Towards an Industrialised Project Delivery System for the Building & Construction Industry

Supported by an integration of two enabling technologies, Systems Engineering and Building Information Modelling

Jae Hyuk Park
The current BC industry has confronted many challenges. In spite of many researches and efforts so far, the future of the BC industry is too hard to be optimistic as proven by the relatively low productiveness of the BC industry. As one of promising solution to meet the demanding challenges, the more actively-applied industrialisation in the BC industry has been discussing by many researchers and practitioners for last two decades. But, based on not only the theoretical literature review but also personal working experiences, it is without any doubt true that this industrialisation in the BC industry has failed or fell short of delivering their expected outcomes in practice. What are the current limitations in the industrialised concept of the BC industry? This documentation starts a series of the argumentations with this broadly-asked question.

First of all, four industrialised efforts previously made in the BC industry were theoretically tackled with in order to look into the possibilities and limitations. Moreover, the importance of the industrialisation in the BC industry was revisited. This research proposed that the more critical factor to transform the current BC industry into the properly and fully industrialised one is not the partly-applied technologies but the holistic transformation of the project delivery system. Without any system thinking in the BC industry, the industrialised paradigm shift is just a long way to go. This system thinking is based on the Living Building Concept initiated by Hennes de Ridder and his colleague researches. This research studied LBC concepts. By exploring two main systems in the BC industry, which are the demand and supply system, it was pointed out that the current project delivery system has to be transformed into the industrialised one.

Three main requirement of the industrialised project delivery system, which bottom-up, parametric and dynamic were proposed in this research. More specifically, the bottom-up approach means the supplier-driven delivery system that enables the generated information to keep reusing and accumulating and that facilitates to the use of the existing components. And the parametric approach is also vital to realise an industrialised system and enhance the productivity in the BC industry. In parametric concept, most of information could be automatically generated by filling in the pre-defined parameters. As other manufacturing industries do, the BC industry should define the parameters to bridge each other objects in the entire supply system in order to efficiently produce and manage the built facilities in the parallel way. Finally, in the dynamic approach, we can expect two main advantages in the industrialised project delivery system. First, change orders could be managed in the
better way or the even better solutions to the society could be delivered within dynamic control area since the focus of delivery is on value, rather than on costs. Second, a variety of solutions with the parametric system could be proposed to clients like other consumer markets do. By adding new and differentiated parameters depending on the strategy of their business, the industrialised BC industry would go into consumer market economy.

In this argument of the industrialised project delivery system, Building Information Modelling and Systems Engineering were theoretically explored as enabling technologies (or methodologies) of the proposed delivery system. BIM provides the solution to transformation of an industrialised project delivery system by visualization in the very early phase of the production, by facilitating collaboration in the production system and by the accumulation of all reusable information in order to make it accessible. Also SE ensures the more satisfaction of the clients, the structured life-cycle management and the integrated design and construction in the industrialised practice. Therefore, both are very important for the industrialised project delivery system. But, based on the interviews with the practitioners in Ballast Nedam, it was recognised that the most critical issue for both technologies in practice is the integration, which means the way of working together and seamlessly.

The above summarised theoretical literature review and interviews with practitioners in Ballast Nedam reformulated the initial and broad research questions to the more specified research questions, which mainly dealt with the integration xBS technologies (from Systems Engineering methodology) and Revit software (as an application of Building Information Modelling). The SE-BIM integrated system was analysed and designed to support the previously-proposed industrialised project delivery system. In other words, the end-product of this research is to explore the practical potentials of the industrialised project delivery system by integrating two emerging technologies which are SE and BIM in the BC industry.

In the beginning of the practical research part, the model-based framework was established for the integration xBS and Revit application. In the modelling aspect, the process and product models are two main categories. In the established framework, three integration issues were specified; 1) SE product model and BIM product model. (In terms of the design-related information structure), 2) BIM process model and SE process model. (In terms of the design-related information process) and 3) the synchronised information structure and process. The key methodologies for each integration issues are Business Process Reengineering (IDEF0), Object-Oriented Systems Engineering (UML) and Process to Product modelling (xPPM). Based on this integration framework, solution methodologies and the used tools, ModuPark project delivery system in the Ballast Nedam was analysed and redesigned focusing on the phases from the requirements analysis and the design development.
Towards an Industrialised Project Delivery System for the BC Industry

This MSc research presented some scientific contributions. First, one of the main scientific findings is that some limitations and opportunities of the current industrialisation in the BC industry was analysed with two research-based projects such as FutureHome and ManuBuild and business-based projects such as BoKlok and Corus Living Solution. Especially, ModuPark of Ballast Nedam in the Netherland was case-studied in the very detailed. And secondly, another scientific contribution is that some critical requirement for better industrialised delivery system in the BC industry was proposed based on the theoretical research. Thirdly, two enabling technologies which are System Engineering and Building Information Modelling were revisited by mentioning some possible contributions for the proposed industrialised project delivery system. Fourthly, one important issue in practice is integration between SE and BIM. To solve the integration problem, this research set up the Model-driven framework. As technologies-integration is regarded as a critical factor of the successful application in practice, this model-driven framework is one of main scientific contributions in this research since it provides a good guideline for other technologies-integration issues. Finally, the SE-BIM integrated system to underpin the proposed project delivery system was analysed and designed along with the previously-mentioned model-driven framework.

The most valuable practical implication, in my opinion, is to open the new possibility that the statically generated information throughout the current project delivery system is transformed to the more dynamically available one by integrating each other, by predefined their parametrical relations based on the knowledge they have already accumulated and by actively reusing them for their coming projects. Some other practical implications are 1) To discover the pitfall of the fragmented application of enabling technologies in the BC industry, 2) To propose one of possible solutions to integrate SE and BIM, 3) To find out the importance and role of Business Process Reengineering using IDEF0 in the integration issue, 4) To discover the limitation of the current SE and to introduce Object-Oriented System Engineering, 5) To present the very practical prototyping of the integrated information system fully covering the phases from Requirement Model to Design Model, 6) To practically present possibilities and limitations of the proposed delivery system enabled by integration of BIM and SE in several interviews and discussions with relevant real business actors.

Since the scope of this MSc research was limited and the research goal was specified, there are some uncovered research areas. Although this research opens a wide range of further research topics, chapter 9.3 will categorise possible further researches into 2 main-groups and 6 topic sub-groups. 2 main-groups are 1) Further practical researches with more development in practice and 2) Further theoretical researches extending the current focus to the whole BC industry and other methodologies. The further practical researches consist of 1-1) Extended scopes such
Towards an Industrialised Project Delivery System for the BC Industry

as construction phase and maintenance phase, 1-2) Other types of BC projects in the industrialised delivery system, 1-3) More detailed case study on ModuPark Business unit to lead to physical development of the integrated information system. And the further theoretical researches are divided into as followings; 2-1) More enabling technologies should be invited and integrated in the near future, 2-2) More requirements for better industrialised project delivery system in the BC industry should be found out and studied in more detailed and 2-3) Other research branches of Living Building Concept should be dealt with to maximise synergy effects in practice.
ACKNOWLEDGEMENTS

“Take the first step in faith. You don’t have to see the whole staircase. Just take the first step.”

- Dr. Martin Luther King (1929-1968)

To my lovely wife, June.
# TABLE OF CONTENTS

Abstract ................................................................................................................................. 2
Acknowledgements ................................................................................................................. 6
Table of contents ..................................................................................................................... 7
List of Tables .......................................................................................................................... 11
List of Figures .......................................................................................................................... 13
List of Abbreviations .............................................................................................................. 18
1. Introduction ........................................................................................................................ 21
   1.1 General Problem description ...................................................................................... 22
   1.2 Motivating experiences ............................................................................................... 25
   1.3 Point of departure ........................................................................................................ 28
   1.4 MSc thesis structure ..................................................................................................... 29
2. Previous efforts for industrialised BC industry ................................................................. 32
   2.1 Research-driven efforts for industrialised BC industry .................................................. 33
      2.1.1 FutureHome project .................................................................................................. 33
      2.1.2 ManuBuild ................................................................................................................ 37
   2.2 Business-driven efforts for industrialised BC industry ................................................... 39
      2.2.1 BoKlok ..................................................................................................................... 39
      2.2.2 Corus Living Solution ............................................................................................... 41
   2.3 Possibilities and limitations of previous efforts for industrialisation in the BC industry .......................................................................................................................................................................................................................................................................................................................... 43
3. Industrialised project delivery system .................................................................................. 46
Towards an Industrialised Project Delivery System for the BC Industry

3.1 Revisited industrialised context

3.2 System thinking for industrialised project delivery
   3.2.1 Living Building Concept
   3.2.2 Project delivery as a system

3.3 Requirements analysis of industrialised project delivery system
   3.3.1 Bottom-up approach
   3.3.2 Parametric approach
   3.3.3 Dynamic approach

4. Enabling technologies
   4.1 Building Information Modelling
      4.1.1 Visualisation in the early phase
      4.1.2 Facilitated collaboration
      4.1.3 Accumulation of all reusable information
   4.2 Systems Engineering
   4.3 Integration issue
      4.3.1 BIM and SE in Ballast Nedam
      4.3.2 Fragmented application in practice
      4.3.3 Interrelated and overlapped concepts

5. Reformulated research questions
   5.1 Background of reformulated questions
   5.2 Reformulated research questions/ goals/ end-products
   5.3 Research methods/ techniques/ mode of inquiry

6. Integration solution framework
   6.1 Model-driven integration
   6.2 Integration framework
6.3 Integration methodologies to be applied ................................................................. 90
   6.3.1 Business Process Reengineering ................................................................. 90
   6.3.2 Object-oriented Systems Engineering ......................................................... 91
   6.3.3 Process to Product modelling ................................................................. 91

7. Conceptual modelings for industrialised project delivery system of ModuPark ..... 96
   7.1 ModuPark of Ballast Nedam ................................................................. 97
      7.1.1 Introduction of ModuPark ................................................................. 97
      7.1.2 Data collections and analysis ................................................................. 101
   7.2 Information Process modelling (IDEF0) ................................................................. 104
      7.2.1 Purpose, Viewpoint and Scope of IDEF0 modelling ..................................... 105
      7.2.2 AS-IS IDEF0 Process modelling ................................................................. 107
      7.2.3 TO-BE IDEF0 Process modelling ................................................................. 117
   7.3 Information Structure modelling (UML) ................................................................. 127
      7.3.1 Purpose, Viewpoint and Scope of UML modeling ..................................... 127
      7.3.2 AS-IS Information Structure modelling for integrated system .................... 128
      7.3.3 TO-BE Information Structure modelling for integrated system ................... 135

8. Prototyping: industrialised project delivery system for ModuPark ..................... 142
   8.1 Process to Product Modeling (xPPM) ................................................................. 143
      8.1.1 Purpose, Viewpoint and Scope of xPPM and Syntax .................................... 143
      8.1.2 Integrated system for ModuPark illustrated by xPPM modeling .................. 146
      8.1.3 Some prototypes in the integrated system ................................................ 151
   8.2 Validation of the proposed integrated system ................................................ 165
      8.2.1 From A to Z in the approach of the questionnaires-type ......................... 166
      8.2.2 From A to Z in the approach of the catalogues-type ............................... 178
   8.3 Further discussion .................................................................................................. 185
Towards an Industrialised Project Delivery System for the BC Industry

8.3.1 Possibilities & limitations of the proposed integrated system................................. 185

8.3.2 Discussion to enhance and develop the proposed system................................. 188

9. Conclusion.................................................................................................................. 191

9.1 Scientific contributions............................................................................................ 193

9.2 Practical implications.............................................................................................. 195

9.3 Suggested further research..................................................................................... 196

9.4 Closing remark....................................................................................................... 200

List of Reference........................................................................................................... 202

Appendix....................................................................................................................... 209

Appendix A. Terminology............................................................................................. 210

Appendix B. Summary of data collections..................................................................... 214

Appendix C. SWOT analysis of 4 previous industrialised approaches......................... 230

Appendix D. Detailed IDEF0 Report ........................................................................... 234

Appendix E. MSc committee’s evaluations.................................................................... 262
Table 1. Toffler’s table of civilisation................................................................. 48

Table 2. Accumulation of all information generated from the construction projects: Without BIM vs. With BIM (Sources: J.H. Park, 2009 & Facilities Information Council National BIM Standard, 2007)............... 70

Table 3. The main BIM-oriented or –related software applications .......... 74

Table 4. Strategic/ Structural/ Operational level in this research.............. 82

Table 5. Interviews list at Ballast Nedam ....................................................... 102

Table 6. In-house documents list that this research importantly used...... 103

Table 7. The basic syntax of xPPM (Source: GTPPM User manual)........ 145

Table 8. List of the standard components derived from the existing Revit of ModuPark .................................................................................................................. 152

Table 9. A represented example-01: Matrix Object for relation-reference between RBS and SBS.......................................................... 154

Table 10. A represented example-02: Matrix Object for relation-reference between RBS and RBS.......................................................... 155

Table 11. A represented example-03: Matrix Object for relation-reference between SBS and SBS.......................................................... 156

Table 12. A represented example-04: Matrix Reference Object.............. 157

Table 13. A represented example-05: Computing Parameters Object...... 159

Table 14. A represented example-06: Excel-based Revit-Family Coordinator .......................................................................................................................... 160

Table 15 Two strategies: The Representation Prototyping using Revit..... 162

Table 16. An example of the parametric design for ModuPark - 01........ 169
Table 17. An example of the parametric design for ModuPark - 02........171

Table 18. Input data in the Excel Based Model Generator of Revit Structure 2010..........................................................................................................................175

Table 19. Some examples of the Catalogue-type interface derived from Revit System...........................................................................................................182

Table 20. Practical limitation of Excel Based Model Generator in the Revit system..............................................................................................................187

Table 21. Red Ocean and Blue Ocean (Sources: www.blueoceanstrategy.com).................................................................................................................200
Towards an Industrialised Project Delivery System for the BC Industry

LIST OF FIGURES

Figure 1. NIST productiveness ................................................................. 22
Figure 2. 3D vs. 3D .................................................................................. 24
Figure 3. Habitat for humanity in South Korea (2007) .......................... 25
Figure 4. Halsuk tasks in a construction site of South Korea .................. 26
Figure 5. MSc thesis structure ................................................................. 30
Figure 6. FutureHome project (Source: http://fire.nist.gov/bfripubs/build02/PDF/b02156.pdf) .......................... 35
Figure 7. ManuBuild vision (www.manubuild.org) ................................. 37
Figure 8. BoKlok website (www.boklok.com/UK) .................................. 40
Figure 9. Concept of Corus Living Solutions (Picture source: Corus Living Solution brochure available at www.corusgroup.com ) .................. 41
Figure 10. Demand and supply systems in the BC industry are presented. Within these systems, the facilities built are delivered by involving several actors and contributing a lot of disciplines (Vrijhoef, R. & De Ridder, H.A.J., 2007b) ................................................................. 51
Figure 11. From demand-driven (Top-down) project delivery to supply-driven (Bottom-up) project delivery .................................................. 53
Figure 12. Bottom-up approach can stimulate to reuse the existing information and accumulate their knowledge to improve the industrialised system in the BC industry .................................................. 54
Figure 13. Parametric approach is vital to realise a industrialised system and enhance the productivity in the BC industry. In parametric concept, most of information could be automatically generated by filling in the pre-defined parameters ................................................................. 56
Towards an Industrialised Project Delivery System for the BC Industry

Figure 14. The essential mechanism of dynamic control (picture source: de Ridder & Vrijhoef 2003)................................................................. 57

Figure 15. Dynamic approach can improve the above-mentioned bottom-up and parametric system........................................................... 58

Figure 16. Growth in BIM use on projects (Source: BIM Market Survey 2008).......................................................................................... 60

Figure 17. Islands of automation (Hannus, 1998)........................................ 61

Figure 18. CAD and BIM........................................................................... 62

Figure 19. Building information model in the whole life-cycle of construction project. (Source: Facilities Information Council National BIM Standard, 2007).................................................................................. 64

Figure 20. Fragmented situation in construction supply chain .................. 67

Figure 21. The role of the demand and supply system integrator (Source: Vrijhoef & De Ridder, 2007)............................................................ 68

Figure 22. Systems Engineering V-model (RWS, 2010).............................. 72

Figure 23. Requirements Verification Document in Ballast Nedam using MS Excel...................................................................................... 75

Figure 24. Relatics software for systems engineering in Ballast Nedam (Picture source: www.pkmsolutions.com)........................................... 75

Figure 25. Another fragmentation of the applications in practice .............. 76

Figure 26. Research reformulation............................................................ 79

Figure 27. Reformulated research goal....................................................... 80

Figure 28. Research design........................................................................ 81

Figure 29. Business Process Reengineering............................................... 90

Figure 30. An example for ModuPark: Object-oriented systems engineering ................................................................................................. 92

Figure 31. The main benefit of ‘Process to Product modelling’ (Source: Ghang Lee, 2004)................................................................. 94

Figure 32. ModuPark website (www.modupark.nl)...................................... 98
Figure 33. ModuPark projects

Figure 34. Basic diagram syntax of IDEF0 process modelling

Figure 35. Textual Node Tree to show the overview of the AS-IS IDEF0 process modelling

Figure 36. Top-level of IDEF0 process modelling for AS-IS ModuPark

Figure 37. A0 level of IDEF0 process modelling for AS-IS ModuPark

Figure 38. A1 level of IDEF0 process modelling for AS-IS ModuPark

Figure 39. A2 level of IDEF0 process modelling for AS-IS ModuPark

Figure 40. Standard structural unit within building code

Figure 41. NEN 2443

Figure 42. A3 level of IDEF0 process modelling for AS-IS ModuPark

Figure 43. Textual Node Tree to show the overview of the AS-IS IDEF0 process modelling

Figure 44. Top-level of IDEF0 process modelling for TO-BE ModuPark

Figure 45. A0 level of IDEF0 process modelling for TO-BE ModuPark

Figure 46. A1 level of IDEF0 process modelling for TO-BE ModuPark

Figure 47. A2 level of IDEF0 process modelling for TO-BE ModuPark

Figure 48. A3 level of IDEF0 process modelling for TO-BE ModuPark

Figure 49. A4 level of IDEF0 process modelling for TO-BE ModuPark

Figure 50. Functional needs, Performance Requirement and Solution Concept (Source: Dik Spekkink, 2005)

