As has been discussed in the ‘Introduction’ and ‘Review of Literature’ sections of this study, the construction industry is grappling with a number of issues which were prevalent on this project. In particular, the integration of many programmes into a single programme, and the communication of this to all, the transfer of knowledge across the team including to less experienced members, improving the logistical management and dealing with issues immediately rather than at a follow up meeting, were all examples where this tool and the process it entails provide a means to overcome many of those failings, in a way that placed little additional responsibility on individuals within the team.
At the same time it provided those team members with additional confidence that the proposed programme was achievable and they had the ability to communicate that vision for the project, which would in turn allow them to deliver on promises made to the client. They also had a medium through which to communicate with the client in pictures rather than words, which saved time and energy to concentrate efforts on resolving issues, not just talking about them. It also provided a platform to maximise the contribution of the collective knowledge base on the project, for the betterment of each individual and each of their respective organisations as well. This then could be translated into a more cost effective and efficient project as that concentrated knowledge base will achieve more than a single planner would ever hope to produce.

![Figure 13: 4D planning presentation models.](image)

Source courtesy of A3D

It has also been stated in the literature surveyed that all of the above areas are where construction organisations need to improve if the industry is going to extricate itself from the present malaise it finds itself in. By being able to start transferring skills from experienced senior management to younger less experienced individuals, they need a reference against which to almost test their own knowledge base on how to do the job. This was aptly provided on this project with the model being used to educate a junior planner and a second Construction Planner, who had no high rise experience, in the complexities and major areas of focus, all clearly communicated in the 4D
environment. The senior planner was thereby able to become involved in other projects where his extended knowledge base could be better utilised whilst still overseeing the operations on site by accessing the model from a web based monitoring platform. With the severe shortages in experienced construction personnel this is one way to both maintain the necessary standards for a client whilst at the same time maximising the potential of the work force available, simultaneously increasing the knowledge pool as part of the process.

In the opinion of the researcher it provided evidence to definitely support hypotheses 1 and 2 of this study and also provided enough evidence to suggest that hypothesis 3 would also be confirmed. In addition it confirmed the theory that the use of 3D models can improve the design coordination process and could enhance the delivery process if more emphasis were placed on using automated clash detection tools. It is also the opinion of this researcher that it proved the value of the tool from a purely financial standpoint, even if calculating this value is extremely difficult to do at present, using existing KPI’s and benchmarking of value add based on traditional estimating techniques. This is therefore the perceived value generated by the process following the creation of the 3D and 4D models and the downstream benefits generated as a consequence of this including, offsite prefabrication, reduced deliveries through improved logistical planning and reduced costs through efficient use of men and materials.
6. THE RESULTS

6.1 Introduction

The results from the two questionnaires have been tabulated separately. A number of terms have been used which need to be clarified:

Minority - 33.3% and less
Half - 50%
Majority - ≥66.7% but <80%
Most - ≥80% but <100%
All - 100%

In order to define with greater detail the responses received, the following terms have been used to represent the weighted mean score for the results:

≥ 1.00 to ≤ 1.80: Not at all to a lesser extent
> 1.80 to ≤ 2.60: Not at all to a lesser extent / lesser extent
> 2.60 to ≤ 3.40: Lesser extent to some extent / some extent
> 3.40 to ≤ 4.20: Some extent to a greater extent / greater extent
> 4.20 to ≤ 5.00: Greater extent to in detail / in detail

Under 6.2, Questions 22 through 25 do not relate directly to the hypotheses, but do provide significant data for reference should future implementation of 4D Planning occur.
6.2 Case Study Interview Questionnaire

Q 1: Have you used or experienced planning methods on previous projects?

<table>
<thead>
<tr>
<th>Response</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>81.8</td>
</tr>
<tr>
<td>No</td>
<td>18.2</td>
</tr>
</tbody>
</table>

Table 3: Respondents exposure to planning methodology.

Most respondents had previously used, or experienced, a planning method on a project. Use or experience of planning methods provides a background and understanding of the role of planning in the management process.

Q 2: If ‘Yes’ to Q1, rate the planning methods used.

<table>
<thead>
<tr>
<th>Planning Method</th>
<th>Used by</th>
<th>Approval Rating (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantt or Bar Charts</td>
<td>9</td>
<td>65.8</td>
</tr>
<tr>
<td>4D Models</td>
<td>8</td>
<td>46.5</td>
</tr>
<tr>
<td>To do list</td>
<td>7</td>
<td>41.8</td>
</tr>
<tr>
<td>Images or Graphics</td>
<td>7</td>
<td>41.8</td>
</tr>
<tr>
<td>Work Breakdown Schedules</td>
<td>3</td>
<td>41.8</td>
</tr>
<tr>
<td>Line of Balance Graph</td>
<td>4</td>
<td>33.3</td>
</tr>
<tr>
<td>Network Analysis Diagrams</td>
<td>5</td>
<td>25.0</td>
</tr>
<tr>
<td>Time Change Graphs</td>
<td>4</td>
<td>12.5</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Table 4: Types of planning methodology used and approval rate.

All nine respondents had used Gantt or Bar Charts, which also had the highest approval rating, which in turn may imply that it would be the method of choice. The high level of 4D model use was to be expected bearing in
mind the sample population for this questionnaire. The low approval ratings for the remaining methods confirm the findings of the literature review relative to existing planning methods.

**Q 3: Did the methods used clearly communicate the project programme to you and your colleagues?**

The mean score, which is in the middle of the mean score range indicates that respondents can be deemed to agree between a lesser extent to some extent / some extent that the methodology used communicated the project programme.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsere</td>
<td>12.5</td>
</tr>
<tr>
<td>Not at all</td>
<td>0.0</td>
</tr>
<tr>
<td>In detail</td>
<td>25.0</td>
</tr>
<tr>
<td>1</td>
<td>25.0</td>
</tr>
<tr>
<td>2</td>
<td>12.5</td>
</tr>
<tr>
<td>3</td>
<td>25.0</td>
</tr>
<tr>
<td>4</td>
<td>25.0</td>
</tr>
<tr>
<td>5</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Table 5: Extent to which planning methods communicated the project programme.

**Q 3.1: If the methods did not at all communicate the project programme, how could project programmes be better presented to enable them to communicate the build process more clearly?**

There were no ‘not at all’ responses.

**Q 4: Have you found that the methods used on 51 Lime Street clearly communicated the project programme to you and your colleagues?**

Given that the mean score is 2.91, the respondents can be deemed to agree between a lesser extent to some extent / some extent that the methodology used communicated the project programme.
Table 6: Extent to which 51 Lime Street planning methods communicated the project programme.

Q 5: Have you made use of or been exposed to the 4D planning method used on 51 Lime Street?

The majority of the respondents had used or been exposed to the use of the 4D planning method.

Table 7: Respondents exposure to 4D Model.

Q 5.1: If ‘Yes’, did it clearly communicate the project programme to you and your colleagues?

Half the respondents who had used or been exposed to the use of 4D planning, agreed that it had to some extent communicated the project programme to them and their colleagues. A further 12.5% identified each of greater extent and in detail as their response. The mean score of 3.00 indicates that the respondents can be deemed to agree that 4D planning had communicated the project programme between a lesser extent to some extent / some extent.
Table 8: Respondents rating of 4D planning’s ability to communicate the project programme.

Q 5.2: If ‘No’, do you believe a 3D Model linked to the project programme i.e. time, would help to communicate that programme more clearly to you and your colleagues?

Of the three respondents who had not been exposed to the 4D planning method, one replied that it would not help at all; one replied that it would only help to some extent, and one replied that they were unsure to what extent it would help. The small number of respondents to this question makes it difficult to draw any objective inference from these responses.

Q 6: Are greater levels of planning detail needed in construction programmes?

Just over half the respondents agreed that greater levels of planning detail are needed.

Table 9: Respondents view on need for greater levels of programme detail.
Q 7: Are the levels of detail included in the construction programme on this project more or less than previous projects?

The mean score of 3.50 indicates that the response can be deemed to be between some extent to a greater extent / greater extent. The 27.3% unsure response is notable, and the highest percentage response was relative to a greater extent.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td></td>
</tr>
<tr>
<td>Not at all ....</td>
<td>In detail</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>27.3</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 10: Level of programme detail on 51 Lime St compared with previous projects

Q 8: Is the level of planning better or worse on this project?

The mean score of 3.38 indicates that the response can be deemed to be between a lesser extent to some extent / some extent. However, it should be noted that 3.38 is marginally outside of the higher range of > 3.40 ≤ 4.20.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td></td>
</tr>
<tr>
<td>Not at all ....</td>
<td>In detail</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>27.3</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 11: Planning performance on 51 Lime St compared with previous projects.
Q 9: Is it your opinion that when a 3D Model of the project is used, it helps to increase the level of planning detail?