Figure 51. SBS for a normal parking garage project in Ballast Nedam

Figure 52. Requirements Model and Design Model (Arto Kiviniemi)

Figure 53. Simply abstracted AS-IS UML: Requirement Model and Design Model in Ballast Nedam general

Figure 54. Simply abstracted AS-IS UML: Information Structure of ModuPark business system
Towards an Industrialised Project Delivery System for the BC Industry

Figure 55. Simply abstracted TO-BE UML: Information structure modelling - 01................................................................................................................. 135

Figure 56. Simply abstracted TO-BE UML: Information structure modelling - 02................................................................................................................. 136

Figure 57. Simply abstracted TO-BE UML: Information structure modelling - 03................................................................................................................. 137

Figure 58. Prototyping system using Excel-based Revit design.............. 138

Figure 59. Simply abstracted TO-BE UML: Information structure modelling - 04................................................................................................................. 139

Figure 60. The concept of Object Tree...................................................... 140

Figure 61. Scope of xPPM modelling......................................................... 144

Figure 62. High level of xPPM modelling for the integrated system of ModuPark...................................................................................................... 146

Figure 63. Detailed level of xPPM modelling for the integrated system of ModuPark - 01................................................................................................................. 147

Figure 64. Detailed level of xPPM modelling for the integrated system of ModuPark - 02................................................................................................................. 148

Figure 65. Detailed level of xPPM modelling for the integrated system of ModuPark - 03................................................................................................................. 149

Figure 66. Grasshopper for the parametric design(Picture source: The grasshopper Primer, second edition)................................................................. 158

Figure 67. a example of questionnaire-type representation prototyping. 163

Figure 68. a example of catalogue-type representation prototyping........ 164

Figure 69. From A to Z in the approach of the questionnaires-type........ 166

Figure 70. Step 3 of the questionnaire-type approach in the proposed integrated system...................................................................................................... 168

Figure 71. System information generated by outcomes of the parametric design system...................................................................................................... 172

Figure 72. Excel Based Model Generation in the Revit Structure.......... 173

Figure 73. Grid Generation in the Revit Structure..................................... 174
Figure 74. An example of the user interface for the generated representation

Figure 75. Extendable system architectures

Figure 76. from A to Z in the approach of the catalogues-type

Figure 77. Two ways of extracting SBS information

Figure 78. A standard structural unit

Figure 79. An example of the user interface for the catalogues-type

Figure 80. Uncovered requirements/ Requirements to be met/ Residual capacity for specification
### LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
<th>References or definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td>Building and Construction Industry</td>
<td>See appendix A.</td>
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<tr>
<td>BIM</td>
<td>Building Information Modelling or Building Information Models</td>
<td>See appendix A.</td>
</tr>
<tr>
<td>SE</td>
<td>Systems Engineering</td>
<td>See appendix A.</td>
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<tr>
<td>Revit</td>
<td>Autodesk Revit Software (In this research, it is mainly Revit Structure 2010)</td>
<td><a href="http://usa.autodesk.com/">http://usa.autodesk.com/</a></td>
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<tr>
<td>UML</td>
<td>Unified Modelling Language</td>
<td><a href="http://www.uml.org/">http://www.uml.org/</a></td>
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<td>BOT</td>
<td>Build, Operate and Transfer</td>
<td>See appendix A.</td>
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<tr>
<td>DB</td>
<td>Design and Build</td>
<td>See appendix A.</td>
</tr>
<tr>
<td>FBS</td>
<td>Functional Breakdown Structure</td>
<td>See appendix A.</td>
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<td>GTPPM</td>
<td>Georgia Tech Process to Product modelling</td>
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<td>Industry Foundation Classes</td>
<td><a href="http://www.buildingsmart.com/">http://www.buildingsmart.com/</a></td>
</tr>
</tbody>
</table>
Towards an Industrialised Project Delivery System for the BC Industry

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>xBS</td>
<td>eXtensible Breakdown Structure</td>
<td>See appendix A.</td>
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<td>OBS</td>
<td>Organisation Breakdown Structure</td>
<td>See appendix A.</td>
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<td>WBS</td>
<td>Work Breakdown Structure</td>
<td>See appendix A.</td>
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<td>CBS</td>
<td>Cost Breakdown Structure</td>
<td>See appendix A.</td>
</tr>
<tr>
<td>SBS</td>
<td>System Breakdown Structure</td>
<td>See appendix A.</td>
</tr>
<tr>
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<td>Computer Aided Design</td>
<td>See appendix A.</td>
</tr>
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<td>Information System</td>
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<td>Object Oriented Systems Engineering</td>
<td>See appendix A.</td>
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<tr>
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<td>Information technology</td>
<td>See appendix A.</td>
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<td>KM</td>
<td>Knowledge Management</td>
<td>See appendix A.</td>
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<tr>
<td>RBS</td>
<td>Requirement Breakdown Structure</td>
<td>See appendix A.</td>
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</table>
1. INTRODUCTION

The aim of this chapter is to introduce this MSc thesis, starting a short description of general (but fundamental) problems that the current BC industry is confronting. In spite of a great importance of taking a big portion of GDP as well as having significantly influence on other industries, it looks as if the BC industry was flurried with being caught in their own snare. Maybe it would be just my personal impression but I have at least two working experiences motivating this impression. And the motivating experiences in the chapter 1.2 will be briefly mentioned in order to explain a starting point of this research with initial research questions in the chapter 1.3. Lastly, the chapter 1.4 gives an overview of the content of all chapters in this MSc thesis report with some reading aids.
1.1 GENERAL PROBLEM DESCRIPTION

“The current BC paradigm is that we construct with yesterday’s viewpoints, using today’s techniques for the people of tomorrow.”

- In a literature, Hennes de Ridder and Reza Beheshti, TU Delft, The Netherlands

The building and construction (BC) industry plays a very important role in their economy and their life quality, having a 10% contribution in the GDP as well as providing housing and infrastructure for the better life quality of their society. According to a survey done by Ligtenberg, J. (2006), the Dutch construction sector produces 35% of the total waste and consumes almost 35% of the total energy consisting of 10% for production and 25% for transportation. Therefore, in general, the better delivery of the built facility is of importance to our society. (de Ridder, H & Vrijhoef, R., 2007) But, the current BC industry is facing a lot of problems. i.e. technical and social complexity, competitive market conditions, demanding specifications, sustainability and so on.
Many researchers have already pointed out that the fundamental problems are derived from the unique characteristics of being fragmented and traditional in the BC industry. A lot of effort and trials have been made to find a better way of dealing with the difficult situation in the BC industry. (Dado, E., 2002) A variety of the integrated approaches has been applied to solve the fragmentation in the BC industry. For instance, a lot of the integrated delivery methods such as Design-Build (DB), Design-Build-Operate-Maintain (DBOM), Build-Operate-Transfer (BOT), etc have already and extensively been using as a alternative or innovative solution all over the world. (Pakkala, P. 2002) But, based on a NIST report tackling with the productiveness of the BC industry, the practical improvement by using the integrated delivery methods is still a big question mark or to be.

Also great many research and development activities have been carried out in order to come up with solutions for increasing expectations from and needs of the BC industry. ICT (Information and Communication Technology) is regarded as one of the technologies offering key solutions within the construction business activity. Researchers, software developers, and construction practitioners have applied ICT-based solutions in order to automate different parts of the construction process in variety of ways. But unfortunately a lot of innovative approaches and ICT-based solutions in the BC industry have failed or fell short of delivering their expected outcome because the construction industry has a different nature when compared with the other industries (Ozsariyildiz 1998, Dado 2002, Kim 2009, Park et al 2010).
Cartoon illustrating the negative image of working in the building industry in Japan: “If you don’t do your best, you will end up like those people” (Naotoshi Tuchida)

With active advent of BIM, three dimensional models have been applying a lot. This image is from Ballast Nedam, The Netherlands.

Figure 2. 3D vs. 3D

Although BC industry was regarded as technology-oriented industry once a long time ago, the present image (or actual state) of BC industry the BC industry want themselves to be called as 3-D(Dimensions)-oriented industry pretending the But what about BC industry in the real world? That story has no sense of reality. Not at all. Maybe we must say the BC industry has to use the same abbreviation with totally different meaning that 3D abbreviates three terms of ‘Difficult, Dirty, and Dangerous’ in the BC industry. What’s going on? Is there on earth any vision for the BC industry which I have studied, I am working for and I still want to be involved in?
1.2 MOTIVATING EXPERIENCES

Figure 3. Habitat for humanity in South Korea (2007)

Generally speaking, each individual tasks of building a house just with structural components such as walls and slabs is not that complex. Almost all of them are undemanding activities such as tailoring the material, cutting as tailored, electing them, anchoring them and so on. Actually, a long time ago we usually built our own house by ourselves and it is still possible as DIY (Do It Yourself) concepts are getting popular. When I was an undergraduate student in the South Korea, I several times participated in Habitat (www.habitat.org) as a crew-leader who have a responsibility on managing certain construction area with 10~20 normal volunteers. While the process of building a house looks very complex, each task is very simplified and iterative in the construction site of Habitat since the concept of Habitat as a non-profitable project is constructed not by specialists and experts but by the normal people without any knowledge on it. Otherwise, a lot of errors and re-works would be happened. Furthermore, it is impossible that a few crew-leaders and project leaders can manage the construction site of Habitat physically built by non-expert volunteer. Moreover, during the interview with specialists in this research, one of the very fundamental findings is that they pointed out that there are no technical problems in practice. Any technical challenges never become a problem. A real problem is shown up in the complex processes of these simple tasks. So, building a
house looks complex but individual tasks are not complex at all. Actually, other types of construction projects are same as well.

Figure 4. Halsuk tasks in a construction site of South Korea

I got another motivating experience when I worked for Lotte construction firm in South Korea. At that time, my main task is to manage the construction site, especially two 15-floors buildings with 45 residential units and one shopping complex. Have you heard about Halsuk(할석, 割石, trimmed stone)? The Halsuk tasks are commonly used to tailor the structural concrete parts for finishing or other crashed works and to remove the certain parts of the concrete structure due to change order. It is very commonly-used as well as often-happened on site without any deep consideration. But, think of it. These kinds of works lose a lot of values in the construction projects. They should and could be reduced. Furthermore, the Halsuk tasks in the construction site present the remarkably disadvantageous characteristics of the current construction projects. Once it is built, it is too difficult to tailor, to decompose and to re-use it. The more important thing is that all built facilities such as these residential buildings have their own life-cycle. In other words, they will be anyhow demolished in 20 years or 30 years, even though the life-cycle of each component in the built facilities is much longer. The more interesting experience was about joints between the industrialised components and non-industrialised
components. Since the residential buildings consist of two types of same units, many components such as windows and doors etc are mass-customised in the design and manufactured in the factory reducing the production cost. Partial industrialised components are usually required to re-tailor the structural concrete parts or to re-do some additional works in order to install it on the right position.

To sum up, the BC industry has a lot of possibilities and strengths for the industrialisation such as simply iterative tasks and the use of standard components. The fact that more industrialisation enables BC industry to be more productive and to provide the better life-cycle of the built facilities speaks for itself. Also, it is unfortunately obvious that the BC industry is not that industrialised, comparing to the other industry. Why on earth didn’t the BC industry make these simple and iterative tasks with standard components more industrialised? What is a main problem for the industrialisation in the BC industry?
1.3 POINT OF DEPARTURE

As I get down to this MSc thesis based on the above-mentioned personal experiences, how we can realise the better industrialisation in the BC industry is initially questioned some initial research questions. This broadly-jumped research question is formulated to the following sub-questions:

- What efforts for the industrialised BC industry were made? What are possibilities and limitation of the previous efforts?
- In spite of previous efforts, is the industrialised approach in the BC industry still really necessary to be revisited? And why?
- What is important to improve the industrialisation in the BC industry? And what is required to do so?
- Which technologies have to be actively imposed on the requirements for the better industrialised approach in the BC industry?
- What is the most important to appropriately and completely use these enabling technologies in practice?

A goal of the first sub-question is to understand the current situation of the industrialisation in the BC industry and explore some limitations and possibilities in order to come up with the better industrialised approach. Also, a reason why the industrialisation is not that successful so far in spite of a lot of efforts and why it is still very critical for the increasing the productiveness of the BC industry will be discussed with the second sub-question. And the third sub-question will be answered by theoretically suggesting some requirements for the better industrialisation. Moreover, it is necessary to explore what technologies in practice could support it. And finally, this theoretical research will be done with answering a question on What is the most important to appropriately and completely use these enabling technologies in practice. Next chapter will describe the entire structure of this MSC thesis report.
1.4 MSC THESIS STRUCTURE

This final MSc thesis consists of introduction, theoretical research, reformulation of research questions, practical prototyping part and conclusion with 9 Chapters and Appendix. In the introduction part, some commonly-faced and fundamental problems in the BC industry were generally described and motivating experiences related the problems were shortly introduced in the above sub-chapters. Then, chapter 1.3 mentioned the initial research questions as a starting point of this research. Now the rest of chapters are been introducing in this chapter. The theoretical part will mainly be discussed in chapter 2, 3, 4 and 6. Based on the theoretical findings and conclusions, chapter 5 will reformulate the initial research question. The practical part with some modelling and prototyping will be found in the chapter 7 and 8. In conclusion part, the scientific contribution, practical implication and suggested further research topics will be summarised with closing remarks.

Chapter 2 will investigate some previous efforts on the industrialisation in the BC industry which is asked in chapter 1.3 as one of initial research questions. Two categories are separated as research-driven and business-driven approach to the industrialisation. It is very important not only because some possibilities and limitation of the current industrialisation in the BC industry are presented based on the previous efforts but also because a new approach of the industrialised project delivery system in the chapter 3 is come up with based on the analysis.

Chapter 3 will theoretically look through some question marks on why this industrialisation in the BC industry is still important, what is the main barrier to realise it and how we can overcome the current pitfalls. By answering some initial research questions in the chapter 1.3, the importance of industrialisation and its system thinking will be revisited. Then, three main characteristics for the better industrialisation will be proposed as a new project delivery system.
Figure 5. MSc thesis structure

Chapter 4 will discuss the enabling technologies to support the previously-proposed industrialisation. Two technologies are BIM and SE. Briefly, how they can positively influence on the proposed project delivery system is theoretically investigated. And, based on the interview and observation in the Ballast Nedam, SE and BIM are
fragmentally applied in practice while they are theoretically interrelated and overlapped each other. The integration issue between SE and BIM will be presented with significantly importance and necessity in practice.

In this regards, chapter 5 will finally reformulate the broadly-asked initial research question to the very practical and specified one. With this reformulation, the research methods, techniques etc which will be applied in the following chapters will be introduced with the short description and reasoning.

Main goal of chapter 6 is to set up the integration framework for solving the reformulated research questions. So, the approach of framework is the model-driven integration. In the chapter 6.2, the framework will be applied to integration issue of SE and BIM. Chapter 6.3 will present each solution for each fragmented area in the integration framework.

In chapter 7, the conceptual modelling will be presented within the previously-set framework. First, design-related information generating, processing and tracking in the ModuPark project delivery will be analysed based on the interviews and the process fitting the proposed industrialised delivery system will be reengineered by actively integrating xBS technologies and visualised objects of Revit design models in more parametric manner. Secondly, the structure of the design-related information such as requirements and components in the proposed integrated system will be modelled by means of simplified UML class diagram.

As one of the very practical and critical parts in this research, chapter 8 will present some models of how to link the fragmented structure and process of information in the SE-BIM integrated system to support the theoretically-proposed industrialised project delivery system. Based on these all conceptual modelling which are IDEF0, UML and xPPM, some prototypes of some important parts will be presented representing how they looks like in practice. Furthermore, in this chapter, some arguments for further development and practical implementation of the proposed system will be taken a place presenting its limitations and possibilities in practice and recommending a roadmap for it.

Finally, chapter 9 is a conclusion part of this report. All scientific findings will be summarised with its practical implications. Since this research will be limited in it scope as other researches do, several further research topics will be come up in the process of evolving its arguments. So, they will be listed up in the chapter 9.3. Chapter 9.4 is a counterpart of the chapter 1.1 and 1.2 in the introduction. Some broadly-asked questions will be exclusively answered as a general conclusion of this research.
Chapter 2 analyses the previous efforts that were made for industrialised BC industry. The industrialised trends analyses in the BC industry are divided into research-driven and business-driven efforts. Two interesting European research projects and business models are investigated. Main goal of chapter 2 is to look into the existing problems of the current industrialisation in the BC industry and to come up with the general requirements of possible solutions. Main goal of this chapter is not to deeply and practically do case studies on these previous efforts on the current industrialisation in the BC industry but to theoretically inspire the better industrialisation. (Note: The findings in the chapter are based on the survey of their officially website, their booklets, and some associated literatures in the journals. As outcomes of the following analyses, SWOT analyses of each project will be found in the appendix.)
Towards an Industrialised Project Delivery System for the BC Industry

2.1 RESEARCH-DRIVEN EFFORTS FOR INDUSTRIALISED BC INDUSTRY

Many researches on the industrialisation have been conducted. It is impossible to look into all research projects related to these industrialised concepts. But, it is necessary to inspire the better idea from the previously-done researches. In this regard, two European research-driven projects for the industrialisation will be briefly explored, focusing on finding out their goals, contributions, limitations and possibilities.

2.1.1 FUTUREHOME PROJECT

The FutureHome projects is a part of the Intelligent Manufacturing Systems (IMS) global program which is an industry-led and international R&D program to develop the next generation of manufacturing and processing technologies in the BC industry. The program was initially established in 1995 since it is recognised that most of technology-oriented innovations are required to take too much initial investment cost and the cooperative development to share costs, risks and even expertise would be more feasible. The FutureHome project which was stated in 1998 and had conducted for around 5 years is a European R&D project bringing together fifteen partners from six European countries and receiving major funding from the European Commission. (Neemlankavil 2009, Robert Wing et al 2002, Carlos Balaguer et al 2002 1 2 3)

Main purpose of this FutureHome project is to develop the automated building construction process with enabling technologies and their integration, focusing on the housing construction, rather than other infrastructure project and touching all related issues from the design phase to the construction site. The motivation of the FutureHome project is that the application of the advanced manufacturing, production, assembling technologies leads to major reduction of cost and time for the housing construction projects. This includes: a) the modular design of buildings with planned robotic erection, b) automatics planning and real-time planning of

1 Neelamkavil, J, 2009, “Automation in the prefab and modular construction industry”
2 Robert Wing and Brian Atkin, 2002, “FutureHome – A prototype for factory housing”
Towards an Industrialised Project Delivery System for the BC Industry

offsite prefabrication, transportation, and onsite assembly and c) onsite automated transportation, manipulation, and assembly of the prefabricated parts. (Robert Wing et al 2002, Carlos Balaguer et al 2002)

As I already shortly said in the earlier, many researches and pilot-projects was conducted in the past since the industrialisation has a lot of valuable potentials in the BC industry. So this kind of a modular housing design and construction is not new. But, some disadvantages or limitations of the previous efforts for the industrialisation were discussed in the beginning of FutureHome project and they mentioned at least three main limitations to be solved in their FutureHome project. The first limitation they presented is a problem on the quality of the modular houses previously-built. And the limited flexibility of the design and construction for the industrialised products is also one of the biggest issues they want to solve. Furthermore, the FutureHome project was interested in the automation of the onsite assembly of the prefabricated modules or industrialised components. (F. van Gassel 1996, Carlos Balaguer et al 2002)

In particular, the FutureHome proposed the innovative system that derives from a Kit-of-Parts approach, which is a collection of discrete building components that are pre-engineered and designed to be assembled in a variety of ways to define a finished building. Kit-of-parts approach throws open the door to several industrialised building system such as prefabrication including joint-based (linear element), panel-based (planar element), module-based (solid element), and deployable (time element) construction systems. (Robert Wing and Brian Atkin 2002, HOWE A. S., ISHII I., YOSHIDA T., 1999)

One of the interesting abilities of their outcomes is to be automatically assembled. developments in the FutureHome project is an assembly connector for the assembly of the modules, the structural connection, and electrical and service pipes connections. This outcome was the starting point of AUTMOD3 software which is an automatic modular construction software environment. According to Diez R. et al

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4 Robert Wing and Brian Atkin, 2002, “FutureHome – A prototype for factory housing”


6 Robert Wing and Brian Atkin, 2002, “FutureHome – A prototype for factory housing”


8 http://en.wikipedia.org/wiki/Kit-of-parts
Towards an Industrialised Project Delivery System for the BC Industry

(2007\textsuperscript{9}), this system integrates architectural design, planning and simulation tools in a commercial CAD program.

And the modular concepts of FutureHome project had been discussed covering off-site (factory), transportation and on-site. In other words, it contains three phases as followings. (Carlos Balaguer et al, 2002\textsuperscript{10})

- Offsite factory planning for the prefabrication of the modules
- Transportation planning
- Onsite building construction planning, including the modules assembly.

![Figure 6. FutureHome project (Source: http://fire.nist.gov/bfrlpubs/build02/PDF/b02156.pdf)](http://fire.nist.gov/bfrlpubs/build02/PDF/b02156.pdf)

The FutureHome research projects opened several possibilities on the industrialised housing projects. First, the existing and emerging ICT application were actively applied and the integrated system with them was in depth discussed. Moreover, its efforts led to the tangible achievements with several prototypes in both process and product modelling. Finally, the FutureHome project tried to take into consideration on almost all supply chain process of the industrialised housing product from factory throughout transportation to assembly on site.

\textsuperscript{9} Diez, R., Padron, V.M., Abderrahim, M, Balaguer, C, 2007, "AUTMOD 3: The integration of design and planning tools for automatic modular construction"

\textsuperscript{10} Carlos Balaguer et al, 2002, "FutureHome: An integrated construction automation approach"
But, in spite of the above-mentioned strengths, there also are some limitations to fall short of the initial expectation of market players. They did not that much take into account on market conditions and commercial business rules in the current BC industry. In this regards, the full-integrated structure and process for a certain business model were not piloted and developed in spite of well-prepared and specific-enough prototypes presented in their research.
2.1.2 MANUBUILD

ManuBuild was an integrated research project involving 24 partners from 10 countries across Europe. Commencing in 2005, it was completed in 2009 and was funded by the European commission. According to the newsletter of the ManuBuild, their vision and goal was presented as the followings\textsuperscript{11};

“...ManuBuild targets a radical paradigm shift from the current craft and resource based construction towards an Open Building Manufacturing System that enables highly customized buildings using manufactured, knowledge based components from the open market and assembling them efficiently on site. This industry driven goal comprises a fundamentally reengineering of the whole construction lifecycle process for buildings and the integration with ambient production methods. The results will consist of open, scalable, cost-efficient, customizable and high quality solutions. The “Open System” approach for building production of ManuBuild combines values driven, innovative, efficient and safe manufacturing and assembly in factories And construction sites, and an open system for products and components offering diversity of supply and building component configuration (on demand) opportunities in the open market...”

\textbf{Figure 7. ManuBuild vision (www.manubuild.org)}

\textsuperscript{11} \texttt{www.manubuild.net}
Towards an Industrialised Project Delivery System for the BC Industry

It is very positive in that the system thinking and holistic approach was established to lead the fully-integrated and industrialised BC industry. They sought to find the solutions of the new open system that enables BC market players to offer the highly customized and manufactured products in the BC industry reducing on-site craft works and assembling market-standard components efficiently on site. The proposed ManuBuild system is composed of the five key strategic research areas\(^12\):

- Building Concepts for efficient assembly of (pre)manufactured building
- Building Process for customer and community involvement in planning, design, configuration and customization
- Production technologies for efficient on-site and off-site manufacturing and assembly
- ICT to support the above-mentioned solutions in the Build Open Building Manufacturing System
- Training to prepare the employees for the ManuBuild Open Building Manufacturing System

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\(^{12}\) *Open Building Manufacturing Book 1, 2007*
2.2 BUSINESS-DRIVEN EFFORTS FOR INDUSTRIALISED BC INDUSTRY

In the BC market, you can find a lot of industrialised-business firms ranged from the simple prefabricators to the total solution providers. This sub-chapter explores two interesting business-driven efforts for industrialised BC industry which are BoKlok and Corus Living Solution. Both have the very unique position in their own business area as well as their own pros and cons in their own system.

2.2.1 BOKLOK

BoKlok concept and brand was initiated in the mid-1990s. At a building exhibition in 1993 in Karlaskrona, Sweden, an IKEA team designed a compact living house to meet the requirements of common people such as affordable price, green area, and so on. This resulted in a two-storey wing house with 3 apartments that became a pilot project of the BoKlok home. In 2001, the project was analyzed for a feasibility study on a real business case. The collaboration of the two companies, IKEA (A world leading furniture manufacturer) and Skanska (A world leading construction firm) was intended to provide low-budget housing by sharing amply accumulated knowledge from their own business experiences. For this purpose, they established a new joint venture (private and limited company), BoKlok, by owning fifty percent of shares each. Most of factories for the production are run by themselves in Sweden and some parts of buildings are outsourced on collaboration with Moelven (Modules Building). Their business area has been extended to Norway (2002), Finland and Denmark (2003), and to the UK (2006).
One of the most valuable strengths of this venture that the business model of BoKlok is based on a lot of tactical knowledge from the IKEA concept on systematic component production and a lot of experience from Skanska on constructability and construction project delivery. This is a win-win strategy for both companies by opening new markets. Still, uncertainty and weakness of their collaboration relation is one of the internal weaknesses. Furthermore, too specific target group, particular at cheap housing, would lead to limit on extending their business to other types of industrialised construction projects. Also the limited flexibility in their solutions should be improved in the near future.

Figure 8. BoKlok website (www.boklok.com/UK)
2.2.2 CORUS LIVING SOLUTION

Corus Living Solutions established in 2003 provide fully fitted steel-framed modules, which are designed and manufactured at its Shotton Works in North Wales and delivered to the construction site as ready for assembly building blocks. The vision of Corus Living Solutions derives from their belief that an off-site manufacturing system like Corus Living Solutions can offer our society cheaper, faster and better houses, resulting in fewer faults, and reduced waste and less transportation cost. A strategic intent of Corus Living Solutions is to become the lowest cost manufacturer of modular buildings. The feasibility and sustainability of their business model have been proven successful when they already achieved 5000th modules of sales in the beginning of 2009 without any lost time injury. Their main target facilities are the accommodation facilities such as Defence Estates, Hotel chains, Halls of residence and hostels and Key worker and specialist accommodation, meeting the immediate and anticipated demand for high quality, functional and innovative accommodation (Storgaard 2009).

![Corus Living Solutions Concept](www.corusgroup.com)

Corus Living Solutions run their business with a ‘No faults forward’ philosophy, which leads to a right-first-time operation. This idea is enabled by having the right skills in...
the right areas within a robust quality assurance process. And they highly take into account of reducing risks and hazards associated with traditional onsite construction. For this purpose, a joint venture was formed between Corus group in metal production industry and two contractors in the construction industry (Mowlem and KBR). This business case shows a well-planned forward integration strategy based on material (Metal) background. They have already received enough orders from specific construction companies to stimulate a sustainable development. Annual production capacity is reached up to 3000 units including MOD living quarters and student halls, etc. Furthermore, comparing to other industrial housing businesses, Corus are also preparing the different types of construction project such as Modular Rail Platforms system and BI-Steel. But, a limitation of design flexibility is addressed; particularly container-box unit design limits their possible market.
2.3 POSSIBILITIES AND LIMITATIONS OF PREVIOUS EFFORTS FOR INDUSTRIALISATION IN THE BC INDUSTRY

Some common possibilities were discovered in the analyses of some presently typical industrialised approaches covering both the business and academic area. First of all, The IT technologies in the BC industry have been advanced throughout trials and errors and its application is not new anymore to the practitioners. Taking into account on the important of the IT technology as an enabler to full achieves the industrialisation in the BC industry, this is one of the positive signals for the further industrialisation. Especially, some business models such as BoKlok and Corus Living Solution to deliver the modular or industrialised construction products were derived with the emerging IT technology. Furthermore, most of the practitioners as well as clients are familiar with IT-oriented tools as IT technologies such as internet and web-based system generally are getting common in their routine lives. Secondly, most of the industrialised and advanced design systems in the above cases are based on the concept of ‘Kit-of-parts’, specific component-based, or even material-based design. In other others, their starting point of the design development is specific components, objects, or materials. Moreover, the current BC industry has a lot of prefabricators who provide the solid solution of the standard components based on the factory-production. So, the ample base of the standard components and objects is very positive factor to transform their existing craft-based production system to full industrialised concept in the near future. Thirdly, the current BC industry already has a great base on the automated manufacturing and production since many innovative pilot projects and researches have been so far conducted. More importantly, the components markets of the prefabrication and off-site production in the BC industry are already available. Even if BoKlok and Corus Living Solution have the well-integrated in-house delivery system, the integrated business models from A to Z are still rare by one integrating companies or not at least mainstream, comparing to the other industries such as automobile industry. But, when it comes to prefabrications and standard components market in the current BC industry, there are more possibilities to improve the industrialisation. Fourthly, as some leading firms such as BoKlok using the industrialised concept recognised and pointed out, there are needs enough to develop the industrialised products in the construction market. In the current market condition that the clients are asking their products to be much cheaper, quickly-delivered and better-quality products, the industrialised products are a good solution without any doubt.
In this sub-chapter, some basic requirements for new project delivery system are presented based on analysis of four different industrialised approaches in the BC industry in above two sub-chapters.

First of all, most of industrialised approaches focus too much on modular housing projects. In perspective of a business actor, the housing projects are obviously one of the most feasible types to be industrialized since it is certain that there are demands for affordable and compact houses all over the world, particularly, it is more demanding by common people in case that overall economic figures are not that good and the housing construction market is shrunken like these days. But, housing project is one of the most complicated construction projects since a house built should be evaluated not only in the functional way but also non-functional factors. While the infrastructure projects such as high-speed railroads and transferring parking facilities focus more on the function-oriented requirements, the housing project should take into account more complicated requirements to meet such as aesthetic factors, property value etc. So, although a modular house looks like the very simple box, it is one of the most challenging BC projects since it would never success in the market without solving these complexities. The other project type should be actively applied these industrialised concepts to make sure of sustainability and competiveness of their industrialised businesses in the BC market. Therefore, it should be reminded that the other infrastructure projects such as highway roads, harbours, railways as well other building projects have more possibilities on industrialization.

Secondly, the project delivery system is still too client-oriented. At this moment (at least), we don’t have to focus on the active involvement of clients and customers. According to the book ‘The third wave’ by Toffler, the concept of ‘Prosumer’, which is a portmanteau formed by contracting either the word professional or producer with the word consumer (PROducer+conSUMER)\textsuperscript{14}, shows up after fully-matured from industrialization age. But, as discussed earlier in chapter 4.1, the current BC industry didn’t realize highly matured level of industrialization as a basis of the success in Information Age. In other words, the fundamental basis such as standardization of processes or materials is not that robust. So, it would be more efficient to discuss more the client-involvement after the proper and matured industrialized system is embodied. At least, for the contractor willing to transform their existing craft-based production system to full industrialized concept as soon as possible, the focus is not on client-oriented, but on producer-oriented industrialized system. Suppose the car industry. Nowadays, some innovative companies are trying to introduce the new

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\item[\textsuperscript{13}] Boklok website: available at \url{www.boklok.com/uk}
\item[\textsuperscript{14}] \url{http://en.wikipedia.org/wiki/Prosumer}
\end{footnotes}
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client-oriented individual design system over the industrialization, so-called mass customization.

Thirdly, the current project delivery system is needed to be fully transformed by reflecting on dynamics of market principles. In most of cases, they were introduced industrialized concept to only certain part of the traditional project delivery system. Even, some projects are initiated throughout bidding competitions of the lowest pricing. In these current conditions with bottlenecks in the BC industry, the synergy from the industrialization cannot be anticipated. It would make the current BC industry more complicated by more and more increasing burdens from the industrialized concept. Therefore, it is time to think of the new project delivery system to maximize the efficiency of the industrialization in the BC industry considering authority, policy, and regulations.

Fourthly, more holistic and various parametric design based on a systems thinking is necessary to be more industrialized. A parametric characteristic of the advanced design system in the most of cases provides a powerful solution to create and edit geometry since model generation and design would be extremely cumbersome and error-prone. In the current parametric designs, their parameters are mainly based on predefined features including topology as well as geometry. Furthermore, even if most of BIM software applications provide the independent function to handle the property and attribute, it is rare to fully well-developed with their own concept of industrialization in the current object-based or component-based parametric industrialization in BC industry. Therefore, the current parametric design for industrialization concept in the BC industry should be develop various parameters to manage whole life cycle of their facilities built. One of the most vital parameters to be better industrialized is to predefined parameter in the holistic perspective for certain type of deliverables built as well as for certain detailed objects. For instance, a parametric design to reflect the requirements from clients and to track them throughout the whole life cycle is needed to shift the BC industry towards better industrialised system.

In this chapter 2, starting from analysing some typical efforts of the industrialisation in the BC industry, the possibilities and limitations were discussed. Based on these analyses and findings in this chapter, the better industrialisation will be discussed in the coming new chapter.

15 Chuck Eastman et al, (2008), BIM Handbook

16 Reza Beheshti, 2008, TU Delft CT4260 Class material
The previous chapter explores four industrialised projects to look into the previous efforts on it. By exploring the deliverables, outcomes and the associated literatures of these projects, possibilities and limitations of the previous approaches for industrialised BC industry were presented. Now the chapter 3.1 will explore why this research revisits the industrialisation in spite of a lot of efforts that has so far been made in the BC industry. And based on the Living Building Concept, the system-thinking for the industrialised BC industry will be introduced in the chapter 3.2. Chapter 3.3 will conclude by theoretically addressing three critical requirements that mainly were given great inspirations by Living Building Concept, that were proposed based on the related literatures and that are bottom-up, parametric and dynamic approaches.
3.1 REVISITED INDUSTRIALISED CONTEXT

An industrialisation is characterised by mass production, standardization, offsite production and machine-made production etc. In the BC industry, some has been more and less applied but others are still hardly applicable in practice. Particularly, while the components-based construction methods in the infrastructure projects and the modular production system in the housing projects are getting common, mass production system and standardisation are lagging behind the other industries. Although it is estimated in a research (Eichert, J. & Kazi, A.S.S. 2007) that 80% of the outdoor activities are moved into indoor factory environment reflecting the industrialised concept and Koskela, L. (2003) insisted that the goal of industrialisation is the reduction of on-site activities, the fact that their end-deliverables in the most of the normal projects are still manufactured or assembled on site by a lot of hand work with a relatively low degree of precision and with a high degree of building failures leaves absolutely no room for doubt. (Nederveen et al. 2009).

Why is the concept of industrialization so important for the BC industry? In order to answer this question, first of all, the current state-of-art and future of the BC industry should be explored and understood in the general context of the technically innovative progress of human society over time. In this respect, Toffler (1980) identified three chronological classifications of the civilization establishing three technical waves. According to his book “The Third wave”, the civilization can be divided into three major phases.
Towards an Industrialised Project Delivery System for the BC Industry

<table>
<thead>
<tr>
<th>Civilization</th>
<th>Production system</th>
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<tbody>
<tr>
<td>The first wave</td>
<td>Agricultural Age thousands of year</td>
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<tr>
<td></td>
<td>Decentralized and self-sufficiency production</td>
</tr>
<tr>
<td></td>
<td>No division between producer and consumer</td>
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<tr>
<td>The second wave</td>
<td>Industrial Age three hundred years</td>
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<td></td>
<td>Mass production based on the specialization</td>
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<td></td>
<td>Division between producer and consumer</td>
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<tr>
<td>The third wave</td>
<td>Information Age In progress</td>
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<td></td>
<td>Customized production system</td>
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<td></td>
<td>Integration between producer and consumer: so-called Prosumer</td>
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Table 1. Toffler’s table of civilisation

We live in the third wave world, the so-called ‘Information Age’, which has tangibly commenced at the end of 20th century with significantly increasing capacity and competency of the IT (Information Technology). The common use of computers and the internet for sharing and developing ideas and processing and transmitting this information not only in their own industries but also in daily lives has lead to reach in good condition to the information revolution anticipated by Toffler. Now most of industries are starting to enjoy benefits of successful application of Information Technology beyond the bottleneck of industrialization.