More than half of the respondents believed that using a 3D Model of the project would lead to an increase in the level of planning detail.

<table>
<thead>
<tr>
<th>Response</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>54.5</td>
</tr>
<tr>
<td>No</td>
<td>27.3</td>
</tr>
<tr>
<td>Unsure</td>
<td>18.2</td>
</tr>
</tbody>
</table>

Table 12: Do 3D models impact the level of planning detail.

Q 9.1: If ‘Yes’, why do you believe this occurs?

Not all could qualify their assertion, but those who did, stated the following:

- Better understanding of overall project;
- Visually highlights gaps, and
- The co-ordination issues are better understood in a 3D model.

Q 10: Have you had experience, using any method, of planning detailed aspects of the construction programme?

The majority of respondents had experience of planning detailed aspects of the construction programme.

<table>
<thead>
<tr>
<th>Response</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>72.7</td>
</tr>
<tr>
<td>No</td>
<td>27.3</td>
</tr>
</tbody>
</table>

Table 13: Experience of detailed planning.
It is important for greater numbers of construction personnel to be involved in creating detailed aspects of the construction programme as it will increase knowledge transfer of critical interface issues.

Q 10.1: If ‘Yes’, had you been able to use a 3D Model of the project to understand the 3D reality required, would it have improved your ability to deliver?

50% of those respondents who had experience of detailed planning believed that a 3D Model would have improved their ability to deliver the 3D reality required, 25% to a greater extent and 25% in detail. The resultant mean score of 3.25 indicates that the response can be deemed to be between a lesser extent to some extent / some extent.

![Figure 14: Extent of 3D models ability to improve delivery.](image)

Q 11: Would being able to use a 4D model to understand the 3D reality required, improve the ability to plan detailed aspects of the construction programme?

The mean score of 2.82 indicates that the respondents can be deemed to concur between a lesser extent to some extent / some extent that using a 4D Model of the project would improve their ability to plan detailed aspects of the programme.
Table 14: Extent to which 4D models may improve the ability to plan detailed aspects of the programme.

Q 12: Will additional construction programme detail help to better deliver the contract programme?

The mean score of 3.44 indicates that respondents concur between some extent to a greater extent / greater extent that additional programme detail would lead to better delivery of the contract programme.

Table 15: Extent to which additional detail helps communicate the project programme.

Q 13: When a 4D Model of the project is used, does it help communicate the 3D reality required for delivery?

The mean score of 3.00 indicates that respondents can be deemed to agree between a lesser extent to some extent / some extent that use of a 4D Model would help to communicate the 3D reality required for delivery.
Table 16: Extent to which 4D model helps communicate 3D reality required.

Q 14: By using location based planning techniques, can project logistics be improved?

Given that the mean score is 3.89, the respondents can be deemed to agree between some extent to a greater extent / greater extent, that project logistics would be improved by location based planning.

Table 17: Extent to which location based planning will improve project logistics.

Q 15: Can visually communicating to your colleagues where and when activities are taking place, help you to deliver a project programme?

The mean score of 3.82 indicates that respondents were of the opinion that visually communicating where and when activities were taking place would, between some extent to a greater extent / greater extent, help deliver a programme.
Table 18: Extent to which visual communication of an activity location will improve project delivery.

Q 16: Would the visual nature of the 4D Planning model help to communicate where and when these activities take place?

More than half the respondents believed the visual nature of the 4D planning model would, to a greater extent, help to communicate where and when activities take place. The resultant mean score of 3.60 indicates that the response can be deemed to be between some extent to a greater extent / greater extent.

Figure 15: Extent to which 4D planning model would help to communicate where and when activities take place.
Q 17: Has the construction programme on 51 Lime Street been better evaluated than previous projects?

Given that the mean score is 3.13, the respondents can be deemed to agree that the 51 Lime Street programme had between a lesser extent to some extent / some extent, been better evaluated than previous projects.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Not at all ............. In detail</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>1 2 3 4 5</td>
<td>0.0 9.1 45.5 18.2 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.13</td>
</tr>
</tbody>
</table>

Table 19: 51 Lime St programme evaluation comparison.

Q 18: Has the planner on 51 Lime Street been able to better communicate the construction programme than on previous projects?

More than half of those surveyed believed that to some extent, the planner on 51 Lime Street had been able to better communicate the construction programme. However, the mean score of 3.38, which is marginally outside of the higher range, indicates that the agreement can be deemed to be between a lesser extent to some extent / some extent.

Figure 16: Extent to which the planner on 51 Lime St had been better able to communicate the construction programme.
Q 19: Is it important to measure progress against planned construction?

All those surveyed agreed that in their opinion it was important to measure actual progress against that originally planned.

Q 20: Would having more tasks to measure progress against help projects to better meet programme dates?

The mean score of 3.00 indicates that respondents can be deemed to agree between a lesser extent to some extent / some extent that measuring more tasks would help projects meet their programme dates.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>36.4</td>
</tr>
<tr>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>18.2</td>
</tr>
<tr>
<td>3</td>
<td>27.3</td>
</tr>
<tr>
<td>4</td>
<td>18.2</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 20: Extent of monitoring more tasks on meeting programme dates.

Q 21: Do you believe visually communicating planned construction against actual progress will improve programme delivery?

Given that the mean score is 3.22, the respondents can be deemed to concur that visually communicating planned against actual would between a lesser extent to some extent / some extent, improve programme delivery.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>18.2</td>
</tr>
<tr>
<td>1</td>
<td>9.1</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>36.4</td>
</tr>
<tr>
<td>4</td>
<td>36.4</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 21: Extent to which communication of progress visually impacts on programme delivery.
Q 21.1: If visually communicating progress would ‘Not at all’ improve programme delivery, what would improve programme delivery?

There was a single ‘Not at all’ response with the following comment:
“Programme delivery is dependant on programmed periods being correct and the management of the build programme.”

Q 22: Do you use a personal computer?

All those surveyed replied in the affirmative.

Q 23: Is construction a technology ‘phobic’ industry?

Given that the mean score is 2.78, the respondents can be deemed to agree that construction is between a lesser extent to some extent / some extent, a technology ‘phobic’ industry.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td></td>
</tr>
<tr>
<td>Not at all</td>
<td>1.0</td>
</tr>
<tr>
<td>.............</td>
<td>2.0</td>
</tr>
<tr>
<td>In detail</td>
<td>3.0</td>
</tr>
<tr>
<td>1</td>
<td>18.2</td>
</tr>
<tr>
<td>2</td>
<td>9.1</td>
</tr>
<tr>
<td>3</td>
<td>36.4</td>
</tr>
<tr>
<td>4</td>
<td>27.3</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
</tr>
<tr>
<td>18.2</td>
<td>2.78</td>
</tr>
</tbody>
</table>

Table 22: Level of technology ‘phobia’ in Construction.

Q 24: If more construction personnel used IT devices i.e. computers, smart phones, MP3 player, PSP's, would the use of technology in construction improve?

Given that the mean score is 3.27, the respondents can be deemed to concur that the use of other IT devices would between a lesser extent to some extent / some extent, improve the use of technology in construction.
Table 23: Extent of improvement in construction IT use from exposure to the use of other IT devices.

This is very relevant when looking at the value of implementing technology into the industry especially with organisations recruiting heavily from schools and university’s in order to replace an ageing workforce.

Q 25: Will the use of 4D Planning models increase as construction personnel become more IT literate?

Given that the mean score is 3.33, the respondents can be deemed to agree that the use of 4D models would between a lesser extent to some extent / some extent, increase in line with increased IT literacy. However, it should be noted that the mean score of 3.33 is marginally outside of the higher range of some extent to a greater extent / greater extent.

Table 24: Extent to which 4D planning model use will increase with IT literacy.

This further emphasises the view that those planning for the longer term need to consider the increasing levels of IT literacy when considering new technology to assist in dealing with a shortage of construction personnel.
6.3 E-mail Questionnaire

Q 1: Have you used / experienced a planning method on a project?

Most respondents had used or experienced a planning method.

<table>
<thead>
<tr>
<th>Response</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>95.2</td>
</tr>
<tr>
<td>No</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Table 25: Respondents exposure to planning methodology.

As almost all had used or experienced use of a planning method it provided a good sample population for the purposes of this study.

Q 1.1: Please indicate what method(s) was used.

Included as part of Figure 17 under Question 2. Sphere size reflects percentage of respondent answers.

Q 2: Rate the ability of the planning methods listed to communicate tasks to be completed?

Figure 17: Types of planning methodology used and approval rate
All respondents had used Gantt or Bar Charts, but it only had the third highest approval rating behind 4D Models and Images or Graphics. The small size of the very good approval rating reflects the perceived inherent weakness in the ability of current planning methodologies to communicate tasks to be completed. The close relationship of 4D models to the very good rating, indicates that respondents do believe that these can be beneficial in communicating tasks to be completed.