But, how is our BC industry faring? With the information technology, today’s consumer markets are changing faster and consumers are more demanding than ever (Piller et al. 2004). Clients currently demand technically and socially complicated requirements from all concerned producers in the BC industry such as the architects, contractors, and so on. Furthermore, it has been broadly accepted in the BC industry that they can maximize output and profit by integrating the existing individual participants in the BC project delivery, as opposed to the traditionally fragmented trend (Matthews et al. 2005, Evboumwan et al. 1998). More importantly, although some information technologies have had a considerable positive effect and proven a possibility on the new way of working in the BC industry, its influence and future is still incomplete and moreover sometimes invisible or nothing at all.

More fundamentally, why did the BC industry never make the quality jump by industrialising its own practice, like most of the other industries did? It is obvious that an industry did not change their traditional system with any urgency as business survival. This in turn raises the question why the BC industry has managed to survive so far without dramatic changes. Regarding this question, Cuperus (2007) interestingly and simply explains that “…there was never the need to change. Poor
as well as affluent societies tend to sustain housing shortage, in which the BC industry has to deliver in a supply market, a market with no alternatives for buyers...” Moreover, Warszawski (1999) pointed out the lack or absence of a sufficient industrialised base in the current BC industry. Actually, among several characteristics of industrialisation such as mass production, standardisation, offsite production and machine-made production, some has been more and less applied in many projects but others are still hardly applicable in practice. Particularly, even if off-site, machine-made production usually applies only to building components and materials, their end-deliverables are still manufactured or assembled on site by a lot of hand work with a relatively low degree of precision and with a high degree of building failures (Nederveen et al. 2009). Therefore, the BC industry looks like a more and less industrialised one, but it is still based on an invisible craftsmanship and unforeseen outsourcing-based industry, rather than a fully industrialised one with efficient and effective benefits.

In this regard, the current BC industry is just willing to enter the new Information Age without any complete basis of industrialization from the second wave described in the above table. In this case, it would be obviously getting more complicated and more challenging to introduce and apply upcoming innovative Information Technology (IT) to the BC industry. In the past the BC industry has postponed to be properly industrialised under a nice excuse that ‘the BC industry is different from any other industries’. Therefore, if we are really impatient to catch up with the progress of the other industries such as the splendid achievements of IT and hence anticipating benefits from the automation concept, the first and most critical task would be to create an industrialized base. That is, the convincing groundwork on the industrialization in the BC industry is imperative to solve the research problem. That is why an attention has to be paid on this topic again.
3.2 SYSTEM THINKING FOR INDUSTRIALISED PROJECT DELIVERY

Although understanding possibilities of an industrialised approach in the BC industry is amply common, system thinking throughout the life-cycle and whole industry is rare for it. This is the most critical barrier to be industrialised in comparisons with the other industries achieved the industrialisation. In this regard, this paper introduces systems thinking as an underlying methodology to rethink the current pitfalls in order to make the current BC industry to be more properly and fully integrated and industrialised.

3.2.1 LIVING BUILDING CONCEPT

LBC initiated by de Ridder, H. (2007) and a group of researchers at TU Delft in the Netherlands is an innovative and comprehensive concept to realise the better performance in the BC industry, adding more values achieved from a dynamic approach to the construction processes and considering the life cycle of the built deliverables. The concept is not the result of one specific research project but the outcomes from continuous efforts that has been developed and tackled with over years. So far, core ideas of LBC can be summarized as value orientation, industrialisation and life-cycle orientation. Value orientation and the dynamic character have been key themes for a number of years, while industrialisation and life-cycle orientation, including concepts such as cradle-to-cradle thinking and remanufacturing, are of more recent date.

According to van Nederveen et al (2009), it is an extendable concept as if it could be seen as a placeholder for a number of innovative concepts and principles such as value-oriented construction processes, parametric design and industrial building, and life-cycle orientation aiming at low waste and low impact construction. Moreover, this concept is established on the systems thinking taking into account on the better BC industry (at least its project delivery) as a designed and managed system. Therefore, based on the review of the relevant literature, it is concluded that LBC is one of the suitable underlying methodologies to set up the new industrialised project delivery system. In next two sub-chapters, their idea will be studied in more detailed, especially focusing on the industrialisation in the project delivery of the current BC industry.
3.2.2 PROJECT DELIVERY AS A SYSTEM

The BC industry is characterised by being a highly segmented industry, involved in one-of-a-kind products that is performed by so-called virtual enterprises (VE). (Beheshti, R. 2008) In general, the current construction projects deliver along the unique supply chains which are changed and reorganised every time. According to Hassan, M. (2006), supply chains of the current project delivery can be viewed as a system, which is defined as an integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective. Systems thinking or systems theory, which originally developed in physics and biology and has exclusively applied in organisational and management literature, views the world in terms of collections of resources and processes that exist to meet super-ordinate goals. Pointing out the importance of two aspects, synergy and entropy, it is claimed that systems thinking can be useful and helpful to analyse and design the project delivery system in a systematic manner, assuring its effective functioning. (New, S. & Westbrook, R., 2004) Based on the systems theory and thinking, Vrijhoef, R & de Ridder, H. (2005 & 2007) schematically illustrated their idea of the project delivery system for the BC industry in the perspective of supply chain integration as figure 10 seen in the following.

![Diagram of Demand and Supply Systems in the BC Industry](image)

*Figure 10. Demand and supply systems in the BC industry are presented. Within these systems, the facilities built are delivered by involving several actors and contributing a lot of disciplines (Vrijhoef, R. & De Ridder, H.A.J., 2007b)*
According to their inception of the project delivery system, it is divided into two systems, demand system mainly responsible for the development of their own context and supply system in charge of providing the solution. A facility built exists as static coupling point of two systems. As these system illustrated, the project delivery in the BC industry has been conducted in the very complex process, imperatively referring to the demography of the industry (many SMEs and specialist firms) and temporarily forming virtual enterprises every time in supply system. More desperately, this system is seen as a less structure project delivery in the BC industry. While the other industries have quite successfully achieved the industrialisation for last two decades, the BC industry with the much less structured delivery system is still struggling with the industrialisation in a vague black box system, spending the extra hard time with a vast network of participants from different disciplines. 

(Vrijhoef, R. & De Ridder, H.A.J., 2007b) To disentangle the BC industry from these critical problems binding for a long time, the industrialised approach is necessary like most of the other industries did. (Note: In this research, the term of the project delivery system will be mentioned quite a lot. The definition is in line with the following one by Kymmell, W (2008\textsuperscript{17}); A delivery system is a contractual method used to realize a construction project. The contracts describe the relationships among all the project team members and their legal and financial responsibilities to the project and to one another.)

\textsuperscript{17} Kymmell, W, 2008, “BIM planning and managing construction projects”
3.3 REQUIREMENTS ANALYSIS OF INDUSTRIALISED PROJECT DELIVERY SYSTEM

Based on some relevant literature review, especially introducing Living Building Concept in the above sub-chapter 3.2, the industrialised project delivery system is proposed by coming up with some critical requirements.

3.3.1 BOTTOM-UP APPROACH

![Diagram showing comparison between Current Project Delivery System and Bottom-up Project Delivery System]

**Figure 11. From demand-driven (Top-down) project delivery to supply-driven (Bottom-up) project delivery**

The current BC industry is quite the client-oriented. As the above figure 3 seen, a group of clients including users and stakeholders that we called demand system usually initiate projects in the BC industry market. The demand system that is responsible for the development of requirements in their own context is interested in...
value for money which means that they get value and spends money for it. But, unfortunately they don’t have enough knowledge and experience as if we are not knowledgeable on its engine system or certain components when buying a car. That means their requirements are highly dependent on the specification of supply system that a group of producers can offer to them. (de Ridder, H. & Vrijhoef, R. 2007, Park et al. 2010) In this regard, at least two important points of the industrialised project delivery system could be followed up by this bottom-up (suppler-driven) Approach:

1. The most critical distinction between the Top-down and Bottom-up project delivery system is whether value of existing information, knowledge, and experience from delivered components and products is maximized or not. Even if producers like contractors in the supply system have knowledge enough to come up with the better specification, they have to analyse every single objects to meet the client’s requirements step by step along the Top-down approach from ‘Zero-Input’. The current top-down approach in the BC industry limits to re-use them because it takes into account on every context and specification and even every single object. Therefore, a bottom-up approach provides a good solution to dramatically reduce

<table>
<thead>
<tr>
<th>Current Project Delivery System</th>
<th>Bottom-up Project Delivery System</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Re-usable Information at the beginning</td>
<td>Input from Re-usable Information</td>
</tr>
</tbody>
</table>

**Figure 12. Bottom-up approach can stimulate to reuse the existing information and accumulate their knowledge to improve the industrialised system in the BC industry**
Towards an Industrialised Project Delivery System for the BC Industry

effort, time, even money not by generate all information from nothing but by reusing them. In other words, the industrialised project delivery system would get a better and more concrete foundation by reusing and accumulating their information.

2. In contrast to the black-box systems of the current BC industry, which means to be temporarily formed and to depend on vague interrelationship between actors, the other consumer markets consist of consumers and producers along integrated supply chain and have the clear distinction of their roles and scopes. In this regards, producers develop their solutions and sell their final products proactively anticipating and meeting the wishes of consumers. In the current project delivery system, the clients in the BC industry are forced to be too much involved in spite of their lack competency and weak willingness, compared to the other consumer markets. Maybe, as IT technologies will be fully supported for the BC industry, the client involvement would be strengthened or should be taken into more account. At least for time being, as the above chapter 2.3 concluded, the first thing to do is to catch up with the achievements of other industries by focusing on the supply-driven industrialisation and to ensure a sufficient industrialised base as soon as possible to jump into the next step. Therefore, producers such as general contractors should be much more involved in industrialised project delivery system lifting some overloaded burden from the demand system.
3.3.2 PARAMETRIC APPROACH

Parametric approach is vital to realise an industrialised system and enhance the productivity in the BC industry. In parametric concept, most of information could be automatically generated by filling in the pre-defined parameters.

Parametric approach in the industrialised project delivery system is very vital to realise it as well as to maximize the benefits from it. Actually, parametric approach is a necessary and sufficient condition. In this paper, parametric approach tackles not only with predefined geometric information in 3D modelling technique but also a variety of inter-relations and correlations through perceived rules that could be defined or should be managed in an industrialised system. Based on the existing information on built facilities and accumulated knowledge from previous experiences, the providers should come up with the parameters to more properly and efficiently operate the industrialised project delivery system. Then, clients simply fill in their requirements using the parametric interface as the following example in the figure 6. In this parametric system, all relevant specifications and detailed orders are automatically generated. As parts, components, objects and even materials get more standardised, the parametric approach would be gaining momentum. Technologies spoken, parametric design or modelling technologies is already available. The only
thing to be prepared is the practical study and decision on what kind of parameters and why they will apply in their business. (Nederveen & Gielingh, 2009)

Therefore, when it comes to the current project delivery system, the final products are delivered in the sequential processes by newly creating all objects and components without any systematic parameter. But, in the parametric project delivery system, the built artificial can be produced in the parallel processes at the same time by simply filling in the pre-defined parameter.

3.3.3 DYNAMIC APPROACH

Dynamic approach means that the above-discussed bottom-up and parametric approaches adjoin to the concept of dynamic control, which was introduced 7 years ago. (de Ridder & Vrijhoef 2003) The essential mechanism of dynamic control is represented by two main strategies to respond to unexpected events (figure 7). The first option is the opportunity of creating more value against little more costs, increasing the benefit when compared to the initial benefit. The second option can be used when confronting a risk. In such a case a little less value should be accepted against a substantial reduction of costs. This option leads also to an increase of benefit.

Figure 14. The essential mechanism of dynamic control (picture source: de Ridder & Vrijhoef 2003)

In this approach, we can expect two main advantages in the industrialised project delivery system. First, change orders could be managed in the better way or the even better solutions to the society could be delivered within dynamic control area since the focus of delivery is on value, rather than on costs. Second, a variety of solutions with the parametric system could be proposed to clients like other consumer markets do. By adding new and differentiated parameters depending on the strategy of their business, the industrialised BC industry would go into consumer market economy.
Figure 15. Dynamic approach can improve the above-mentioned bottom-up and parametric system

Therefore, the inefficient and fixed coupling points in two different systems should be changed. A better idea is that a group of producers actively provide their specification like the other industries make a successful progress on their production system. Flexible coupling point between the clients and producers towards bottom-up approach in the BC industry is necessary. Also the rule of consumer market should be applied with dynamic control into the parametric approach.
4. ENABLING TECHNOLOGIES

Previously, three approaches for the new project delivery system to transform the current BC industry to the industrialisation were addressed, which are bottom-up, parametric and dynamic. The main goals of this chapter 4 is to theoretically explore the emerging (or already on the market) technologies enabled for the paradigm shift to the industrialisation. Chapter 4.1 will shortly explore the history and definition of Building Information Modelling and its sub-chapters will present why BIM is so important for the proposed industrialised project delivery system. Actually, there might be more BIM’s contributions for the industrialisation but in this research three main potentials which are visualisation, collaboration and reusable information will be shortly discussed. Chapter 4.2 will introduce Systems Engineering as a possible enabler of the previously-proposed industrialised concept. With general definition of SE, three main intended SE’s contributions on the proposed system will be briefly addressed. More importantly, the integration issues of these enabling technologies to well support the proposed delivery system will be addressed throughout the interviews in the Ballast Nedam.
4.1 BUILDING INFORMATION MODELLING

Building Information Modelling is the really hottest issue in the current BC industry. According to BIM Market Survey (Young, N et al, 2008), BIM is being broadly adopted across the BC industry with over 50% of each specialised discipline such as architects, engineers etc. The following figure in the same survey presents the trend of the rapid growth in the use of BIM on the construction projects.

Figure 16. Growth in BIM use on projects (Source: BIM Market Survey 2008)

While many practitioners who recently come into contact with BIM software felt something new, some researchers in the BC industry mention that the concept and history of the Building Information Model have been done for a long time and it is not new anymore in the technical perspectives. As the following picture illustrates, the concept of BIM or the relevant technologies surrounding BIM field had been discussed more than for the several decades. BIM would be a virtual bridge the various separate islands of automation.

![Figure 17. Islands of automation (Hannus, 1998)](http://www.vtt.fi/cic/hannus/islands.html)

More theoretically, Jerry Laiserin emphases on the fact in the foreword of BIM Handbook “...the concepts, approaches and methodologies that we now identify as BIM can be dated back nearly thirty years, while the terminology of the “Building Information Model” has been in circulation for at least fifteen years...” Recently, with the active advent of BIM (Building Information Modelling) as an innovative driver for a paradigm shift in the BC industry, all relevant participants are facing new challenges. But, unfortunately, BIM have been lead to many of misunderstandings and even unreachable expectations. In this regard, the definition of BIM will be shortly explored to go further.

One of the most often misunderstandings is that BIM is simply Computer Aided Design (hereinafter CAD). It is true somehow. But, BIM should be the more progressed and advanced system than CAD system. It is supposed that CAD-based way of working is a transitional period between the traditional paper-based and BIM-based way of working. In traditional, the BC industry used the paper-based way of

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Towards an Industrialised Project Delivery System for the BC Industry

working for a long time. All information such as drawings and text specifications was placed on the paper. Although the ICT tools like the computers and their applications could facilitate to produce their information in CAD-based production system, the only information producer is human and all information was stored by means of recompiling the information on the paper or printing out them. But, BIM-based way of working is totally different. The collaboration and cooperation among the different actors by modelling the interoperable BIM will be lead. Although the human-to-human communication was the most important success-factor for the paper-based way of working, not only the human-to-computer (and the computer-to-human) but also the computer-to-computer communication is in need in the level of at least information exchange.

Comparing to the structure of information in the previous CAD system, BIM is characterized on the basis on the parametric and object-oriented modelling technologies. More specific, parametric modelling means the modelling technique to control and manipulate 3D geometry pre-programmed such as dimensional constraints, position and size constraints and alignment relationships. And Object-oriented modelling is one of the software language technologies to use pre-defined and customizable object styles to globally manipulate geometry and features such as doors, walls, windows, and assembly components (Stan Guidera, 2007).

Depending on the structure of information in the previous CAD system, BIM is characterized on the basis on the parametric and object-oriented modelling technologies. More specific, parametric modelling means the modelling technique to control and manipulate 3D geometry pre-programmed such as dimensional constraints, position and size constraints and alignment relationships. And Object-oriented modelling is one of the software language technologies to use pre-defined and customizable object styles to globally manipulate geometry and features such as doors, walls, windows, and assembly components (Stan Guidera, 2007).

![Figure 18. CAD and BIM](image)

Furthermore, BIM is not only technologies matter but also process innovations. According to a book ‘BIG BIM little bim’, it is believed that the prime goal of BIM is to integrate all participants throughout all life-cycle by means of the well-defined

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20 Rafael Sacks et al.(2005), A Target Benchmark of the Impact of Three-Dimensional Parametric Modeling in Precast Construction

information. The integration in this regard means to optimise the way of working in the BC industry so as to create new value invisible in the last ages and to get maximum value by working together efficiently and effectively (Finith Janigan, 2007\textsuperscript{22}). Regarding the information perspective, mainly discussed in this research, BIM makes it possible to integrate all information from the project participants of different disciplines which traditionally work in different phases of the bundling process (Rizal Sebastian et al, 2009\textsuperscript{23}). As there are too many different BIM software applications, it is necessary to import and export all relevant information in the interoperable formats. In the BIM HANDBOOK, two primary approaches to support integration with other applications and workflows are explained. One is to choose one software vendor and use all BIM-related applications provided by one firm. And another solution is not to limit the use of several applications from different vendors under the condition that can exchange data using industry supported standard (Chuck Eastman et all, 2008\textsuperscript{24}). (Note: This integration issue of BIM software applications will be dealt with in chapter. In this integrated BIM issues, it is supposed that the second approach to develop their own ICT platform within the globally standardized trends such as IFC and IDM is better since it provides more flexibility at the expense of reduced interoperability as they are keeping overcoming their limitations.)

\textsuperscript{22} Finith Janigan(2007), BIG BIM little bim

\textsuperscript{23} Rizal Sebastian et al, 2009, BIM application for integrated design and engineering in small-scale housing development: A pilot project in the Netherlands

\textsuperscript{24} Chuck Eastman et all, 2008 "BIM Handbooks"
Therefore, BIM is a new way of working achieved by using the virtual information from the very early phase of the project delivery process, by collaborating all disciplines with the BIM-communicable way, and by sharing the information throughout the entire BC industry. Back to the paradigm shift mentioned in the chapter 1-1, the embodiment of BIM is inevitable for the BC industry to reduce a lot of the unnecessary iterative tasks and improve the competitiveness of the BC industry by stimulating their cooperation and collaborative in the integrated system.

With BIM, all types of accurate geometrical representation of building deliverables are expected to be basically available. In the preface of the BIM Handbook, which is considered as a tutorial for BIM users, Prof. Eastman pointed out that BIM does not refer to a kind of Modelling technique such as 3-D visualization but Building Information Modelling as a multidisciplinary and interactive concept including all relevant tools, processes, methodologies etc. (Azhar et al. 2007, Eastman et al. 2007, Wright, F. 2009) A core purpose of BIM is the better communication and integration in the currently fragmented BC industry by means of enabling information technologies based on object-oriented and parametric modelling. This approach is very useful for the industrialised concept; almost it is in line with the industrialised...

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concept. Therefore, the industrialised project delivery systems should invite BIM technologies as enabler to lead to paradigm shift in the BC industry. The three following sub-chapters explain the main reasons why BIM is so important for the industrialised concept in the BC industry and how it supports the proposed system in this research.

So far, starting the definition matter of BIM, the overview of BIM was briefly tackled with. Next sub-chapter will discuss why the BIM is an important player to realise the industrialised project delivery system by mentioning three major expected contributions on it.
4.1.1 VISUALISATION IN THE EARLY PHASE

In the industrialised project delivery system, one of the critical successful factors is the coupling problem between the demander’s and supplier’s system. Comparing to the other industrial products such as car and mobile phone, the mock-up of the expected deliverables in the BC industry is too limited or hard for the client as a non-expert to understand. For example, many projects in the BC industry BIM used by architects groups in the traditional delivery system or by general contractors in the more integrated delivery system plays an important role to visualize and communicate design intentions in order to lead the healthy business between two systems. Historically, this use of BIM exemplifies the most common use of 3D in the BC industry (Campbell, D.A., 2007\textsuperscript{26}). It can be used to visualise the design of expected deliverable at any stage of the process and in any view. (Chuck Eastman et al., 2008) Regarding the visualisation of BIM, BIM Handbook mentions as following;

“...The 3D model generated by the BIM software is designed directly rather than being generated from multiple 2D views. ... BIM provides earlier 3D visualizations and quantifies the area of spaces and other material quantities, allowing for earlier and more accurate cost estimates... For technical buildings (labs, hospitals, etc.), the design intent is often defined quantitatively, and this allows a building model to be used to check for these requirements. For qualitative requirements (this space should be near another, etc.), the 3D model can support automatic evaluations...”

Furthermore, the BIM-oriented representation is not only the 3-D visualisations but also the parametric models to reduce time to market. BIM-based industrialisation in the BC industry greatly reduces the gap between the demander’s system and supplier’s system and the project duration from the contract of the industrialised product to facility completion since the parametric nature of the BIM models with the industrialised components which are standardised, prefabricated and market-available makes the client’s requirement in the demander’s system fulfilled and the design changes well-managed. (Kymrell, W, 2008\textsuperscript{27} and Chuck Eastman et al., 2008) Therefore, BIM is one of the critical enabler to support the proposed industrialised project delivery system because the visualisation of the industrialised deliverables

\textsuperscript{26} Campbell, D.A., 2007, “Building Information Modeling The Web3D Application for AEC Web3D”

\textsuperscript{27} Kymrell, W, 2008, “BIM planning and managing construction projects”
Towards an Industrialised Project Delivery System for the BC Industry

using BIM provides the better communications between the clients and the suppliers as well as between the currently-fragmented suppliers.

4.1.2 FACILITATED COLLABORATION

As the above diagram seen, the current system in construction supply chain is definitely fragmented and several construction actors such as designer, engineer and sub-contractor meet in certain phase of construction life cycle, work as defined in their mutual biding contract for certain period and just dissolve after completing certain part without any sharing information. Since, especially, construction industry consists of many SMEs and specialist, this fragmentation gap is too large and deep to provide right information at right time and place in order to improve supply chain management in construction field. (J.H. Park et al, 2010\textsuperscript{28})

\textsuperscript{28} J.H. Park et al, 2010, "Integrated supply chain management" (Not published, TU Delft)
Due to the inconsistent gap of this information flow in construction supply chain, a lot of expectable and achievable value in construction project has been disappeared without any consideration. For instance, a considerable amount of components in construction project are delivered in type of ‘engineering-to-order’ (ETO) or ‘designed-to-order’ (DTO). Although these types of components usually require the very sophisticated engineering and careful collaboration to ensure that pieces fit within the building properly without interfering with other building systems, the failures of communication and collaboration in the current system of construction supply chain very often are brought in. And these failures lead to lose the project value, that no certain actor could take an overall responsibility because it is not from performance or production problem, but from system problem just such as miscommunication and misleading. More critical problem in the fragmented system of construction supply chain is that it is impossible to reuse critical construction information for from construction schedule management to facility management later on. Under the current fragmented system, it also is not that easy to develop the knowledge management system, considered as one of the most important resources accelerating their business growth.

Figure 21. The role of the demand and supply system integrator (Source: Vrijhoef & De Ridder, 2007)

Therefore, in this highly-fragmented supply chain in the current project delivery system of the BC industry, the collaboration is the very important factor for the

successful delivery of the certain industrialised construction project as well as the sustainability of the industrialised business model in the certain company. This collaboration in the industrialised project delivery system is possible only when the demand and supply systems are well integrated as the above figure represents. In this regard, many researchers mentioned that BIM-based project delivery provide the better collaboration. (Ning Gu et al, 2009\textsuperscript{30} and C.C. Sullivan, 2007\textsuperscript{31}) According to the BIM Handbook written by Chuck Eastman et all (2008), the following sentences are pointed out regarding the possibilities of the BIM-facilitated collaboration in the construction projects;

“...BIM technology facilitates simultaneous work by multiple design disciplines. While collaboration with drawings is also possible, it is inherently more difficult and time consuming than working with one or more coordinated 3D models in which change-control can be well managed. This shortens the design time and significantly reduces design errors and omissions. It also gives earlier insight into design problems and presents opportunities for a design to be continuously improved. This is much more cost effective than waiting until a design is nearly complete and then applying value engineering only after major design decisions have been made...”

In the industrialised project delivery system, the BIM technology plays undoubtedly an enabling role of the system integrator ensuring the better collaboration in the virtual factory without walls on site.

\textsuperscript{30} Ning Gu et al, 2009, "Adopting building information modeling as collaboration platform in the design industry"

\textsuperscript{31} C.C. Sullivan, 2007, "Integrated BIM and Design Review for Safer, Better Buildings"
4.1.3 ACCUMULATION OF ALL REUSABLE INFORMATION

As previously mentioned, the BIM technology enables the information generated in the process of the project delivery to reuse. Ghang Lee et al (2006)\(^{32}\) defines the BIM as the process of generating and managing building information in an interoperable and reusable way. This is enabled by two main natures of BIM, which are object-oriented and parametric.

<table>
<thead>
<tr>
<th>Without BIM</th>
<th>With BIM</th>
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<tbody>
<tr>
<td>Stakeholders</td>
<td>Construction Project</td>
</tr>
<tr>
<td>Future users</td>
<td>Virtual Enterprise (VE)</td>
</tr>
<tr>
<td>Current owner</td>
<td>Consortium</td>
</tr>
<tr>
<td>Architect</td>
<td>Decision-making</td>
</tr>
<tr>
<td></td>
<td>IFC+IFD product model</td>
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</tbody>
</table>

Table 2. Accumulation of all information generated from the construction projects: Without BIM vs. With BIM (Sources: J.H. Park, 2009 & Facilities Information Council National BIM Standard, 2007)

Unfortunately, the accumulation of all information generated from the construction projects that already was delivered has so far limited due to the fragmented way of working in the traditional delivery system. This is one of main reasons to in terms of the industrialisation, comparing to the other industries. Therefore, with BIM, the industrialised base should be reinforced by accumulating all reusable information.

\(^{32}\) Ghang Lee et al, 2006, “Specifying parametric building object behaviour (BOB) for a building information modelling system”
4.2 SYSTEMS ENGINEERING

Systems Engineering is the design and management methodology used to acquire and execute projects in a standardized way using a structured method that guarantees that one gets what one is asked for as well as establishing a relationship between the problem (requirements) and the solution (designs). It includes all aspects that play a role in the projects life cycle ensuring that clear design choices are made (Ballast Nedam, 2009). The Dutch European construction clients have been asking the construction contractors to apply SE functionality to their project for maximizing the achievable efficiency in design and construction process and leading to the advanced synergy. (RWS, 2010)

According to Menno de Jonge & Arjen Adriaanse (2009), an importance of System Engineering with ongoing project case is strongly pointed out as the following;

“...Clients in the European Construction sector are starting to force contractors to use Systems Engineering techniques to manage Design & Construction projects. Ballast Nedam is using Systems Engineering functionality on a number of projects, for example on the Avenue2 project in the city of Maastricht, a one billion Euro project where a highway is brought underground (similar to Central Artery project in Boston). The project consists of a 2,5 km long double deck tunnel with 2 x 3 lanes, which will be realized in 2016. After that on top of the tunnel a park, housing and office development will be executed, which will be finished in 2027...”
As the above concept diagram of System Engineering represents, it is the integrated design methodology covering the whole life-cycle management. By using SE philosophy, the contractors such as Ballast Nedam ensure that more satisfaction of clients can be delivered to clients in the integrated project delivery system, one example of which is Design-Build.
4.3 INTEGRATION ISSUE

Previously, two enabling technologies for the industrialised project delivery system, which are BIM and SE, were introduced. Now on the more practical issue will be arose in the current BC industry, particularly in Ballast Nedam. It is about integration of BIM and SE software applications to get the synergy.

4.3.1 BIM AND SE IN BALLAST NEDAM

Ballast Nedam has been using the several different software application to carry out their business. According to the interview with Menno de Jonge, Director Innovation & Strategic Information Manager of Ballast Nedam, the information system architecture is currently very complicated since new technologies or concept has been introduced and merged.

The main BIM-oriented or –related software applications presently used in Ballast Nedam are as following; (Note: This information is derived from the interview with Ruud van der Meer who is a Senior CAD manager of Ballast Nedam Engineering. Some of them are out of my definition of BIM)
<table>
<thead>
<tr>
<th>BIM-oriented or –related software applications in Ballast Nedam</th>
<th>Introduction from website (usa.autodesk.com)</th>
</tr>
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<tbody>
<tr>
<td><strong>Revit Architecture and Structure</strong></td>
<td>Purpose-built for building information modeling (BIM), Autodesk® Revit® Architecture building design software helps architects and designers capture and analyze early concepts, and then better maintain designs through documentation and construction. Enjoy a more collaborative, integrated building design process by sharing essential BIM data with your partners, and use BIM workflows to help drive more efficient sustainable design analysis, clash detection, construction planning, and material fabrication.</td>
</tr>
<tr>
<td><strong>AutoCAD</strong></td>
<td>Design and shape the world around you with the powerful, flexible features found in AutoCAD® design and documentation software, one of the world’s leading 2D and 3D CAD tools. Speed documentation, share ideas seamlessly, and explore ideas more intuitively in 3D. With thousands of available add-ons, AutoCAD design software provides the ultimate in flexibility, customized for your specific needs. It’s time to take design further. It’s time for AutoCAD</td>
</tr>
<tr>
<td><strong>Civil-3D</strong></td>
<td>AutoCAD® Civil 3D® software, the building information modelling (BIM) solution for civil engineering, helps project teams deliver higher-quality transportation, land development, and environmental projects faster. Explore design ideas and analyze what-if scenarios to help optimize performance before projects are built. Extend Civil 3D model data to perform geospatial and stormwater analysis, generate quantity takeoffs, and support automated machine guidance during construction. Civil 3D provides the BIM advantage and tools you need to deliver more innovative design solutions.</td>
</tr>
<tr>
<td><strong>Navisworks</strong></td>
<td>Autodesk® Navisworks® products deliver project review software for 3D coordination, 4D planning, photorealistic visualization, dynamic simulation, and accurate analysis. Create a whole-project model by integrating design and construction information, including complex building information modelling (BIM), Digital Prototyping (DP), and process plant data.</td>
</tr>
</tbody>
</table>

*Table 3. The main BIM-oriented or –related software applications*
Towards an Industrialised Project Delivery System for the BC Industry

For systems engineering, they have heavily used simple spreadsheet of MS Excel. But, in the cases of more complicated projects, they use MS Access to manage all requirements and the fulfilled specifications.

Figure 23. Requirements Verification Document in Ballast Nedam using MS Excel

Figure 24. Relatics software for systems engineering in Ballast Nedam (Picture source: www.pkmsolutions.com)

Also, Ballast Nedam recently purchased the new software application more specialised in System Engineering as the above.
4.3.2 FRAGMENTED APPLICATION IN PRACTICE

As the previous chapter mentioned, Ballast Nedam uses several tools to apply the concepts of SE and BIM in Ballast Nedam. The practitioners in Ballast Nedam mentioned during the formal or informal interviews that these recently added software applications makes the current information system architecture more fragmented. In other word, many enabling applications are not integrated each other in practice. As the following figure represents, this fragmentation hinders to improve the productiveness expected by the use of them.

Figure 25. Another fragmentation of the applications in practice
4.3.3 INTERELATED AND OVERLAPPED CONCEPTS

Many researchers have developed, proposed and introduced the new way of working for the better industrialised BC industry with available technologies such as BIM. And many industry-leading practitioners in the BC industry have actively applied these technologies to their projects earmarking as sustainable growth engines. But, according to Nederveen et al (2009), a vital success factor for realisation of full industrialisation in the BC industry is not the separately independent applications of these technologies but an integration of them. They put an emphasis on the fact that any synergy as well as efficiency is never anticipated in the current fragmented application. In this regard, BIM concept with IFC is struggling with solving the integration problem. i.e. the link between n IFC-models and library structures, the link between library elements and functions or algorithms etc. According to BIM handbook (2008), it is highly pointed out that one of the most necessary factors for implementing BIM is to continue to integrate BIM capabilities into all aspects of the firm’s functions and reflect these new business processes in contractual documents with clients and business partners. The Dutch construction industry with the governmental initiative or public sectors are asking to apply Furthermore, since SE approach provides more structure library elements and functions with the currently limited-used BIM, the integration of BIM and SE is the most critical issues in practice. (Nederveen & Gielingh, 2009). Therefore, SE and BIM applications should be integrated each other to fully support the industrialised project delivery system.
Based on the previous theoretical research on the industrialisation in the BC industry, this chapter will reformulate the initial research question in more focused and detailed manner. To do so, the chapter 5.1 will briefly review the findings and meanings of the previously-done theoretical research and explain the background of the reformulation in this research. The chapter 5.2 will present the reformulated research question and research goal and the expected end-products in the rest of this research. Finally, the chapter 5.3 will introduce the research methods, techniques and mode of inquiry that will be applied to answer the reformulated questions and achieve the research goal of the coming practical research in the rest.
5.1 BACKGROUND OF REFORMULATED QUESTIONS

Figure 26. Research reformulation

This MSc research motivated from the importance and necessity of the better industrialisation in the BC industry has discussed several important issues so far. Some previous efforts for industrialised concept of the BC industry were discussed and some possibilities and limitations of them were concluded. Based on these analyses, the industrialisation was revisited to unravel an entangled thread in the BC industry. By applying the system thinking that regards the BC industry as a system, a project delivery system for the better industrialisation was proposed characterising by bottom-up, parametric and dynamic approaches. The proposed system is theoretically based on Living Building Concept initiated by Hennes de Ridder and his research colleagues at TU Delft. Since the proposed industrialised delivery system was presented in the theoretical models, the detailed solutions should be discussed with some case studies or prototyping in the practical manner. But, there are several approaches, technologies and methodologies to contribute on the proposed system. In this regard, this research focused on enabling technologies in practice. So, two technologies which are SE and BIM were introduced as enablers of the proposed industrialisation in practice, explaining how the current project delivery system is transformed into the industrialised one by them and why. In this process of exploring two enablers with some interviews and observation in Ballast Nedam, the integration between the existing technologies in practice was recognised as the biggest emerging issues. This process was illustrated in the above figure.
5.2 REFORMULATED RESEARCH QUESTIONS/ GOALS/ END-PRODUCTS

The main goal of this MSc research is to lead to the industrialised paradigm shift (Mainly derived from TUD expectation as a part of Living Building Concept) in the BC industry, by integrating enabling technologies such as BIM and SE (Mainly derived from BN expectation as a part of 5Di). To meet both expectations, ModuPark business unit in this research is tackled with as a practical prototyping.

![Diagram]

**Figure 27. Reformulated research goal**

Based on the theoretical research on industrialisation, BIM and SE, the new project delivery system for a better industrialization in the BC industry is proposed and the system is supported by integration of SE and BIM. And for this integration, practical research is conducted by investigating existing documents ( Relevant Manuals or Handbooks, In-houses documents etc) and doing interviews in the Ballast Nedam, related to ModuPark Business. Based on both theoretical and practical background, the integrated system for TO-BE ModuPark is analyzed and designed in conceptual modelling techniques. The main end-product of this research is a conceptual modelling of the integrated system for TO-BE ModuPark, reflecting the concept of the proposed project delivery system, which is bottom-up, parametric and dynamic controllable.
5.3 RESEARCH METHODS/ TECHNIQUES/ MODE OF INQUIRY

Figure 28. Research design

In the above diagram, the blue boxes and circles mean what I have so far done, the yellow ones are in progress, and the red ones are still to be. As a main outcome of this research, the conceptual modelling is based on two main resources. First, the theoretical background, which is mainly derived from three theoretical concepts (Industrialization, BIM and SE) has been concluded so far. (See previous documents) Secondly, the practical research is in progress as you can see. The most important factor of the practical research is the data collection to underpin the conceptual modelling. The relevant manuals, handbooks, in-house documents were provided from Ballast Nedam and has been analyzed in process modelling technique. (If more relevant documents please send me) The formal interview is necessary to get some more practical input data for the conceptual modelling and develop the process modelling as well as product modelling in more detailed way. The conceptual modelling consists of process modelling (tool: IDEF0) and product modelling (tool: UML). Process modelling part had already been done. But it could be revised based on more data such as interviews, more in-house documents and even your comments. Product modelling part is still in progress. Product modelling part deals with information structure and information exchange requirements etc. Since product modelling part would be too broad to fully cover in this MSc research, the limited
scope of the integrated system will be prototyped by showing some object examples in the ModuPark business unit. Also if necessary, Process to Product modelling as one of the integrated modelling technique will be conducted in order to facilitate the further development and reduce time and errors (tool: GTPPM).