Q 3: Does using an image help to better communicate project tasks to colleagues?

All the respondents agreed that using an image helped to better communicate project tasks to colleagues, with 57% believing it does so in detail. The resultant mean score of 4.52 indicates that overall, the response can be deemed to be between a greater extent and in detail / in detail.

Figure 18: Extent to which an image helps communicate project tasks to colleagues

Q 4: Would using a 3D Model image further improve your ability to communicate these tasks to colleagues?

The mean score of 4.24 indicates that respondents can be deemed to agree between a greater extent and in detail / in detail that the use of a 3D Model image would improve their ability to communicate project tasks to colleagues.
Table 26: How 3D and 4D improves the communication process.

Questions 4 through 7 all provide further clarification to Question 3 and the results have therefore been grouped in Table 26.

**Q 5: Do you believe that using a 3D Model linked to a programme of tasks i.e. a time based model, would further improve this communication?**

The mean score of 4.33 indicates the respondents can be deemed to agree between a greater extent and in detail / in detail that time based models would further improve communication of project tasks to colleagues.

**Q 6: In your opinion, would construction personnel better understand the required 3D reality if they had a 3D Model of that reality?**

The mean score of 4.19 indicates that the respondents can be deemed to agree between some extent to a greater extent / greater extent that construction personnel would better understand the required 3D reality if they had a 3D Model of that reality. However, it should be noted that 4.19 is marginally outside of the higher range of > 4.20 ≤ 5.00.
Q 7: Does having additional information including time based 3D models, help to better understand the requirements needed to deliver a project?

The mean score of 4.24 indicates that respondents agree between a greater extent and in detail / in detail that having additional information does help to better understand the requirements needed to deliver a project.

Q 7.1: If ‘Not at all’, what would help to deliver a project to programme?

There were no ‘Not at all’ responses, but two comments were provided:

- All the forms of presentation have been used to present a particular case. 3D modelling and 4D modelling are okay if relevant; and
- Please remember that most people involved with a project only deal with a very small 'window' i.e. what they have to do today or tomorrow, and not the big picture. A handful deal with the big picture.

Q 8: Would additional detail in a construction programme i.e. a greater number of tasks, help to communicate programme delivery requirements better?

The mean score of 2.95 indicates the respondents can be deemed to agree between a lesser extent to some extent / some extent that a greater number of tasks would help to communicate programme delivery requirements better.

| Table 27: Extent to which additional detail would help to communicate delivery programme requirements. |
|---|---|---|---|---|---|---|
| **Response (%)** | **Unsure** | **Not at all** | **In detail** | **Mean score** |
| **1** | **2** | **3** | **4** | **5** | **2.95** |
| 5.0 | 10.0 | 30.0 | 20.0 | 15.0 | 20.0 |
Q 9: Would additional tasks communicated through an image, further aid delivery of the requirements?

Half the respondents agreed that to a greater extent, communicating additional tasks through a model would aid delivery of requirements. The resultant mean score of 3.58 indicates the overall response can be deemed to be between some extent to a greater extent / greater extent.

Figure 19: Extent to which additional image tasks would aid delivery of requirements.

Q 10: Does the level of detail in construction programmes need to increase?

Given that the mean score is 3.27, the respondents can be deemed to agree between a lesser extent to some extent / some extent that the level of programme detail needs to increase.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>Not at all</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Table 28: Extent to which construction programme levels of detail need to increase.
Q 11: Do construction programmes need to better communicate the location of tasks?

Given that the mean score is 3.90, the respondents can be deemed to agree between some extent to a greater extent / greater extent that programmes need to better communicate the location of tasks.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>3.90</td>
</tr>
<tr>
<td>Not at all</td>
<td>0.0</td>
</tr>
<tr>
<td>.............</td>
<td>0.0</td>
</tr>
<tr>
<td>In detail</td>
<td>15.0</td>
</tr>
<tr>
<td>1</td>
<td>10.0</td>
</tr>
<tr>
<td>2</td>
<td>45.0</td>
</tr>
<tr>
<td>3</td>
<td>30.0</td>
</tr>
</tbody>
</table>

Table 29: Extent to which construction programme’s need to communicate the location of tasks.

Q 12: In your opinion, would it be easier and faster to complete a construction task if you already knew its location?

The mean score of 3.79 indicates that respondents believed between some extent to a greater extent / greater extent that it would be easier and faster to complete a construction task if its location was already known.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>3.79</td>
</tr>
<tr>
<td>Not at all</td>
<td>5.0</td>
</tr>
<tr>
<td>.............</td>
<td>0.0</td>
</tr>
<tr>
<td>In detail</td>
<td>10.0</td>
</tr>
<tr>
<td>1</td>
<td>30.0</td>
</tr>
<tr>
<td>2</td>
<td>30.0</td>
</tr>
<tr>
<td>3</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Table 30: Extent to which knowing a construction task location would aid in its completion.
Q 13: Would you find it difficult to communicate the location of a task without an image to assist you?

Given that the mean score is 2.80, the respondents can be deemed to agree between a lesser extent to some extent / some extent that they would find it difficult to communicate the location of a task without an image to assist them. The 25% not at all response is notable.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td></td>
</tr>
<tr>
<td>Not at all</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25.0</td>
</tr>
</tbody>
</table>

Table 31: Extent to which respondents would have difficulty in communicating the location of a task without an image.

Q 14: Would a 3D Model showing the location and process of a task to be completed, assist in completing that task as planned?

The mean score of 3.79 indicates that respondents can be deemed to agree between some extent to a greater extent / greater extent that a 3D Model showing the location and process of a task would assist in completing the task as planned.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td></td>
</tr>
<tr>
<td>Not at all</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 32: Extent to which a 4D model would assist in the completion of a task as planned.
Q 15: In your opinion, would planning of project tasks be improved if you could use a location based planning tool?

The mean score of 3.95 indicates that respondents believed between some extent to a greater extent / greater extent that the planning of project tasks would be improved if a location based planning tool could be used.

<table>
<thead>
<tr>
<th>Response (%)</th>
<th>Not at all .......... In detail</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsure</td>
<td>1 2 3 4 5</td>
<td>5.0 0.0 40.0 20.0 35.0</td>
</tr>
</tbody>
</table>

Table 33: Extent to which planning would be improved if a location based planning tool were used.

Q 16: How often do you believe progress should be monitored on a project?

50% of the respondents believed it should be monitored at least ‘Once a day’ whilst a further 35% would monitor at least ‘Once a week’.

Figure 20: Monitoring frequency.
Q 17: In your opinion, is monitoring a programme important in achieving programme delivery?

All of those surveyed answered in the affirmative.

Q 18: If you had more tasks to monitor, do you believe it would be easier or harder to manage programme delivery?

Given that the mean score is 2.86, the respondents can be deemed to agree that with more tasks to monitor it would be between slightly easier to no difference / no difference to manage the programme delivery.

![Pie chart showing responses to Q 18](chart.png)

Figure 21: Extent to which monitoring would be affected by having more tasks to monitor.

Q 19: If you could visually communicate actual vs. planned progress, would it make programme management easier or harder?

Given that the mean score is 2.10, the respondents can be deemed to agree that it would be substantially easier to slightly easier / slightly easier to manage the programme if the actual against planned progress could be visually communicated.
Table 34: Extent to which visually communicating progress against baseline would aid in programme management.

Q 20: When using visual tools, is it easier or harder to understand the implications of process implementation?

The mean score of 2.11 indicates that the respondents can be deemed to agree it would be between substantially easier to slightly easier / slightly easier to understand the implications for process implementation using visual tools.

Table 35: Extent to which visual tools aid in addressing implications of process implementation.

Q 21: How often have you been exposed to a 4D Model on a project?

On average respondents had been exposed to a project using a 4D model almost nine times. However, this figure was skewed due to a number of very high usage responses and the more relevant figure was the median of three. It was important to clarify the answer to this question.
Q 21.1: If ‘Once’ or ‘More’, did it communicate the process implications of creating the 3D reality better?

Of those answering ‘Once’ or ‘More’ to Question 21, 55% believed that the 4D model did, to a greater extent, communicate the process implications of creating the 3D reality better. The resultant mean score of 3.58 indicates that the overall response can be deemed to be between some extent to a greater extent / greater extent.

![Pie chart showing the extent to which 4D models helped to communicate the process implications of creating the 3D reality.]

Figure 22: Extent to which 4D models helped to communicate the process implications of creating the 3D reality.

Q 22: How many hours a week do you use a computer?

The majority of respondents use a computer for more than 15 hours a week.