The framework of my research consists of three hierarchically different levels. They are so-called as the strategic, tactical (structural), and operational layers, which are oriented usually from the discipline of business management. Main concept of these layers (or levels) is based on the belief of business professionals, that a business management should be covered in a wide range of actives to achieve their business goals in different level, to in total improve the effectiveness and efficiency of their business area, and to maximize their value of business organization. To manage this in business, they think that higher decision-makers need to focus on the vision of their business organization as well as operational managers need to pay more attentions to dealing with a variety of the detailed activities at the same time. Then, they can fully achieve their initial set-up goal for their whole business organization. Based on these reasons, the professionals in the discipline of the business management has used the concept of three hierarchical framework to analyze the business problem in the whole organization and design the solution covering strategic, structural, and operational levels of their business organization. It is firmly believed that this approach of the business-oriented framework with three hierarchical layers is definitely necessary to do my research, the goal of which is to design and provide the integrated system in practice. To make clear my own definition of three levels in my research, the following diagram is illustrated. Also, regarding the mode of inquiry in this reformulated research, the following rest of research will be conducted in qualitative manner.

Table 4. Strategic/ Structural/ Operational level in this research
6. INTEGRATION SOLUTION FRAMEWORK

In the chapter 5, the initially-asked research questions were reformulated aiming at the proposed industrialised project delivery system by integrating the enabling technologies, which are SE and BIM, especially focusing on xBS and Revit software in the Ballast Nedam. The main goal of this chapter is to set up the theoretical framework of the integration solution. Chapter 6.1 will explore the definition of some important terms such as Model and System and then chapter 6.2 will introduce the Model-driven framework for this integration issue. Chapter 6.3 will present three integration methodologies to solve each fragmentation in the model-driven framework, which are Business Process Reengineering, Object-Oriented Systems Engineering and Process to Product Modelling.
6.1 MODEL-DRIVEN INTEGRATION

This chapter explores the definition of Model. It is very important for not only the chapter 1-2-3 on BIM definition but also the chapter 1-4 on the integration framework because the point-of-view of this research is the integrations aspect of the different types Models. What is a model? The book, which titles Building Informatics written by F. Tolman et al (2009), defines that a model is an abstraction, or picture of something from reality with conservation of one or more key properties. And they explain that a model is of importance because we can understand the certain properties of Real System (RS) by using a model. There are a variety kinds and examples of models depending on their own purpose, viewpoint, and scope. In this research, a model means an information model in the construction industry. An information model is derived from Information System which is fully reflecting on Real system by means of the information.

![Diagram of Information System and Model]

Figure 1. A model in Information System reflecting Real system

The most important thing in the definition of a model is to represent something in the information system. Depending on what kind of information they represent, it would be totally different like the process model and product model. Also depending on by what kind of information it is represented, it would be the graphical model, object-oriented data model, or mathematical model. In this research, primarily deal with the process model and product model in the information system.

33 Building Informatics, Frits Tolman et al, 2009
To sum up, people live in Real World. In Real World, we design, construct and use a Real System to achieve a purpose with several components. RS in this research is considered as a real thing to construct or build. For example, suppose that the contractors should develop the new parking garage building in Rotterdam. The Real System is a physical and visible building that will be constructed. It has several sub-systems like the structural system or HVAC system (Heating Ventilating Air-Conditioning) and more specific, each sub-system consist of several components throughout several hierarchical layers. An information system is fully transformed from the Real System and facilitates to analyze, design and manage the Real System by corresponding each other. The components or objects of the Real System in the construction industry would be the visible walls as a structural part, amount of concrete as a construction material, and so on. Finally they can formulate and generate a information model, representing with certain goal, viewpoint and scope in the above-discussed information system.

Figure 2. Relations in RW, RS, IS, and Model

This research approaches all systems such as the office building and parking garage with the point-of-view of the model. Especially, two type of models consist of the solution framework for the integrated system in this research. Product model called in this research means the representation of all relevant and aggregative information to study the artificial system composing of sub-systems and components. Process model represents the activities or procedures to produce something or use something by means of information flow.
Towards an Industrialised Project Delivery System for the BC Industry

According to Shane Sendall et al (2003\textsuperscript{34}), the model-driven developments are recommended as the followings;

“...One of the best ways to combat complexity of software development is through the use of abstraction, problem decomposition, and separation of concerns. The practice of software modelling has become a major way of implementing these principles. Model-driven approaches to systems development move the focus from third-generation programming language (3GL) code to models (in particular models expressed in UML and its profiles). The objective of model-driven development is to increase productivity and reduce time-to-market by enabling development at a higher level of abstraction and by using concepts closer to the problem domain at hand, rather than the ones offered by programming languages. The key challenge of model-driven development is in transforming these higher-level models to so-called platform-specific models that can be used to generate code...”

Furthermore, many researchers and practitioners in the software or system development field have been dealing with this approach. According to Peter Denno et al (2003\textsuperscript{35}), the strengths and necessities of the Model-driven integration was mentioned as following;

“...Continuing system evolution and repeated large-scale and expensive integration are commonplace with virtually all moderately complex software. Traditional integration makes little or no use of the models, which were created at great expense and which provide valuable information about a system. These models can and should be maintained and reused for maintenance and integration. Creating and using joint action models and linked component models, which meld other specialised models, is the key to making the best use of prior investments in model construction. This will significantly ease integration projects by allowing automation of tasks that are presently performed manually...”

The following chapter will explore SE and BIM in the aspects of both Process model and Product model. Based on the distinction of Process and Product model on SE and BIM, the integration solution framework will be presented.

\textsuperscript{34} Shane Sendall et al(2003), "Model Transformation – the heart and soul of model-driven software development"

\textsuperscript{35} Peter Denno et al(2003), "Model-driven integration using existing models"
6.2 INTEGRATION FRAMEWORK

As one of the important parts in the theoretical conclusion, the definitions of a system and a model and their relation is fundamentally defined in order to set up the ‘model’-based point-of-view and to design the integrated ‘system’. It is concluded that a system is derived from our interpretation of the real world with certain purpose, viewpoint and scope and defined as a rearranged and combined complexity of components which are naturally existed or artificially created such as people, products and processes. And a system is divided into two main domains with the more embodied perspective, which is referred from RS-IS paradigm. Regarding the relation between a system and a model, it is concluded that a model represents a system in their specific purpose, viewpoint and scope. So a model in this research is defined as a kind of the virtual representation of objects and their relations in a system.

Based on these definitions of the fundamental terms, two main keywords in this research is re-defined. A systems engineering in this research is a sort of methodology to design and engineer a system such as a aircraft or high-speed railway. As a system is technically or socially more complicated, a systems engineering should provide the well-defined procedures and appropriate techniques by using decomposition and integration in a system to meet all requirements of not only the clients but also the relevant stakeholders. When taking into consideration of the more competitive and complex construction industry (i.e. more often use of the integrated Design-Build contract), the methodology of a systems engineering should be applied more and more to deal with design and engineer a sophisticated system and manage it well in all their life-cycle. However, the current application of a systems engineering in the construction industry has been limited. In many cases, the process of a systems engineering is not well-integrated into the construction project since its application is not supported by the well-defined ICT system, especially BIM environment so far. Therefore, this research tackles with this problem.
What do we have to do to integrate SE and BIM? According to the literature study so far, it is concluded that these two philosophies, SE and BIM, have their own models to facilitate the construction project. In the regards of the above definition of a model and the model-based point-of-view, it is broadly divided into two type of models, which are process-oriented and product-oriented. Main objective of SE is related to the process of designing a system. But also SE definitely produces the product model in the certain format, which is usually text-based format. When it comes to model-oriented thinking, the systems engineering could initiate a process model to describe the design procedures, how they will design. And it could generate the product model to describe the design result, what they will build. On the other hands, the main objective of the building information model is to set up a product data model covering all factors, elements and elements in whole life-cycle, which is so-called BIM modelling. The comprehensive building product model could be applied in all relevant process not only to improve their efficiency and competiveness in the design and construction but also to ensure the better facility management.

Figure 3 Model-based integration framework
Towards an Industrialised Project Delivery System for the BC Industry

So far, the theoretical background of this research have been explored from the definition of a system and model, through systems engineering and building information model, finally to distinguishing the process and product model in two promising innovations of the construction industry. Based on this 2x2 framework (SE vs. BIM X Process vs. Product), the integration problem discussed in the last plenary meeting (See the Kick-off document) is revisited. According to this integration framework, there are three types of integration problem as following;

1. SE product model to BIM product model (related to information structure)
2. BIM process model to SE process model (related to information process)
3. SE process model to BIM product model (related to software application)

Figure 4  Theoretical solution framework
6.3 INTEGRATION METHODOLOGIES TO BE APPLIED

6.3.1 BUSINESS PROCESS REENGINEERING

Comparing to other industries, the BC industry are highly fragmented along its supply chains as well as delivery processes. Derived from this fragmentation, the gap between SE and BIM is discovered in the model-oriented solution area as previously presented. Since two different innovative drivers in BC industries have been recently applied in the separated way, the new relevant ICT software applications have been separately introduced. To properly apply two enabling technologies, BIM and SE, in practice and fully create the synergy of them, the current business process should be reengineered.

![Business Process Reengineering Diagram]

In practice, the most critical problem is not the absence of enabling technologies or methodologies but the fragmented application of them. Nederveen et al (2009) pointed out that all enabling technologies such as parametric design, building information modelling, cost calculation and industrial production are already available but a vital factor for realization of full industrialisation in the BC industry is an
integration of them since any synergy as well as efficiency is never anticipated in the current fragmented applications. Furthermore, they put an emphasis on that it is more important that an innovative business model is developed and introduced that is based on the concept of "supplier-driven demand". This means the bottom-up approach described in this paper. In this regards, this paper argues that BIM and SE should be revisited as enabling technologies for industrialisation of the BC industry. More importantly, the process should be reengineered in order to be well integrated in the business models of the industrialised BC industry.

According to Hammer & Champy (1993), Business Process Reengineering (BPR) is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed. Since BPR provides the fundamental rethinking and redesign for dramatic improvements, it is imperative for the BC industry to transform their traditional project delivery system to an industrialised system. One of the tools for BPR is a process mapping or operational method study (O’neill & Sohal 1999). These concepts have been incorporated into specified tools such as IDEF0 (Yu & Wright 1997). IDEF0 process modelling in this paper is generated for Business Process Reengineering to be reshaped to an industrialised bottom-up project delivery system by integrating Systems Engineering into the BIM. It can provide a well-visualized means for modelling the functions, relationships and data required by an information system or business process (Dorador et al. 2000). An IDEF0 model is composed of a hierarchical series of diagrams that display increasing levels of detail describing functions and their interfaces within the context of a system (NIST 1993).

6.3.2 OBJECT-ORIENTED SYSTEMS ENGINEERING

Indeed, systems engineering is necessary to more properly use BIM. As defined in previous theoretical part of this research, SE is a design and management methodology covering the whole life-cycle to fully meet clients or future users of the built facilities. More actually, I suppose that it could not be new concept. Most of construction companies are partly and tacitly used. Suppose that the integrated delivery contract such as DB or BOT. Without the application of SE, they have to find out the client’s requirements, reflect them into design specification and track them during construction and even maintenance phase. The only difference is how much their processes and enabling information are properly structuralised and well integrated in practice. The Dutch construction market are demanding to design the built facilities such as highway and the residential development etc., to better manage the construction projects and to properly operate and maintain them. (Arjen
Towards an Industrialised Project Delivery System for the BC Industry

and Menno, 2009) More importantly, Ballast Nedam is one of the companies that have actively applied and enhanced their SE methodology. Based on the interview with the strategic information manager in the Ballast Nedam, they are very struggling with the application and development of their own SE manuals. Some limitations and integration issues in the other information system architecture are confronted by Ballast Nedam.

In this research, an approach of the Object-oriented Systems Engineering proposes. The Object-oriented Systems Engineering offers at least two fundamental advantages over non-object-oriented SE. First, Object-oriented Systems Engineering enables the established information during the project period to be reusable for the other projects. Object technology itself provides the reusable information. Another expected advantage of the Object-oriented Systems Engineering derives from the extensible characteristic of the Object-oriented technology. The current fragmented use of the Systems Engineering application can be changed and expanded easily without adversely impacting any existing information structures that has been applied so far in practice. It significantly reduce the lifetime cost of the each industrialised facilities built as well as improve their industrialised business model such as ModuPark with more tangible profit. (Jeffrey L. Whitten et al, 200436)

Figure 30. An example for ModuPark: Object-oriented systems engineering

For instance, we can use UML for the Object-oriented Systems Engineering. UML has been applied to SE project in practice to analyze their system delivery as well as it is known as one of the most popular Object-Oriented modelling language. UML is a group of computing languages providing a vocabulary and the rules for combining words in that vocabulary for the purpose of communication. It based on the Object-Oriented modelling paradigm as one of the standard languages providing the software application blueprint in the visualised fashion. (Grady Booch et al, 1998)

The above example is Object-oriented Systems Engineering by means of UML. This research will apply this methodology and tool in the chapter 7.3.

6.3.3 PROCESS TO PRODUCT MODELLING

The previous two chapters 6.3.1 and 6.3.2 individually set up the research frame in the perspective of process modelling and product modelling. According to the user manual for GTPPM developed by Ghang Lee et al (2003), there are two types of models as following;

“...Process modelling and product modelling are two different modelling methods with different purpose representing two different aspects of a domain. A process is a series of activities that are a piece of work that forms one logical step within a process. A process model describes how activities within a process are connected, ordered, and structured. Process modelling serves business analysis, business reengineering, requirement engineering, organizational knowledge management, and organizational learning. On the other hand, a product model describes the definition, structure, and relation of information required to design, engineering, produce, and manage a product. Product modelling serves information structure analysis, software development, database design, and also organizational knowledge management and learning...”


38 Ghang Lee et al (2003), Eliciting Information for Product Modeling using Process Modeling
Towards an Industrialised Project Delivery System for the BC Industry

Figure 31. The main benefit of ‘Process to Product modelling’ (Source: Ghang Lee, 2004)

In practice of developing the software application or information system, many difficulties are arose between the process model (AAM in the above) and the product model (ARM in the above) due to the weak link and static modelling. ‘Process to Product modelling’ method is one of the best solutions to overcome the limitation reducing the development time. Many up-to-date modelling tools are based on the ‘Process to Product modelling’. One of them is IDM. IDM means Information Delivery Manual. It is being initiated by BuildingSmart (the old IAI International Alliance for Interoperability), who for almost 20 years have developed the standard for construction industry process improvements through improved collaboration tools such as the open, global ISO standard IFC - Information for Construction protocol\(^39\). The purpose of IDM is to provide the integrated reference for process model and product model required by BIM software application, by defining the discrete processes in the BC project, the information that should be changed in practice, and the result of that activity. By using IDM, it is expected to make the current IFC development more actively reflect real project needs as well as to stimulate to speed up the wide application of Open BIM with IFC in practice. The IDM benefits not only BIM users but also BIM software developers since it enables seamless processes to be successfully carried out by providing the information requirements and processes

Towards an Industrialised Project Delivery System for the BC Industry

in easy-understandable and text-based manners. Also, other methodologies to integrate process modelling and product modelling were taken into consideration to find the most appropriate one. One of them, the GTPPM (Georgia Tech Process to Product modelling), which Prof. G. Lee developed with Prof. C. Eastman and R. Sacks and which is based on the methodology of ‘process to product modelling’, was also considered as the possible method to integrate them. They offer the well-defined and easy-learning modelling technique for parallel modelling with both process and product model, even if it is not sure that it is widely used in the BC industry when comparing to IDM. Moreover, the POP (Process, Organization, and Product) meta-model, which is include as an annex to the ISO19440 standard and the aim of which eases model interoperability and exchange between different modelling approaches.

In this research, the propose system finally will be modelled by means of xPPM (or GTPPM) which is a kind of the integrated modelling technique.

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41 G. Lee(2003), "GT PPM: User Manual"

42 ATHENA AI(2005), "Report on Methodology description and guideline definition, version 1.0"
Previously, the framework of integration solution was presented. Main goal of this chapter is to develop the practical conceptual modelling for industrialised project delivery system by doing a casestudy of ModuPark business unit in the Ballast Nedam. First sub-chapter 7.1 will introduce ModuPark of Ballast Nedam. I believe that ModuPark is composed of the innovative concepts in the Ballast Nedam and is a providing ground for emerging technologies of the current BC industry. This ModuPark will be explored based on the investigation of in-house documents and interviews. Also, the method of data collections and the analyses on them will be shortly mentioned. (More information on this part will be included in the appendix) Chapter 7.2 will present AS-IS and TO-BE information process modelling of the ModuPark. And chapter 7.3 will illustrate AS-IS and TO-BE information structure modelling by means of the abstracted class diagram of UML. In the beginning of each modelling part, the purpose, viewpoint and scope of the modelling will be presented to clearly develop these conceptual modelling.
7.1 MODUPARK OF BALLAST NEDAM

This chapter 7.1 introduces ModuPark of Ballast Nedam and describes how the data were collected and analysed.

7.1.1 INTRODUCTION OF MODUPARK

ModuPark is a unique and innovative business model for a modular parking garage built mainly from prefabricated components. Some companies in the BC industry raised the question of where travellers and staffs parking their vehicles during the construction phase of their running projects. This initial question was a starting point for developing this business model for delivering a temporary and re-usable parking garage. In this background, ModuPark started their business focusing on temporality use of parking garage few years ago. Main concept of ModuPark derived from the needs of short-term use and re-use of parking garage. Since most of components such as foundations and standard units are reusable, ModuPark concept is feasible enough. Now ModuPark can offer temporarily or permanently available parking garages to clients in very short time.
So far, 6 ModuPark projects were done and now 7th ModuPark project is just started up. 7 ModuPark projects are divided to three types of clients; Local governments, hospitals and real-estate firms. 7th project is for hospital and recently started up. Clients of ModuPark could be quite different parties. For instance, the local governments are one of clients for ModuPark business. When they redevelop the certain town in their local cities, this kind of temporarily parking facilities always are needed. Also hospitals, schools and universities, real-estates companies are all ModuPark clients.