<table>
<thead>
<tr>
<th>Hours</th>
<th>Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;15 to ≤ 22</td>
<td>30.0</td>
</tr>
<tr>
<td>&gt;28</td>
<td>30.0</td>
</tr>
<tr>
<td>&gt;22 to ≤ 28</td>
<td>25.0</td>
</tr>
<tr>
<td>&gt;8 to ≤ 15</td>
<td>15.0</td>
</tr>
<tr>
<td>≤ 1</td>
<td>0.0</td>
</tr>
<tr>
<td>&gt;1 to ≤ 8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 36: Use of computers by respondents.
7. TESTING THE HYPOTHESES

7.1 Introduction

Mention has already been made in Chapter Six of a number of terms which will also be used to clarify the data within Chapter Seven.

It should also be noted that:

- The respondents chosen for the Pilot interview were selected on the basis of their commitment to use of technology to improve the construction process,
- The Phase 2 – Stage 1 survey was conducted amongst respondents who had been involved in a project where 4D planning was part of the management process,
- Of the 54 individuals contacted to participate in the Case Study survey, 11 responded which was a 20% rate of return. Thus 80% did not respond.
- Of the 91 individuals contacted to participate in the E-mail survey, 21 responded which was a 23% rate of return. Thus 77% did not respond.

Although the above mentioned indicate some bias, it should be remembered that:

- The Pilot interview respondents were approached to contribute to the development of subsequent questionnaires,
- Researchers cannot influence a sample population, and therefore have no control over the percentage committed vis-à-vis the uncommitted respondents, and
- Respondents in the Case Study survey were contacted in their individual capacity and were not under instruction by the client or construction manager to participate in the survey.
7.2 **Hypothesis 1**: That using 4D planning models to interrogate the construction programme will highlight the process implications of creating the 3D reality.

7.2.1: **Interview Survey**

- Respondents believed between a lesser extent and some extent / some extent that using a 4D Model of the project would improve their ability to plan detailed aspects of the programme;
- Those surveyed believed between a lesser extent to some extent / some extent that the 51 Lime St programme had been better evaluated than previous projects;
- Respondents replied that they believed project logistics would be improved between some extent to a greater extent / greater extent, by location based planning;
- The mean score of 3.82 indicates that respondents were of the opinion that visually communicating where and when activities were taking place would between some extent to a greater extent / greater extent, help deliver a programme, and
- More than half the respondents believed that the visual nature of the 4D planning model would to a greater extent help to communicate where and when activities take place.

7.2.2: **E-mail Survey**

- The respondents can be deemed to agree between some extent to a greater extent / greater extent that programmes need to better communicate the location of tasks;
- Those surveyed believed between a lesser extent to some extent / some extent, they would find it difficult to communicate the location of a task without an image to assist them;
- Respondents agreed between a greater extent and in detail / in detail, that the use of a 3D Model image would improve their ability to communicate project tasks to colleagues;
Respondents agreed between some extent to a greater extent / greater extent that a 3D Model showing the location and process of a task would assist in completing the task as planned;

- The mean score of 3.95 indicates that respondents believed that planning of project tasks would be improved between some extent to a greater extent / greater extent, if you could use a location based tool;
- Those surveyed believed it would be between substantially easier to slightly easier / slightly easier to understand the implications for process implementation using visual tools, and
- Of those who had been exposed to a 4D Model on a project, slightly more than half believed to a greater extent that the 4D model did communicate the process implications of creating the 3D reality better.

7.2.3: Case Study

The 4D Model was used for all aspects of programme review and one of the main functions was to review an activity and the actions needed to carry it out in the 3D environment over a period of time. Some of the issues dealt with included:

- Lay-down areas for the core formwork at basement level alongside core piling at the same level whilst at all times maintaining vehicle access routes to and from the main site access ramp;
- The initial installation of tower cranes and subsequent commencement of the steel frame installation whilst the concrete cores were being constructed. This required alternate zonal and sequential programming due to logistics constraints caused by delays to the main concrete core erection as well as delayed removal of scaffolding being used by drilling teams to access pockets within the existing foundation wall. These activities were not on the original programme but were added as part of the 4D planning process as they formed part of the design information for those areas of the project;
The installation of missing cladding panels following the removal of the tower crane’s ties, was identified as a problem area. The standard fixing method was to use a machine on the floor above, which was not possible, as this panel would already have been installed. Leaving the entire column of panels out was considered, but soon discarded, as this would have had severe implications on the handover date for each floor. An alternate sequence was implemented that allowed the missing panel to be installed from a derrick crane mounted on the BMU device. The contractor estimated this saved them 12 to 16 weeks delay on their programme;

Figure 23: Cladding installation process.

H&S constraints were highlighted by a contractor working on the cladding of the building who was unaware of the proposed prior installation of services on a floor which had yet to be clad. This meant working with the sub-contracted installation crew to provide an alternate installation strategy which would not impact on the programme as much as had initially been envisaged, and

It was noted from review of the combined project model that the accommodation units built in the corner of the site, although having been designed to accommodate the steel frame and glazed cladding panels, did not have any allowance for the installation of the panels, requiring the relocation of the accommodation unit. This was identified well in advance of the works commencing allowing all parties to minimise the cost and disruption that could have occurred to both the site staff and contractor responsible for installation.
7.2.4: Test

The findings of the surveys and case study support the hypothesis: ‘That using 4D planning models to interrogate the construction programme will highlight the process implications of creating the 3D reality.’ International literature also supports the hypothesis.

7.3 Hypothesis 2: Using a 4D Build Plan methodology, will better communicate to construction personnel the reality / complexity of the programme.

7.3.1: Interview Survey

- Those surveyed deemed to agree between a lesser extent to some extent / some extent that the methodology used communicated the project programme;
- More than half of the respondents believed that using a 3D Model of the project would lead to an increase in the level of planning detail and that the reason for this was that it provided a better understanding of the overall project; visually highlights gaps, and the co-ordination issues are better understood in a 3D model;
- The respondents concurred between a lesser extent to some extent / some extent that using a 4D Model of the project would improve the ability to plan detailed aspects of the programme;
- The respondents deemed to agree that between some extent to a greater extent / greater extent, that the levels of planning detail are more on this project than previous projects;
- The mean score of 3.38 indicated that respondents deemed that the planning on this project was between a lesser extent to some extent / some extent, better than for previous projects, and
- Respondents believed that using a 4D Model of the project would between a lesser extent to some extent / some extent improve their ability to plan detailed aspects of the programme and in addition, that between a lesser extent to some extent / some extent, it would help to communicate the 3D reality required for delivery.
7.3.2: E-mail Survey

- The respondents agreed between some extent to a greater extent / greater extent, that construction personnel would better understand the required 3D reality if they had a 3D Model of that reality;
- The respondents agreed between a greater extent and in detail / in detail, that having additional information, including time based 3D models, would help to better understand the requirements needed to deliver a project, and
- Half the respondents agreed that to a greater extent, communicating additional tasks through a model would aid delivery of requirements.

7.3.3: Case Study

A build plan process revolves around the use of the design information to develop the programme by expanding each main heading within the construction programme 10 to 20 times. This is done by amending the design models to reflect the proposed construction process and in particular the interfaces between different contractor tasks within that environment. In addition, all the logistics items that may only be included for reference in the design information are now included in detail and their installation process is also interrogated in conjunction with the design elements. The contractors are involved at an early stage, even prior to award of contract, to impart knowledge into the process in order to achieve the best build sequence based on the constraints and scope of activities to be completed. As the project design information develops, so the models are adapted to include for this and the programmes are expanded further with any design change implications analysed through the model environment.

An example of its use was in the detailed sequence of the basement services and blockwork fit-out where the early delivery of the main equipment including 5m long ductwork sections, had to be coordinated with the ongoing installation of blockwork walls and the rest of the ductwork, pipework, sprinkler, electrical and other cable service trays as well as openings from
tower cranes and hoists that penetrated the ground floor slab in around 6 locations. The eventual sequence included for multiple work zones and a three stage blockwork installation which took account of the contractors’ labour constraints as well as ground level access constraints due to incomplete works. Although start dates were delayed, the programmes including all interfaces were more efficient in their use of men and materials and the cumulative man-hours were less than originally envisaged by each contractor working in separation. In addition:

- Logistics constraints which may have led to walls being knocked down after they had initially been installed, due to the need to get equipment through that was wider than the corridor created, were averted, saving time and money whilst possibly creating a better end product;
- The multiple layering of the services was also coordinated from both a design and construction perspective by using the 3D models created by the contractors design teams alongside the structural model created in the 4D process;
- The small roof spaces on both buildings were crammed with services equipment as well as building maintenance unit (BMU) devices and a complex steel frame structure, all of which were amended continuously throughout the construction phase, and
- The added logistical requirements to be located on each roof impacted on the proposed sequence as outlined in the construction programme and therefore required a greater level of detailed planning to communicate to all parties involved, including the Architectural and BMU teams. The complexities of the interfaces between the various teams tasked with installing the services equipment and the constraints posed by the removal of the adjacent tower crane, along with waterproofing design amendments, the installation of a curved steel roof frame and subsequent infill panels, required an immense amount of forward planning to enable the proposed installation sequence, starting eight weeks later, to proceed as planned.
All of this was managed through the 3D / 4D interface and in far greater detail than was initially proposed in the construction programme.

7.3.4: Test

The findings of the surveys and case study support the hypothesis: ‘Using a 4D Build Plan methodology will better communicate to construction personnel the reality / complexity of the programme.’

7.4 Hypothesis 3: That by using the 4D Planning models to communicate the Build plan, greater certainty of contract programme delivery will occur.

7.4.1: Interview Survey

- When asked whether the 4D Planning method had clearly communicated the project programme to them or their colleagues, half the respondents agreed that to some extent, it had done so;
- Of the three respondents who had not been exposed to the 4D Planning method, all three differed in their opinion on its possible ability to communicate the project programme to them or colleagues;
- More than half of those surveyed believed to some extent, that the planner on 51 Lime St had been better able to communicate the construction programme than on previous projects;
- The survey determined that where the 3D Model had been used to plan detailed aspects of the project, 25% of respondents believed to a greater extent and 25% in detail, that it had improved the respondent’s ability to understand and therefore deliver the 3D reality required;
- The mean score of 3.82 indicates that respondents were of the opinion that visually communicating where and when activities were taking place would, between some extent to a greater extent / greater extent, help deliver a programme;
• Just over half agreed that greater levels of planning detail are needed in construction programmes, whilst respondents agreed between a lesser extent to some extent / some extent, that measuring more tasks would have an impact on projects meeting their programme dates;
• Between some extent to a greater extent / greater extent, respondents believed that additional programme detail would lead to better delivery of the contract programme, and
• Those surveyed believed that visually communicating planned tasks against actual progress of those tasks would, between a lesser extent to some extent / some extent, improve programme delivery.

7.4.2: E-mail Survey
• The respondents indicated that to a lesser extent to some extent / some extent, a greater number of tasks in a construction programme would help to communicate programme delivery requirements better;
• A mean score of 4.33 indicates respondents agreed between a greater extent and in detail / in detail, that they believed time based models would further improve communication of project tasks to colleagues;
• All of those surveyed agreed that monitoring a programme is important in achieving programme delivery, with 50% of respondents believing it should be monitored at least ‘once a day’ and a further 35% at least ‘once a week’;
• Respondents believed it would be slightly easier to no different / no different to manage programme delivery when having more tasks to monitor, and
• Respondents agreed it would be substantially easier to slightly easier / slightly easier to manage the programme if you could visually communicate actual progress against planned.
7.4.3: Case Study

Once the Build plans had been coordinated for the different areas of the building, which on this project were the basement, tower, Fenchurch Avenue Building (FAB) and roof, individual models of these areas and a combined model for the entire project were used to communicate to the various stakeholders the proposed schedule of works. In addition to being used in the regular management meetings the models were also available to the entire project team through the site extranet and a separate web portal, which also doubled up as the project monitoring interface. Through this environment all project team members could access the latest baseline programme models and review their own task programmes, as well as being able to update the programme with the latest progress dates. These would then be reflected automatically in the project model linked to the programme, giving an opportunity to review visually on-screen actual progress against the proposed programme.

Unfortunately the project suffered from two contractor liquidations which adversely affected the programme, one of these being the main cladding contractor who was responsible for both manufacture and installation. Therefore, assessing the ability of the build plan to provide certainty of contract programme delivery is near impossible. It can, however, be safely stated that having the detail of the build plan allowed the project team to completely understand all the implications caused by the inability of the contractor to supply the glazing panels. In addition, the availability of the model as a communication tool to explain the previously agreed process to the new contractors, including the major interfaces with other contractors and logistical constraints, provided a fast track introduction to the project for the new contractor and would have attributed to more efficient and time saving policies being implemented during their own installation procedure. By rescheduling large proportions of the remaining project tasks to take this into account, the aim of the construction management team was still to complete the project within the original contract programme duration.
7.4.4: Test

The findings of the surveys and case study suggest support for the hypothesis: ‘That by using the 4D Planning models to communicate the Build plan, greater certainty of contract programme delivery will occur.’ However, the hypothesis can not be fully proven without a more detailed analysis of construction programmes from across a number of projects and the use of KPI’s with relevance to the processes being implemented, which will then can provide more than a perceived certainty of delivery.

7.5: Other Findings

When reviewing the perception type questions, the disparity between the case study and e-mail survey questionnaires as regards existing planning processes is notable. Although both show Gantt or Bar Charts as the most used planning methodology, it only gained the highest approval rating from the case study participants, with the e-mail respondents only giving it the third highest approval. This may be a reflection of a demographic trend between site and office based participants, but more responses from both surveys need to be received before reaching such a conclusion. In addition, those from the case study survey agreed to a greater extent that the methodology used communicated the project programme, whilst most of the e-mail survey respondents agreed that using an image helped to better communicate project tasks to colleagues. This confirmed their earlier assertion that 4D Models provided the best way of communicating tasks to be completed. However, they both did agree that to some extent, greater levels of detail are required in construction programmes.

With respect to developing a perception regarding using technology in construction, although those surveyed believe that the industry is to some extent still technology ‘phobic’, the majority also believe that as more construction personnel use devices such as smart phones, MP3 players and PSP's, whilst becoming even more IT literate as computers pervade our
society to an even greater degree, so the use of technology, including 4D Planning, will increase to a greater extent.

The biographical questions posed in both questionnaires reflect that most of the sample populations have used or experienced planning methodology on previous projects. They had also had experience of 4D Technology with the case study respondents having a greater than 70% exposure, and most of the e-mail respondents having experienced it on at least three occasions. In addition, they all were computer literate and in the case of the e-mail respondents, most used a computer for in excess of 15 hours a week.

In the opinion of the researcher, this showed a change in the attitude of construction personnel to the use of technology in the industry which somewhat contradicted the information contained in Figure 1 of the Preface. This may have implications for the implementation of new planning technology onto future projects.
8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary

4D planning, and more specifically, the process followed in creating the 4D model from the 2D or 3D design information and initial programme, highlight to those construction personnel who are involved in that process, the implications of creating the 3D reality. Getting those individuals to commit to the process and transfer that information across to the greater team, in order that the complexity of the programme can be clearly communicated to all levels of a project, requires a shift in the collective understanding of the place of technology in construction and an acceptance of it in improving the site based work environment.

The levels of acceptance to technology in achieving this are a cause for concern, although the perceived opinion that use of technology by more and more construction personnel within their daily life environment will provide a catalyst for change in this regard, is encouraging. In the future, the critical mass, probably driven by the younger generation, will shift, and it will become a necessity in carrying out daily tasks to use such technology. This will be further encouraged by the shift occurring within the design fraternity towards the use of BIM which will add critical weight to the process of change.

With greater acceptance so too will a willingness to investigate the full potential of the technology known to only a handful of practitioners at present result. This in itself will drive further refinement of the process and new methodologies will be developed to further improve on the efficiencies of the current practices. As that happens and management starts to understand the implications of this to their delivery time and cost structures, it will receive the necessary high level approval from all organisations within the project framework. This in itself will aid in reducing the occurrence of delayed completion through a more integrated worksite environment.
Although the study cannot conclusively state that this process has occurred on the case study project or any other previous project where 4D planning has been implemented, the fact that the first and second hypotheses have been supported, indicates that in all likelihood, should the process be implemented on future projects that it will improve on the construction planning process and contribute towards greater certainty in contract programme delivery.

8.2 Conclusions

The combination of the use of the 3D design information, alongside the outline construction sequence programme, form the catalyst to improving the ability of construction personnel to communicate the complexity and 3D reality of the programme, thereby aiding those self same personnel to provide greater certainty of contract programme delivery to their clients.

In addition, the process required to achieve the coordination of these two separate but related environments, provides the opportunity to visualise the process implications required in creating that 3D reality, thereby providing additional benefits in design coordination, cost estimation, lean construction and more efficient construction programme delivery. The cumulative benefit of achieving this will not only be improved contract programme delivery but also a more cost effective build process which will convert to savings for the client and a higher quality product.

The industry and its client base want to see improvements to the way projects are currently managed and a large part of that process is borne by construction planning. There are a number of different planning methodologies being tried at present to improve on the ability of planners to deliver projects to programme. Of these the Last Planner techniques have had the most success in dealing with the detailed planning at the site level environment, but no one method has been found to create and communicate the higher level programme’s needed by management to coordinate the initial contractor programme’s. 4D planning provides both the tools and process to
address this situation whilst also being compatible with the site based techniques. It also provides a visual communications interface which can be scaled for use from the client level all the way down to the detailed coordination of site activities on a daily basis.