Although ModuPark is currently run by the cooperation with three firms working in the BC market, a main player is indubitably Ballast Nedam Parking. Ballast Nedam, which is a multidisciplinary Dutch property and infrastructure construction group offering a wide range of construction-related products and services, is not only strong in the precast concrete for a modular parking garages but also is a leading general contractor in the Netherlands that has accumulated a lot of experience and knowledge in the project management such as financial engineering and contracting (www.ballast-nedam.nl). Actually, among several individual companies of Ballast Nedam group, Ballast Nedam Parking initiates this business model and manages the entire processes and cooperation in the life-cycle of parking garages that they
delivered. In other words, while other two parties are involved in certain part of the whole project as a consulting firm or prefabricator, Ballast Nedam Parking plays a core role as main contractor figuring out a clients, designing the modular parking garage, managing the manufacturing and constructing of the designed parking garage with even taking all risks that could be happened during project-running period. Also some employees from a different company of Ballast Nedam group participate in certain engineering phase. For example, some BIM drafters and engineers from Ballast Nedam Engineering provide some solution and develop drawings for Ballast Nedam Parking.

One of the other partners involved in ModuPark is Grontmij Park Consult which has extensive expertise in the parking garage projects as an engineering firm (www.grontmij.nl). More importantly, in the process of this ModuPark project, Grontmij can officially offer consultant services to government organization but Ballast Nedam as a general contractor is too difficult to participate in this consulting process. Taking into a consideration on the public clients such as governmental organisations and municipalities, it is regarded that the cooperation with Grontmij Park Consult is a win-win situation for Ballast Nedam in some of ModuPark project. Another partner company which also play important role in ModuPark project is Oostengh which is a steel production company (www.oostingh.nl). They provide almost of all steel components and structural engineering solutions.
In terms of the project delivery system (or ModuPark business model), several differences can be found. ModuPark does initiate the parking garage projects and actively find their clients by themselves. And they can sell this modular parking facilities to clients or rent them for temporary use of it. Even Ballast Nedam Parking is ready to aggressively operate the built facilities by making profits from the parking or advertising business in case that a client cannot afford to build it. In other words, ModuPark find the opportunities for their business recognising the clients’ currently-confronted problems and they present some solutions one of which is a ModuPark. And if clients are not that satisfied with their solution, then they try to offer another solutions. So, it is very important to find out possibilities of ModuPark using Ballast Nedam network, newspapers or internet etc. So it is somehow different concept with the traditional tendering projects. Also that’s why Systems Engineering is so critical to deal with this new type of business model since it can provide a good solution to meet client requirements, wishes and needs within their solution area.

Business target and goal of ModuPark is to deliver a temporary or permanent modular parking garage using standard components such as HE steel and TT-Beam of precast concrete in order to quickly assemble, reuse and disassemble. In this regard BIM has played a significant role from the beginning of developing this business model. Especially, Ballast Nedam is anticipating that information management and collaboration between disciplines and stakeholders for a modular parking garage project can be efficiently designed by using BIM since parametric and
Towards an Industrialised Project Delivery System for the BC Industry

Object-oriented data of BIM in the supply chain management covering whole life-cycle are recorded and reused. Moreover, BIM can be used to efficiently and quickly generate the first visualized draft of the modular parking garage based on a number of choices. Also BIM takes into account offering other possibilities such as quantities take-off, cost analysis, structural analysis etc. (Ballast Nedam 2009). For this purpose, BIM has been actively introduced and applied to ModuPark in practice.

7.1.2 DATA COLLECTIONS AND ANALYSIS

This practical research is based on data collection and analysis from Ballast Nedam consisting of interviews with the relevant actors, the survey of some in-house document, and observation at Ballast Nedam Engineering. The analysis were made in the manner of the qualitative research as a set of research techniques in which data is obtained from a relatively small group of respondents and not analysed with statistical techniques. In other word, as the mode of inquiry mentioned in the chapter 5.3, this research analysed the relatively small amount of data collection but the concentrated and in-depth efforts were made to extract the core idea and understanding from the critical data. So, it is very essential to introduce what data from Ballast Nedam or ModuPark are inputted. Therefore, the goal of this chapter is to summarise the data collection that this research analysed and used.

First of all, several formal and sometimes informal interviews were done to understand the current situation in the ModuPark business and their expectations for the integrated system with both SE and BIM. The following table lists up the general information of formal interviews. All interviews were conducted with open question method. Among the above interviews, some of the important interview will be summarised in the appendix B.
<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>General information of interviewees</th>
<th>Main questions and goals</th>
</tr>
</thead>
</table>
| 1  | 3rd May, 2010 | Fred Groot (Director of Ballast Nedam Parking)  
Arjen Adriaanse (Participant, BIM manager of Ballast Nedam Engineering) Jaap Schreiber (Commercial manager of Ballast Nedam Parking) | 1. To check out if the previous survey on ModuPark is valid and modified  
2. To analyse the information structure and process of AS-IS situation in ModuPark business  
3. To discuss the information structure and process of AS-IS situation in ModuPark business |
| 2  | 19th May, 2010 | Joep Tunnissen (Dept Head Building Science & Innovation of Ballast Nedam)                           | To make my understanding on ModuPark and its engineering background knowledge more validated. Especially, parametric design matrix that I have developed will be revised and validated with interview results and his advice. |
| 3  | 28th May, 2010 | Paul Warmerdam (System Engineer of Ballast Nedam)                                                    | To ask some detailed questions on the SE software application which is Relatics recently applied in Ballast Nedam                                                                                                         |
| 4  | 20th May, 2010 | Jaap Schreiber (Commercial manager of Ballast Nedam Parking)                                         | To make my understanding on ModuPark and its engineering background knowledge more validated                                                                                                                                 |
| 5  | 21st May, 2010 | Ruud van der Meer (Senior CAD manager of Ballast Nedam Engineering)                                 | To ask some detailed questions on the BIM and SE software applications (their limitations and possibilities)                                                                                                               |
| 6  | 25th May, 2010 | Menno de Jonge (Director Innovation of Ballast Nedam & Strategic Information Manager of Ballast Nedam Infra) | To understand the current situation of SE and BIM in Ballast Nedam and validate findings from this MSc research. Main interview question: how Ballast Nedam have individually applied SE and BIM in practice, why integration between SE and BIM is so critical in Ballast Nedam and what possibilities and limitation in the proposed system |

*Table 5. Interviews list at Ballast Nedam*
Towards an Industrialised Project Delivery System for the BC Industry

Secondly, many in-house document of Ballast Nedam from SharePoint, some of which was received from company supervisors were studied. Also some confidential documents such as internal documents of 5Dinitive (5Dinitive website: 5d-initiative.eu/home.php) thankfully allowed with the permission of the internal website had some influence on the general direction of the proposed system in this research. The following table presents some of the important in-house documents that this research used.

<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Use case System Engineering/ Requirements Processing Ballast Nedam</td>
<td>Menno de Jonge &amp; Arjen Adriaanse</td>
</tr>
<tr>
<td>2</td>
<td>Project Structure and Coding</td>
<td>S.L van der Geest</td>
</tr>
<tr>
<td>3</td>
<td>A series of Work Instruction</td>
<td>F. van der Woerdlt</td>
</tr>
<tr>
<td>4</td>
<td>SBS/ WBS for parking garage</td>
<td>F. van der Woerdlt</td>
</tr>
<tr>
<td>5</td>
<td>Plan van Aanpak: Realisatie tijdelijke parkeergarage Hoofddorp</td>
<td>J. Schreiber</td>
</tr>
<tr>
<td></td>
<td>(No English title)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Eisen Controle Matrix: Kralingse Zoom</td>
<td>Group work</td>
</tr>
<tr>
<td></td>
<td>(No English title)</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. In-house documents list that this research importantly used

Also thankfully, Ballast Nedam Engineering provided some chances to closely observe how they use the BIM software and SE software. Especially, Dante van Wettum who is a CAD technician of Ballast Nedam Engineering did spare no effort and pain for me to show some similar cases currently-doing and to examine some prototypes of the proposed system.
7.2 INFORMATION PROCESS MODELLING (IDEF0)

IDEF0 is a kind of process modelling technique to provide a means for illustrating the activities or processes of the required system in detailed manner and for analysing their relationships (information or objects) that support the integration of those processes. IDEF0 is widely applied in a variety of disciplines such as research and business field since its flexibility and clarity for modelling activities and the information flows between them enable a diversity of modelling expert even a non-expert to evaluate the business processes. In this reason, IDEF0 is commonly used to reengineer their business processes by analysing AS-IS process model which allows to evaluate the present situation of the system and by presenting TO-BE process model which improves the system. (J. M. Dorador and R. I. M. Young, 2000)

![Basic diagram syntax of IDEF0 process modelling](image)

**Figure 34.** Basic diagram syntax of IDEF0 process modelling

The basic diagram syntax of IDEF0 modelling consists of activity boxes and relationship arrows in the above figure. An activity as a function or process in the

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43 J. M. Dorador and R. I. M. Young, 2000, "Application of IDEF0, IDEF3 and UML methodologies in the creation of information model"
existing (or proposed) system is represented by a box in IDEF0 diagram syntax. There are four types of arrows as followings (F. Tolman, 2002);

- The arrow entering the box from the top represents the control information.
- The arrow entering the box from the left describes the input material or information for the function. Inputs are transformed or consumed.
- The mechanism which performs or supports the function enters the bottom of the box. Mechanisms are not transformed, or consumed.
- The output of the function is represented by the output-arrow.

The following chapter 7.2 will apply this IDEF0 process modelling.

7.2.1 PURPOSE, VIEWPOINT AND SCOPE OF IDEF0 MODELLING

As shortly mentioned in the above, a process model is a representation of the activities (or processes) and the relationships between and among those activities in an existing or planned system. Since a collection of diagrams, glossary and text in the process modelling are differentiated depending on their scope, viewpoint and purpose, it is very important to clearly set up the scope, viewpoint and purpose in the beginning of every modelling in order to design the process models in effective and efficient way. The scope of modelling defines the modelling boundaries of the analysed (or proposed) system. Determining the scope of modelling is the most critical factor in IDEF0 process modelling since the model having too broad scope would become complex and the model in the case of too narrow scope would become too trivial. Also the purpose of a modelling should be defined to set up the reason to develop this particular process model and the viewpoint can explicate the perspective of the person or group developing the model. (R. Beheshti and E. Dado, 2005) In this regard, this chapter describes the process modelling which uses IDEF0 for business process reengineering of ModuPark and is described in the following chapter 7.2.2 and 7.2.3.

The purpose of process modelling by means of IDEF0 is to analyze the current process in Modular Parking Garage System as one of the industrialised construction

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44 F. Tolman, 2002, “Class Material: CT4270 Information and Knowledge Management in Building Process”

45 R. Beheshti and E. Dado, 2005, “Class material: CT4270 Knowledge Management for Building Design and Construction”
projects and to come up with a better process by integrating Systems Engineering and BIM. Especially, Business Process Reengineering is intended to be reshaped to an bottom-up (supplier-driven), parametric and dynamic business model by means of a comparison between AS-IS and TO-BE IDEF0 diagrams. The viewpoint is from a System developer or Information Manager who understands and analyses all related information flow. It means that input and output are a variety of types of all relevant information from certain information systems, software applications, etc. Mechanism and Control parts in the following IDEF0 modelling are also something related to information. Finally, the scope of IDEF0 modelling is the design phase of entire life cycle of the project. Actually, life cycle management of all relevant information is one of the main reasons why Systems Engineering should be integrated with BIM in the industrialised BC industry. More efforts for further research are necessary for other phases in the whole life cycle of the industrialised built deliverables. Therefore, this paper presents IDEF0 process modelling as a means for better information processing of an industrialised and bottom-up project delivery system, tackling with only the design phase.

Now the scope, purpose and viewpoint of modelling were clarified in order to properly and clearly establish the IDEF0 process model in the following chapters. Chapter 7.2.2 will illustrate AS-IS process modelling to understand and analyse information processes in a design phase of the current ModuPark business. And chapter 7.2.3 will propose the reengineered process model by integrating particular tools from Systems Engineering and Building Information Modelling in order to practically support better industrialised project delivery system which was theoretically proposed in the chapter 3.
7.2.2 AS-IS IDEF0 PROCESS MODELLING

Node Tree for C:\Users\PARKJA~1\Desktop\IDF0\BNMP A07.IDD

[A0] Design modular parking garage system (Ballast Nedam ModuPark)
   [A1] Analyze the program of parking garage system
      [A11] Pre-analyze the programs and requirements
      [A12] Discuss and analyze constraints and requirements
      [A13] Develop a conceptual model
   [A2] Re-design parking garage system
      [A21] Plot layout conditions
      [A22] Adjust levels for floors
      [A23] Array components for slabs
      [A24] Array other components (ramp and hall)
      [A25] Adjust all components as a final touch
   [A3] Develop detailed drawings
      [A31] Develop initially detailed drawings under conditions, rules etc
      [A32] Discuss some issues and find solution
      [A33] Finalize the detailed drawings with relevant specification

Figure 35. Textual Node Tree to show the overview of the AS-IS IDEF0 process modelling

Based on the several interviews with the ModuPark-related employees in Ballast Nedam and relevant in-house documents, this IDEF0 process modelling was finalised as the following sequential figures in this chapter. The process related to data collection and analysis was described in the above Chapter 7.1.2 and more detailed back-up data can be found in the attached appendix. This chapter starts with description of node-tree representing the overview of IDEF0 process modelling. The top-level activity is to design a modular parking garage in ModuPark. This is decomposed into three sub-activities which are to analyse the program of parking garage, to re-design a modular parking garage using existing information and to develop the detailed drawings.
A top-level (A-0) of AS-IS IDEF0 process modelling in the above figure consists of 3 input, 8 mechanisms, 2 controls and 1 output. First of all, the output is tailored Revit information as a design model of the modular parking garage. Ballast Nedam mainly uses Revit Structure 2010 of Autodesk as BIM software. ‘Tailored’ Revit information means that it is usually developed by modifying the existing Revit design model in the context of the clients’ requirements. Since a design solution of the current ModuPark represented by Revit is based on Modularised components, structural modellers (drafters) can re-use more and less the existing or previous design specifications. Secondly, at least four software and four employees are involved as mechanisms of IDEF0 in this design phase. Project manager and conceptual modeller are from Ballast Nedam Parking, a structural modeller is from Ballast Nedam Engineering and a specification specialist is from Grontmij which is special consulting firm for parking facilities. Each actors use the different software and tools such as AutoCAD, Tekla Structure, Revit Structure, MS Excel and Word. Thirdly, three main inputs which are 1) Standard component information, 2) Existing Revit information and 3) Requirements and constraints information from clients are invited to generate the final tailored Revit information as output. One of the interesting finding from the interview with ModuPark team is that initial requirements and constraints from clients are not that much. Especially, the more interesting thing is that the concept of ModuPark business is not to receive some official requirement documents in the bidding phase but to actively find the clients by themselves and figure out the requirements by Ballast Nedam themselves. It means that this business model is
totally different with the traditional delivery system of BC industry as well as it is
differentiated from some innovative integrated delivery contract such as Design-Build
contract. It could be regarded that the bottom-up characteristic (supplier-driven) of
the proposed delivery system is more and less applied into this ModuPark business
model. Finally, the design phase of modular parking garages in the Ballast Nedam is
controlled by external factors such as regulations, building codes and local policies
and by internal factors such as in-house business rules or strategies.

Figure 37. A0 level of IDEF0 process modelling for AS-IS ModuPark:

A0 diagram is one-step more detailed in the above-seen figure than one in the
previous figure. The design phase for the current Modular Parking Garage System is
illustrated and specified by three activities. The first activity is to analyse the
program of the parking garage system in the client’s context. Three input information
is needed to analyse the program of modular parking garages. Two of them are
feedback from the next activities and the only initial input is requirements and
constraints information for the modular parking garage. According to the interview
with ModuPark employees, this information is very limited and lack. In 6 ModuPark
projects so far, they started in the design process just with the very basic
information of clients’ requirements and wishes such as land boundary conditions
from Google map or the approximately-required number of parking spaces. Involved
employees only from Ballast Nedam have several meetings to discuss and develop
the conceptual design of modular parking garage. At this moment, there is no
external cooperation and discussion with consulting firm ‘Grontmij’ or prefabricator
Towards an Industrialised Project Delivery System for the BC Industry

‘Oostengh’. The first activity in A0 diagram produces two output information which are a conceptual design and the refined information of clients’ requirements and constraints.

The second activity in the above A0 IDEFO diagram is to re-design a modular parking garage system based on five main information inputs which are 1) Information related to standard components and materials such as HE steel and 16m TT-Beam, 2) Existing Revit design model (what they already designed for previous similar ModuPark projects), 3) The refined information of clients’ requirements and constraints, 4) A very conceptual design generated by AutoCAD (or even hand-drawings) and 5) A feedback from next activity (if necessary). One of the most interesting findings from interview with a drafter in Ballast Nedam is that they more and less use e parametric approach by manually handling Revit software. So they re-use the existing information by simply revising some already-done Revit design model, structural objects of which are based on standard prefabricated components and already included in all required specification information for construction phase. This activity is conducted mainly by so-called a drafter (Structural modeller in ballast Nedam Engineering) with Revit Structure software. And main output information is draft Revit information as a kind of BIM-oriented design information.

The Last activity in a design phase of modular parking garage illustrated in the above figure is to develop the detailed drawing with all specifications needed. In this process, co-operators such as participants from consulting firm ‘Grontmij’ or prefabricator ‘Oostengh’ is joined to discuss some specification issues and find the best solutions. Draft Revit information is inputted and tailored BIM-oriented information (with all specification information) is outputted as a kind of design model. If necessary to go back to the previous steps, the feedback loop is used. According to the interview and observation in Ballast Nedam, actually these processes are extremely iterative with several feedback loops.