Although there is a perceived negative attitude to the use of technology within the construction industry and, in addition, that the monitoring process using the 4D planning interface exposes too much information in the visual review environment, management need to be aware that if they do not implement technology to improve their process delivery, clients will in all likelihood take their business elsewhere, as they end up paying for the inefficiencies of the current methodologies.

8.3 Recommendations

8.3.1 Process Implications

- Clients should demand the use of 3D in the design phase, whilst that information should be used downstream for construction planning, off-site prefabrication, H&S planning and Facilities Management;
- Contractors should be brought into the process at an earlier stage in order that they can provide expertise in the initial planning of the project;
- This could be coupled with partnering or a scoring system which awards those who participate additional bonus points at Tender stage;
- Planners should be trained to use 4D planning software in order that they can use and interrogate models and then communicate this to contractors;
- 4D models should be issued as part of the tender package or presented at briefing meetings so that contractors are all working from the same information, not interpreting design drawings and programmes to try understand what the construction team want;
And the contractors should provide their programme for review in the 4D model environment so that any proposed amendments to the construction programme can be quickly highlighted and analysed for their impact to not only time but also cost and manpower requirements;

By incorporating logistical elements into the construction model, site constraints can be highlighted earlier to reduce delay and cost escalation;

As part of H&S planning, the location and working processes for each activity can be reviewed through the 4D model environment alongside other contractor activities, reducing the risk of employees being unaware of hazardous working conditions;

Use the models to communicate the process with statutory agencies so that they are aware of possible noise and other site conditions which may cause project works to be halted, and

The models should be used in weekly or fortnightly site meetings by all levels of the construction management team to interrogate and communicate process implication issues.

**8.3.2: Greater evaluation of the programme**

Project and Construction Managers should look to employ young planners who can be trained to use the new technology to improve on their own planning skills and to increase the level of detail using the visual interface;

The extra detail, including additional input from the contractors, should be interrogated using 4D Planning to provide alternative scenarios including increasing crew sizes and other constraints, to provide the optimum build plan for each contractor to follow;

The 4D models should be used by the planner to review multiple contractor programmes in a meeting environment thereby highlighting the major interface tasks and handover tasks;
Contractors should also be using the same models to review their proposed sequence to maximise the use of men and logistical constraints for delivery of materials including lead time items;

The contractors can then use the models to evaluate with their site based staff the critical activities which will form part of their site based planning processes, including the Last Planner approach, and

“How does a Project get to be a year late … One day at a time.” Dr Frederick P. Brooks. Therefore, the programme should be monitored against daily tasks and reviewed weekly.

8.3.3: Communication

Project and Construction Managers should embrace the new technologies available to them and see it as an opportunity to improve on their ability to deliver a better product for their client by being able to better communicate with both their client and the downstream team;

The 4D models should be used throughout the communication process, from the client in briefing meetings explaining the implications of a design change on the programme, to the site based staff who have the construction sequence played on plasma screens over lunch;

No contractor programme should be signed off until it has been reviewed by the Construction Director in the 4D model environment;

The models should be used for Clash detection and this should be communicated to the design teams even if they are not using a 3D model design environment;

The project progress should be highlighted in the models by using Actual task views against Planned views of the programmed tasks and where tasks are slipping, the reason for this delay can be managed immediately;
Site induction should include a 4D Planning model explaining the complete build sequence and including a review of H&S information, and

- The 4D Planning model and programme should be the only Baseline followed!

8.3.4: General

- 4D Planning and the sexy images it generates can be used to lure a whole new generation of potential recruits to the industry by explaining to them and their parents how a construction project goes together and the many varied roles that provide an opportunity for employment within the industry;

- The industry can address its poor reputation with government, investors and the general public using a medium that they understand;

- 4D planning models can be used to communicate without the need to translate a language or explain the missing what occurs between static images in a slide show;

- The information can be posted on websites and is secure and cannot be amended without direct input from the project team, and

- A picture tells a thousand words!
9. CLOSURE

On the internet there is a website dedicated to Networking, Planning, Scheduling, Programme & Project Control Professionals around the world. A thread was posted in the Forum section of the site on 4D Planning & Visualisation which read as follows: ‘1.0 Should we be using visualisation as a planning tool? 2.0 If Yes, What do we want the tool to do.’ (Pearce, 2005*)

In response, Gary France, the Chairman of the Planning Engineers Organisation, the pre-eminent professional body for planners, provided the following confirmation of the emergence of 4D as a legitimate alternative to existing methodologies in the quest to improve Construction Planning.

“Dear all,

I am amazed at the strength of feeling posted in this thread.

Of course, there is no substitute for good people, but I don’t believe that is the point.

4D software is a brilliant tool and a very powerful communication medium. Let’s think about how important that is. We all create programmes and schedules – then what do we do with them? We communicate them to other people, so anything that makes that communication better and simpler has to be a good thing. Planners have to be good communicators otherwise their work will not be appreciated or indeed understood.

Waseem says there will be no buyers for this idea. I really cannot agree with that for there are a huge amount of people who will want to use this. It is a matter of who you are presenting the programme information to. I have used 3D models of projects to show how / when those projects will be constructed and I have presented these to clients, funders, banks, neighbours, town
planners, Governments and many more. It is exactly these sort of people – key shapers of projects – who want to understand the programme but cannot read barcharts, or even worse, network diagrams. These people love looking at such 3D presentations, because they can understand them.

I also believe they are very useful in the site environment.

The opportunity to link a 3D CAD model to a timeframe (hence 4D) is certainly the way forward. Being able to automatically update the 3D model whenever you change the programme is superb. I will certainly be using it. Definite. Without a doubt. It is the way to go.

Gary France,
Chairman,
Planning Engineers Organisation”
REFERENCES


Bovis Lend Lease (2001) *A radical step to take? Improving the construction demand chain.* [Available from Bovis Lend Lease, 142 Northolt Road, Harrow, Middlesex, HA2 OEE, England]


http://www10.aeccafe.com/goto.php?encode_url=aHR0cDovL3d3dy5jaWFyL3d3dy5jaWFyL3Nhc2VzdHVkaWVzLzREX0NBRF9Nb2RlbGluZy5wZGY= [Accessed 11 Aug 2005]


http://www.mtruant.com/process/Implementing_5D_Virtual_Construction_Technology.pdf [Accessed 6 November 2006]

Gibson, R. (2003) *Analysis of project delay-theoretical or interrogation of the facts?* [online]. Available from:  

Graphisoft’s *The world’s first commercially available 5D Construction Management system* (2004) [online]. Available from:  


Graphisoft (2005b) *Control* (Brochure). Budapest: Graphisoft zrt


Goldstein, H. (16 April 2001) 4D: Science Fiction or Virtual Reality? *Construction.com* [online]. Available from:  


113


120


APPENDICES

APPENDIX A

Mace Limited
51 Lime St Project Office,
31 Lovat Lane,
London,
EC3R 8EB

Case Study in the use of 4D Planning to better Communicate and Evaluate the Construction Programme

To Nick Moore

I am currently engaged in studies towards an MSc in the Built Environment, the topic of my treatise being “Improving Construction Planning through 4D Planning”.

As part of my research I am looking to conduct interviews with construction personnel who have been exposed to both traditional planning techniques and the use of 4D Planning on a project. As a result of the involvement of all levels of personnel on the 51 Lime St Project in the use of 4D planning, it is an ideal candidate project for this research. As Construction Project Director, I am therefore asking for your permission to conduct interviews with those personnel.

The interviews would be conducted in a structured manner on site and will last no more than 20 minutes per interview. Any data obtained will be treated in the strictest confidence and the findings of the study will be made available to all participating organisations after completion of the study.

Should you require any further information concerning the study as a whole or this survey in particular, please do not hesitate to contact me at:

T: 0208 879 8130
M: 07775848516
E: chris@a3duk.com

I look forward to receiving your response and thank you in anticipation for your willingness to participate.

Yours Sincerely,

Chris Allen
MSc (BE) student in the Faculty of Engineering, Built Environment and Information Technology
Department of Construction Management
Nelson Mandela Metropolitan University
Port Elizabeth
6031
South Africa
T: +27415042398 | F: +27415042345
APPENDIX B

Interview Questionnaire for Treatise
“Improving Construction Planning through 4D Planning”
from Case Study Project:
51 Lime Street, London, EC2

<table>
<thead>
<tr>
<th>Question</th>
<th>Selections</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Have you used or experienced any planning methods on previous projects?</td>
<td>Yes ☐ No ☐ Unsure ☐</td>
</tr>
<tr>
<td>2. If Yes, on a scale of 1 (very poor) to 5 (very good), rate the planning methods used.</td>
<td>Unsure</td>
</tr>
<tr>
<td>To do list</td>
<td>☐</td>
</tr>
<tr>
<td>Gantt or Bar Charts</td>
<td>☐</td>
</tr>
<tr>
<td>Line of Balance Graph</td>
<td>☐</td>
</tr>
<tr>
<td>Images or Graphics</td>
<td>☐</td>
</tr>
<tr>
<td>Network Analysis Diagrams</td>
<td>☐</td>
</tr>
<tr>
<td>Work Breakdown Schedules</td>
<td>☐</td>
</tr>
<tr>
<td>4D Models</td>
<td>☐</td>
</tr>
<tr>
<td>Time Change Graphs</td>
<td>☐</td>
</tr>
<tr>
<td>Other</td>
<td>☐</td>
</tr>
<tr>
<td>3. On a scale of 1 (not at all) to 5 (in detail), did the methods used clearly communicate the project programme to you and your colleagues?</td>
<td>Unsure ☐</td>
</tr>
<tr>
<td>3.1. If Not at all, how could project programmes be better presented to enable them to communicate the build process more clearly?</td>
<td>☐</td>
</tr>
<tr>
<td>4. On a scale of 1 (not at all) to 5 (in detail), have you found that the methods used on 51 Lime Street clearly communicated the project programme to you and your colleagues?</td>
<td>Unsure ☐</td>
</tr>
<tr>
<td></td>
<td>Question</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>5.</td>
<td>Have you made use of or been exposed to the 4D Planning method used on 51 Lime Street?</td>
</tr>
<tr>
<td>5.1</td>
<td>If Yes, on a scale of 1 (not at all) to 5 (in detail), has it clearly communicated the project programme to you and your colleagues?</td>
</tr>
<tr>
<td>5.2</td>
<td>If No, on a scale of 1 (minor extent) to 5 (major extent), do you believe a 3D Model linked to the project programme i.e. time, would help to communicate that programme more clearly to you and your colleagues?</td>
</tr>
<tr>
<td>6.</td>
<td>Are greater levels of planning detail needed in construction programmes?</td>
</tr>
<tr>
<td>7.</td>
<td>On a scale of 1 (lesser degree) to 5 (greater degree), are the levels of detail included in the construction programme on this project more or less than previous projects?</td>
</tr>
<tr>
<td>8.</td>
<td>On a scale of 1 (lesser degree) to 5 (greater degree), is the level of planning better or worse on this project?</td>
</tr>
<tr>
<td>9.</td>
<td>Is it your opinion that when a 3D Model of the project is used, it helps to increase the level of planning detail?</td>
</tr>
<tr>
<td>9.1</td>
<td>If Yes, why do you believe this occurs?</td>
</tr>
<tr>
<td>10.</td>
<td>Have you had experience, using any method, of planning detailed aspects of the construction programme?</td>
</tr>
<tr>
<td>10.1</td>
<td>If Yes, on a scale of 1 (minor extent) to 5 (major extent), had you been able to use a 3D Model of the project to understand the 3D Reality required, would it have improved your ability to deliver?</td>
</tr>
<tr>
<td>11.</td>
<td>On a scale of 1 (minor extent) to 5 (major extent), would being able to use a 4D model to understand the 3D Reality required, improve the ability to plan detailed aspects of the construction programme?</td>
</tr>
<tr>
<td>12.</td>
<td>On a scale of 1 (not at all) to 5 (definitely), will additional construction programme detail help to better deliver the contract programme?</td>
</tr>
<tr>
<td>13.</td>
<td>On a scale of 1 (not at all) to 5 (definitely), when a 4D Model of the project is used, does it help communicate the 3D reality required for delivery?</td>
</tr>
<tr>
<td>Question</td>
<td>Response Options</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>14. On a scale of 1 (not at all) to 5 (definitely), by using location</td>
<td>Unsure</td>
</tr>
<tr>
<td>based planning techniques, can project logistics be improved?</td>
<td></td>
</tr>
<tr>
<td>15. On a scale of 1 (not at all) to 5 (definitely), can visually</td>
<td>Unsure</td>
</tr>
<tr>
<td>communicating to your colleagues where and when activities are</td>
<td></td>
</tr>
<tr>
<td>taking place, help you to deliver a project programme?</td>
<td></td>
</tr>
<tr>
<td>16. On a scale of 1 (lesser degree) to 5 (greater degree), would the</td>
<td>Unsure</td>
</tr>
<tr>
<td>visual nature of the 4D Planning model help to communicate where and</td>
<td></td>
</tr>
<tr>
<td>when these activities take place?</td>
<td></td>
</tr>
<tr>
<td>17. On a scale of 1 (not at all) to 5 (in detail), has the construction</td>
<td>Unsure</td>
</tr>
<tr>
<td>programme on 51 Lime Street been better evaluated than previous</td>
<td></td>
</tr>
<tr>
<td>projects?</td>
<td></td>
</tr>
<tr>
<td>18. On a scale of 1 (lesser degree) to 5 (greater degree), has the</td>
<td>Unsure</td>
</tr>
<tr>
<td>planner on 51 Lime Street been able to better communicate the</td>
<td></td>
</tr>
<tr>
<td>construction programme than on previous projects?</td>
<td></td>
</tr>
<tr>
<td>19. In your opinion, is it important to measure progress against</td>
<td>Yes  No  Unsure</td>
</tr>
<tr>
<td>planned construction?</td>
<td></td>
</tr>
<tr>
<td>20. On a scale of 1 (not at all) to 5 (definitely), would having more</td>
<td>Unsure</td>
</tr>
<tr>
<td>tasks to measure progress against help projects to better meet</td>
<td></td>
</tr>
<tr>
<td>programme dates?</td>
<td></td>
</tr>
<tr>
<td>21. On a scale of 1 (not at all) to 5 (definitely), do you believe</td>
<td>Unsure</td>
</tr>
<tr>
<td>visually communicating planned construction against actual progress</td>
<td></td>
</tr>
<tr>
<td>will improve programme delivery?</td>
<td></td>
</tr>
<tr>
<td>21a. If not at all, what would improve programme delivery?</td>
<td></td>
</tr>
<tr>
<td>22. Do you use a personal computer?</td>
<td>Yes  No  Unsure</td>
</tr>
<tr>
<td>23. On a scale of 1 (not at all) to 5 (definitely), is construction a</td>
<td>Unsure</td>
</tr>
<tr>
<td>technology ‘phobic’ industry?</td>
<td></td>
</tr>
<tr>
<td>24. On a scale of 1 (not at all) to 5 (definitely), if more construction</td>
<td>Unsure</td>
</tr>
<tr>
<td>personnel used IT devices i.e. computers, smart phones, MP3 player,</td>
<td></td>
</tr>
<tr>
<td>PSP's, would the use of technology in construction improve?</td>
<td></td>
</tr>
<tr>
<td>25. On a scale of 1 (not at all) to 5 (definitely), will the use of 4D</td>
<td>Unsure</td>
</tr>
<tr>
<td>Planning models increase as construction personnel become more IT</td>
<td></td>
</tr>
<tr>
<td>literate?</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C

Survey on Improving Construction Planning through 4D Planning

To,

I am currently engaged in post-graduate studies, the topic of my Treatise being “Improving Construction Planning through 4D Planning”.

As part of my research, I am conducting surveys to obtain data on user perceptions on the use of the 3D and 4D Models in improving Construction Planning. As a result of your involvement in or experience of 4D Planning on projects, I would like to invite you to take part in this groundbreaking study. Your views and opinions concerning the processes involved being of major importance, not only for this study, but also in shaping further advancement in the field of Construction Planning.

Accompanying this cover letter is a 3 page questionnaire which can be filled in electronically to be sent by email return. Alternatively, please print this document off and complete before faxing back. Returns for the survey need to arrive by the 3rd November 2006 to be included.

All data obtained will be treated in the strictest confidence (no name recognition will be used) and findings of the study will be made available to participants after completion of the study which will be published early in 2007.

Should you require any further information regarding the study as a whole or this survey in particular, please do not hesitate to contact me on:
+44 (0)20 81239843 (SkypeIn)
+44 (0)7775 848516 (Mobile)
+44 (0)20 88798130 (Work)
chris@a3duk.com or craz25@hotmail.com

Alternatively, questions can be directed to:
Professor John Smallwood PhD (Constr Man) Pr CM FCIOB MACPM MESSA MiIoSM
Head, Department of Construction Management
Programme Director, MSc (Built Environment) Programme
Nelson Mandela Metropolitan University
PO Box 77000
Port Elizabeth
6031
South Africa

Tel.: + 27 41 504 2790 / 551
Fax.: + 27 41 504 2345 / 574
Mobile: + 27 83 659 2492

I look forward to receiving your response and thank you in anticipation for your willingness to participate.

Yours sincerely

Chris Allen
MSc(BE) Student in the Faculty of Engineering, Built Environment and Information Technology
Before completing the questionnaire, please enter your initials and occupation in the boxes provided. Please answer all questions unless otherwise directed. To complete the questionnaire electronically, select your response, right mouse click and then using the ‘Properties’ option, select ‘Checked’ under ‘Default value’. Should you wish to print off and complete manually, please use a black pen and fax your answers to +44 208 8796420 or +27 41 3742944. Any questions please ring +44 208 1239843.

<table>
<thead>
<tr>
<th>Questionnaire Ref.: CAMSc(BE)2006-EQ</th>
<th>Initials:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupation:</td>
<td>Occupation:</td>
</tr>
<tr>
<td>Questionnaire number:</td>
<td>Questionnaire number:</td>
</tr>
</tbody>
</table>

### 1. Have you used or experienced a planning method on a project?
- [ ] Yes
- [ ] No
- [ ] Unsure

#### 1.1 If ‘Yes’, please indicate what method(s) was used.

- **To do list**
- **Gantt or Bar Charts**
- **Line of Balance Graph**
- **Images or Graphics**
- **Network Analysis Diagrams**
- **Work Breakdown Schedules**
- **4D Models**
- **Time Change Graphs**
- **Other**
2. Rate the ability of the planning methods listed to communicate tasks to be completed? (Please rate on a scale of 1 to 5 where 1 is poor and 5 exceptional.)

<table>
<thead>
<tr>
<th>Method</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>To do list</td>
<td></td>
</tr>
<tr>
<td>Gantt or Bar Charts</td>
<td></td>
</tr>
<tr>
<td>Line of Balance Graph</td>
<td></td>
</tr>
<tr>
<td>Images or Graphics</td>
<td></td>
</tr>
<tr>
<td>Network Analysis Diagrams</td>
<td></td>
</tr>
<tr>
<td>Work Breakdown Schedules</td>
<td></td>
</tr>
<tr>
<td>4D Models</td>
<td></td>
</tr>
<tr>
<td>Time Change Graphs</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

3. On a scale of 1 (minor extent) to 5 (major extent), Does using an image help to better communicate project tasks to colleagues?

<table>
<thead>
<tr>
<th>Rating</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsure</td>
</tr>
</tbody>
</table>

4. On a scale of 1 (minor extent) to 5 (major extent), Would using a 3D Model image further improve your ability to communicate these tasks to colleagues?

<table>
<thead>
<tr>
<th>Rating</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsure</td>
</tr>
</tbody>
</table>

5. On a scale of 1 (not at all) to 5 (definitely), Do you believe that using a 3D Model linked to a programme of tasks i.e. a time based model, would further improve this communication?

<table>
<thead>
<tr>
<th>Rating</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsure</td>
</tr>
</tbody>
</table>

6. On a scale of 1 (minor extent) to 5 (major extent), In your opinion, would construction personnel better understand the required 3D reality if they had a 3D Model of that reality?

<table>
<thead>
<tr>
<th>Rating</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsure</td>
</tr>
</tbody>
</table>

7. On a scale of 1 (not at all) to 5 (definitely), Does having additional information including time based 3D models, help to better understand the requirements needed to deliver a project?

<table>
<thead>
<tr>
<th>Rating</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsure</td>
</tr>
</tbody>
</table>

7.1 If "Not at all", what would help to deliver a project to programme? Please type your answer in the space provided.
<table>
<thead>
<tr>
<th></th>
<th>Question</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>On a scale of 1 (minor extent) to 5 (major extent), Would additional detail in a construction programme i.e. a greater number of tasks, help to communicate programme delivery requirements better?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>9</td>
<td>On a scale of 1 (minor extent) to 5 (major extent), Would additional tasks communicated through an image, further aid delivery of the requirements?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>10</td>
<td>On a scale of 1 (not at all) to 5 (definitely), Does the level of detail in construction programmes need to increase?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>11</td>
<td>On a scale of 1 (not at all) to 5 (definitely), Do construction programmes need to better communicate the location of tasks?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>12</td>
<td>On a scale of 1 (minor extent) to 5 (major extent), In your opinion, would it be easier and faster to complete a construction task if you already knew its location?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>13</td>
<td>On a scale of 1 (minor difficulty) to 5 (major difficulty), Would you find it difficult to communicate the location of a task without an image to assist you?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>14</td>
<td>On a scale of 1 (minor difficulty) to 5 (major difficulty), Would a 3D Model showing the location and process of a task to be completed, assist in completing that task as planned?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>15</td>
<td>On a scale of 1 (minor extent) to 5 (major extent), In your opinion, would planning of project tasks be improved if you could use a location based planning tool?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>16</td>
<td>How often do you believe progress should be monitored on a project?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Once a day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Once a week</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Once a fortnight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Once a month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Once a project</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Never</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>17</td>
<td>On a scale of 1 (not important) to 5 (very important), In your opinion, is monitoring a programme important in achieving programme delivery?</td>
<td>□</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>Question</td>
<td>Response Options</td>
<td></td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>18.</strong> On a scale of 1 (substantially easier) to 5 (substantially more difficult), If you had more tasks to monitor, do you believe it would be easier or harder to manage programme delivery?</td>
<td>□ □ Unsure</td>
<td></td>
</tr>
<tr>
<td><strong>19.</strong> On a scale of 1 (substantially easier) to 5 (substantially more difficult), If you could visually communicate actual vs. planned progress, would it make programme management easier or harder?</td>
<td>□ □ Unsure</td>
<td></td>
</tr>
<tr>
<td><strong>20.</strong> On a scale of 1 (substantially easier) to 5 (substantially more difficult), When using visual tools, is it easier or harder to understand the implications of process implementation?</td>
<td>□ □ Unsure</td>
<td></td>
</tr>
<tr>
<td><strong>21.</strong> How often have you been exposed to a 4D Model on a project?</td>
<td>□ □ Unsure</td>
<td></td>
</tr>
<tr>
<td><strong>21.1</strong> If ‘Once’ or more, On a scale of 1 (minor extent) to 5 (major extent), did it communicate the process implications of creating the 3D reality better?</td>
<td>□ □ No</td>
<td></td>
</tr>
<tr>
<td><strong>22.</strong> How many hours a week do you use a computer?</td>
<td>□ ≤ 1 hour □ &gt;1 ≤ 8 hours □ 8 to 15 hours □ 15 to 22 hours □ 22 to 28 hours □ more than 29 hours</td>
<td></td>
</tr>
</tbody>
</table>

**Thank you for completing this questionnaire.**
APPENDIX E

Survey on Improving Construction Planning through 4D Planning

To,

This is a brief reminder regarding the completion of the questionnaires for my post-graduate study into “Improving Construction Planning through 4D Planning”.

In the event that you have misplaced the original 3 page questionnaire, I have provided another copy which can be filled in electronically to be sent by email return. Alternatively, please print this document off and complete before faxing back. I have extended the date by which returns are required by to the 26th November so as to allow the maximum number of participants to be included.

All data obtained will be treated in the strictest confidence (no name recognition will be used) and findings of the study will be made available to participants after completion of the study which will be published early in 2007.

Should you require any further information regarding the study as a whole or this survey in particular, please do not hesitate to contact me on: +44 (0)20 81239843 (SkypeIn) +44 (0)7775 848516 (Mobile) +44 (0)20 88798130 (Work) chris@a3duk.com or craz25@hotmail.com

Alternatively, questions can be directed to: Professor John Smallwood PhD (Constr Man) Pr CM FCIoB MACPM MESSA MIoSM Head, Department of Construction Management Programme Director, MSc (Built Environment) Programme Nelson Mandela Metropolitan University PO Box 77000 Port Elizabeth 6031 South Africa Tel.: + 27 41 504 2790 / 551 Fax: + 27 41 504 2345 / 574 Mobile: + 27 83 659 2492

I look forward to receiving your response and thank you in anticipation for your willingness to participate.

Yours sincerely

Chris Allen
MSc (BE) Student in the Faculty of Engineering, Built Environment and Information Technology
APPENDIX F

Survey on Improving Construction Planning through 4D Planning

To,

Time is now running out to get your replies in for the post-graduate study into “Improving Construction Planning through 4D Planning”.

In the event that you have misplaced the previously emailed 3 page questionnaire, I have provided another copy which can be filled in electronically to be sent by email return. Alternatively, please print this document off and complete before faxing back. The final deadline for acceptance of all responses has now been set for Saturday 9th December, so get your responses in today and don’t miss out on this once in a lifetime opportunity to contribute to a scientific study.

All data obtained will be treated in the strictest confidence (no name recognition will be used) and findings of the study will be made available to participants after completion of the study which will be published early in 2007. Faxed responses can be sent to +442088796420.

I look forward to receiving your response and thank you in anticipation of your participation.

Yours sincerely

Chris Allen

MSc (BE) Student in the Faculty of Engineering, Built Environment and Information Technology