The most attention-grabbing finding in the AS-IS IDEFO modelling is that the current design processes of modular parking garages in Ballast Nedam is not that much different with the traditional fragmented, iterative and inefficient processes in spite of the innovative and differentiated entire delivery system in Ballast Nedam ModuPark. They try to actively use 3D design model by Revit Structure 2010. But, the use of BIM is limited in spite of containing more enabling competencies and functions even in a software application such as Revit Structure. For example, they are quite positive and active to re-use the BIM-oriented information and most of tasks is still iteratively and manually done. And another significant finding from the interview and observation in the Ballast Nedam for AS-IS analysis is that they can insert in-house codes for SBS or WBS into each objects of Revit design model by using add-on program in Revit software in order to track SE-oriented information and make full use of xBS codes in the following phases of project delivery such as the on-site
construction management. Although it is relatively more active to apply a tool of SE comparing to the other companies, the more proper application of SE is still rare or to-be.

Figure 38. A1 level of IDEF0 process modelling for AS-IS ModuPark:

The first activity of A0 diagram, which is to analyse the program of the parking garage system, is specified as the above-seen A1 level of IDEF0 process model. It is made up of three sub-activities which are 1) to pre-analyse the programs and requirements, 2) to discuss and analyse more in-depth and 3) develop a conceptual design model by AutoCAD software. According to the interview done with a drafter in Ballast Nedam Engineering, they have several meeting in this phase and main output information is the conceptual design model reflecting the land boundary condition. And the processes are also iterative with feedback loop from the super-activities discussed in the previous figure.
Figure 39. A2 level of IDEF0 process modelling for AS-IS ModuPark:

The above figure illustrates how to re-design the existing Revit model in the very detailed. Main mechanisms are a drafter (structural modeller) and Revit software. First of all, he plots the layout condition of Revit model using the information from conceptual design model. Then, levels of floors are adjusted and standard components with objects such as slabs and columns of a modular parking garage are arrayed as floors. After that, additional standard components such as ramps and halls with staircase are arrayed. There are some options for these standard components. For instance, regarding ramp for going up and down to the next floor you can install on the floor or out of slabs. Then the previous arrangement of standard components should be adjusted. (Actually it is a very repetitive work)

An interesting thing in these activities is that not many standard components are used to re-design it since the main concept and advantage of modular parking garage is the open modular parking garage with natural ventilation system focusing on structural components, rather than considering all HVAC or architectural decoration. Although other sub-system (or components) such as signal system, lighting system and HVAC system should be together designed to be more realistic and make more explicit, ModuPark during this phase focuses on properly arraying all structural components which are standardised and prefabricated in cooperation with Oostengh. The fact that a design with a small number of standard components can be done has its own pros and cons. For example, it seems likely to be regarded as a limitation of design solution area reducing the flexibility. (This issue regarding less
flexibility or uncovered requirements will be more discussed in the chapter 8.3) but at least at this moment, they can easily generate their design solution already including relevant specification information in spite of the fully and well integrated design system that can cover this function in practice. Furthermore, as some enabling tools are step by step integrated and available knowledge and information is growing in ModuPark team, it would be enabled in the near future.

![Figure 40. Standard structural unit within building code](image)

Another interesting findings in the process of interview for AS-IS IDEF0 modelling is that they don’t have to that much pay an attention on building code which should follow to construct a parking garage. One example is in the above figure. A Revit drafter for ModuPark starts the design with objects-families which consist of several standard sub-objects. One of the important building regulations considering the construction of a parking garage is to save enough space to park or drive a vehicle, according to the relevant Dutch building code, NEN 2443 partly seen in the below figure. In normally and based on the personal experience, this kind of building codes that are too complicated documents are followed by manually and iteratively checking it out in the design phase or even the construction phase. Since this is one of the critical barriers to improve the productiveness of the BC industry reducing continues re-works and failures, it would better minimise it. (Alshawi 2007"46 and

46 Mustafa Alshawi, 2007 " Rethinking IT in construction and engineering"
Sommerville et al 2006\textsuperscript{47}) When designing a ModuPark parking garage, it would be somehow fitted by merely using the well-defined objects-families in the process of Revit design without any additional attention. (Note: 1. The way of dealing with this issue will be more discussed in chapter 8.2. 2. Ballast Nedam is still developing some variables of standard objects-families to fully and properly meet all related building codes)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image1.png}
\caption{NEN 2443}
\end{figure}

One more attention-grabbing issue related to the focus of this research is about the way of using SE tool in cooperation with BIM tool which is Revit Structure 2010 in this research. During this AS-IS IDEF0 process modelling, the contribution and cooperation of SE tool which is xBS technology in this research are more and less limited in spite of clearly-known advantage that SE provides a more clear information structure to manage in the entire project life cycle. More important idea is not what information they develop but how much they use. For instance, xBS technologies for a modular parking garage have well developed but they have not much applied. According to interviews, in some pilot projects of ModuPark, SBS code which has been already generated by SE specialist in Ballast Nedam was given to each object in Revit design model. There are two way of uploading these codes in the current Revit system of Ballast Nedam. They can do by using basic function of Revit system without any add-on. But, it is indeed iterative and time-consuming. So recently they purchased the Revit add-on program which is developed by ITANNEX and handy feed in-house SE codes to related objects in the Revit system in order to make the better use of them and well track them. (\url{www.smartrevit.com}) Even though they

\textsuperscript{47} James Sommerville et al, 2006 "Implementing IT in construction"
Towards an Industrialised Project Delivery System for the BC Industry

have xBS templates for a modular parking garage and some detailed-described excel spreadsheet for SBS and RBS of particular projects, there are not enough information to the relationship between objects from SBS and RBS. That is why they have to manually feed code-information into each object. In this regards, it is regarded that parametric approach linking clients’ requirement and design solutions is limited. So the parametric matrixes which will be discussed mainly in chapter 8.1.3 is necessary to be develop in order to actively make the most use of the existing coding system for the ModuPark.

Figure 42. A3 level of IDEF0 process modelling for AS-IS ModuPark:

The above figure illustrates how they can develop detailed drawings in more detailed by dividing into three sub-activities. First, ModuPark team with some relevant specification specialists from other company such as Grontmij Park Consult and Oostengh initially develops a detailed drawings and specifications under site conditions, constraints, etc. As explained in the previous A2 diagram, some of them such as NEN 2443 building codes would be fitted without any additional consideration if they just use the list of standard object-families. It is regarded as a good example of the bottom-up approach in ModuPark project delivery system in that they more focus on reusing their existing design-information and on maximising it within the competency of suppliers such as ModuPark. But, according to interviews with ModuPark team and a drafter in Ballast Nedam Engineering, they are still developing this bottom-up approach so as to more fully cover the related building codes etc. In this reason, the detailed drawing of current ModuPark is still made up
for by these processes of A3 level somehow following the conservative design process, which is top-down consecutive processes from program design throughout draft design to the detailed specification and iterative works with several discussions, and feedbacks. The more bottom-up approach in TO-BE ModuPark is very critical to completely and appropriately realise the anticipated vision of ModuPark by extremely diminishing time-consuming and iterative works.

So far, all processes from requirement analysis to design for a modular parking garage were modelled by means of IDEF0. During this AS-IS analysis, some interesting discussion points were discussed. As shortly summarised, three characteristics of the proposed industrialised project delivery system which are bottom-up (supplier-driven), parametric and dynamic has already been influenced more and less on the current ModuPark business. Some is already handy available and others are still in progress. Especially parametric approach should be much more tackled with by smoothly and tangibly liking a requirement mode and design model of ModuPark. In Next chapter presents TO-BE IDEF0 model based on the AS-IS IDEF0 modelling to reflect the proposed industrialised project delivery system supporting the integration xBS technology and Revit model. The most focused characteristic among three industrialised approaches is on parametric design.
7.2.3 TO-BE IDEF0 PROCESS MODELLING

TO-BE IDEF0 process modelling presented in this chapter 7.2.3 consists of three levels which are top-level (A-0 diagram), the detailed level (A0 diagram) and the more detailed levels (A1, A2, A3 and A4 diagram). Comparing to AS-IS IDEF0 process modelling, the purpose, scope and viewpoint of modelling are almost same. The only difference is that all activities are described with mentioning the facilitated tool since some tools, software and information system are to-be or proposed. Therefore, process-related tools and software in the mechanism part of TO-BE IDEF0 are not seen. Also, while participants such as project managers, specification experts and structural modellers etc in AS-IS are realistically specified based on the interviews, TO-BE model does not divide in such a way. When it is assumed that this integrated system is introduced, their tasks in ModuPark business organisation should be revised as well. But, the organisational analysis of ModuPark project delivery system is another issue and it would be left as further research.

Figure 43. Textual Node Tree to show the overview of the AS-IS IDEF0 process modelling

TO-BE IDEF0 process modelling presented in this chapter 7.2.3 consists of three levels which are top-level (A-0 diagram), the detailed level (A0 diagram) and the more detailed levels (A1, A2, A3 and A4 diagram). Comparing to AS-IS IDEF0 process modelling, the purpose, scope and viewpoint of modelling are almost same. The only difference is that all activities are described with mentioning the facilitated tool since some tools, software and information system are to-be or proposed. Therefore, process-related tools and software in the mechanism part of TO-BE IDEF0 are not seen. Also, while participants such as project managers, specification experts and structural modellers etc in AS-IS are realistically specified based on the interviews, TO-BE model does not divide in such a way. When it is assumed that this integrated system is introduced, their tasks in ModuPark business organisation should be revised as well. But, the organisational analysis of ModuPark project delivery system is another issue and it would be left as further research.
The above figure is the top-level of IDEF0 process models for design phase of the better ModuPark project delivery system that I suggest. Some important differences are marked in red of the figure. First, I recommend in the mechanism of IDEF0 that client be actively but limitedly participated in. In other word, the client as one of the mechanisms is called in during the design phase in order to ensure more clients’ involvement. By doing so, the suppliers (ModuPark in this research) clearly provide alternative rooms on their design specification and clients actively answer the questions that are predefined by suppliers and are automatically generated some prototypes fitting their just filled-in requirement. But at the same time, the clients’ involvement should be limited by certain process to provide the initial requirement data as parameters and make a contract within the integrated system and but it is critically necessary for better supplier-driven project delivery system to make a clear distinction between clients’ and suppliers’ responsibilities. In this regard, business rules even in the design phase would be more imperative to control this kind of interactive processes between clients and suppliers. Also systems engineering methodology should more and more influence as the integrated design system would be developed in practice and existing information from ModuPark projects that will be done would be accumulating in order to handle enormous amount of extending information.

Also some new and interesting inputs are existing xBS information and contract information such as official contract documents. First, we can re-use the existing xBS information. We don’t have to develop every time. But, a critical factor to re-use is
related to how it is generated and managed in well structural manner. By using design-related information generated by the method of an object oriented systems engineering, the current xBS technologies in practice would be improved. (Since this chapter focuses on the information process, this issue will be discussed in the chapter 7.2 about information structure part of the integrated system)

And, another interesting input is information related to making a contract. In terms of making a contract between client and providers, two different types could be roughly divided. In the traditional way of working in the BC industry, a contract is made after design-information is illustrated. In this case, the contractor as one of main providers just constructs their deliverables as designed in the previous phase. (It is close to Top-down approach described in chapter 3.3) Since there are not that much room for design changes, it is often a cause to lead to project failure. (Pekka Pakkala, 2002\textsuperscript{48} and Jilei Wang, 2008\textsuperscript{49}) In this regards, many variables for the integrated project delivery was introduced and applied. One of the commonly-used integrated project delivery types is Design-Build. (Beard, 2006\textsuperscript{50}) In the case of Design-Build contract, the contract just based on a few clients’ requirements is made before kicking-off of design phase. The current ModuPark project delivery system is also close to Design-Build contract taking most of all further risks to Ballast Nedam. But, this TO-BE process model proposes clients’ involvement during the design phase to clearly and actively provide their own requirements and to check out what will be delivered. Then, a contract between clients and providers is made based on all agreed design specifications as much as reducing the risk of project failure that will be happened in the construction phase or later on. (Note: This research does not tackle with the content of the proposed contract type. It would be left as one of further researches since this research focuses on design-related information processing and structuring.)

And at least four outputs information in the above figure are generated along this IDEF0 process model. One is information related to a contract that is made in design process as proposed. The others are BIM-oriented design information, revised xBS information and order information of the standard components. With the following detailed IDEF0 diagrams, how can they are outputted is described.

\textsuperscript{48} Pekka Pakkala, 2002, “Innovative project delivery methods for infrastructure: an international perspective”

\textsuperscript{49} Jilei Wang, 2008, “Integrated project delivery: achieving relational constricting through traditional project management methods”

\textsuperscript{50} Beard, 2006 “Design-Build Project Delivery”
Figure 45. A0 level of IDEF0 process modelling for TO-BE ModuPark:

The design phase of TO-BE IDEF0 information process model consists of four detailed activities which are 1) Use parameter design tool, 2) Use system integrator, 3) Make a contract and 4) Specify specification of components and assembly. Among them, the second activity is not participated by both client and provider. According to this process is very iterative and time-consuming work in spite of simplicity of the work, it would be critical to be automated in the proposed integrated system in order to efficiently run ModuPark. (This part will be more specifically modelled in the chapter 8.1 using xPPM method.) Client as an information-dealing mechanism is involved in using parametric design tool to provide their own requirements as parameters for a modular parking garage and finally signing a contract with ModuPark team. And ModuPark providers including project manager and designers are involved in two processes which are to make a contract and to specify specification with final touch before ordering the standard components and assembly.

In output information, most design-related information could be generated from the second activity. First, even though BIM-oriented design-information provides a verity of functions and possibilities with add-on utilities, it mainly means 3D visualised representation in this process modelling. Actually, as precisely defined in the chapter 4.1, the concept of BIM is definitely much more than just 3D visualisation itself. Furthermore, the most of currently-developed BIM software such as Revit of
Autodesk or Project Wise of Bentley etc. enables more functions to provide than the just 3D drawing tool fully based on Object-Oriented paradigm. Although BIM-oriented design-information may include xBS-oriented information in the perspective of the definition matter, this IDEF0 modelling divides in order to well illustrate how they are interacted and integrated.

See input information from a process to next process in the above figure. A1 delivers input data for the parametric design to A2. This is filled in by clients. Therefore, the user-friendly interface to receive their requirements is very important. Some example of user interface will be presented in the chapter 8.1.3 but the issues on how these interfaces can be more user-friendly are out of this research. Furthermore, one of successful factors for ModuPark parametric design linking between clients and providers is what requirements should be necessarily filled in by clients. Based on interviews with ModuPark team and some related engineers in Ballast Nedam, some critical requirements for generating a design solution of modular parking garage were selected. This issue will be presented also in the chapter 8.1.3 but it would be necessary to do detailed further researches on the selection of parameters. Specification information between A2 and A3 is sent. But, it does not mean all specification information for a modular parking garage designed. All specification information is delivered out by BIM-oriented information and xBS-oriented information. A part of it which is only related to making a contract or facilitated for the client is specially selected and sent. All specification information would be a kind of knowledge asset to ModuPark business actors that should be kept in-house. Only information enough to understand the conceptual ModuPark design such as simple solid model representing in 3D is delivered to the next A3 process. The following diagrams more specify A1, A2, A3 and A4 in one-level detailed.
The above figure more illustrates A1 which process is use parametric design interface tool in the integrated system. All sub-activities are conducted by client openly without any controls. The current ModuPark website provides short description of ModuPark, possible projects information with previously-done references and nice-looking pictures etc. (www.modupark.nl) According to interview with ModuPark, a lot of efforts have been making to find possible clients through in-house organisational network and newspaper etc. I suggest that this website be more interactive in supplier-driven manner. By using parametric design methodology, the clients easily and quickly check out possible design solutions and the suppliers immediately generate all necessary information such as the production-information of prefabricated standard components as well as detailed design-information. As the first step to do so, the website with the function of easy-prototyping using parametric design is visited and initial clients’ input-information for parametric design is received. This process is divided into 1) Visit the ModuPark website with the function of parametric design and log in, 2) Click and open a parametric design tool in the website and 3) Filled in input-information sheet for easy-prototyping. These sub-processes are done by clients in the website. Maybe it would better ask clients to some basic information to log in this parametric prototyping functions of the ModuPark website in order to track their requirements and improve it with feedback. Rather than to describe all clients’ general wishes and functional expectations for a modular parking garage in the textual manner, clients simply provide the initial
Towards an Industrialised Project Delivery System for the BC Industry

design requirement for a parametric prototyping function by filling in pre-defined questionnaires on a clients’ requirements. According to the interview with ModuPark team, the clients can provide the very small amount of functional requirements. More interestingly, they are not that interested in detailed specification-type requirements and complicated building codes as well as they don’t have any knowledge and expertise to describe that kind of all detailed requirements. Therefore, we can ask the clients in the website to provide a very limited number of initial requirements, which is more close to the functional description of deliverables. (Note: A question on what kind of requirements should be filled in by clients is very critical and it will be more discussed in the chapter 8.1.3)

Figure 47. A2 level of IDEF0 process modelling for TO-BE ModuPark:

The above figure illustrates A2 level of IDEF0 process modelling for TO-BE ModuPark. It specifies three detailed sub-processes which are 1) Tailor Revit design model by parametric design system, 2) Revise generic model system based on tailored Revit design model and 3) Generate all necessary information and representation from System integrator. As you can see, there is no additional mechanism in the proposed A2 process because I suggest most of these sub activities be automated in this integrated system. According to AS-IS IDEF0 process modelling as well as the interviews with a modeller and engineers in Ballast Nedam, it was pointed out that these processes for design development are very iterative and time-consuming in practice due to easily-happened change order and unclear initial requirements and constraints from clients. It would be more efficient way of working if these iterative tasks are automated in the integrated system. The core thing to be automated is to link the client’s requirements to related-objects in parametric manner.
Towards an Industrialised Project Delivery System for the BC Industry

First of all, A21 sub-process brings three inputs into play, which are 1) Input data from previous user interface for parametric design, 2) Standard components information and 3) Existing Revit design model. And the tailored Revit design information is generated in this sub-process and delivered to the next step. Secondly, A22 sub-process deals mainly with the Generic Model System, which is a kind of neutral Meta-Model with a generic but extendable architectures of a deliverables (in this research, the generic model for a modular parking garage) and which contains all information for the built facilities (in this research, it is all design-related information but cost, schedules, organisation information would be possible using other xBS structure), based on Object-Oriented Systems Engineering. The final step is to send the required information from the revised system integrator so far. For instance, the conceptual design representation would be shown to the clients or the detailed specification immediately prepared based on the existing information (Bottom-up approach) would be delivered to the providers.

When taken as a whole, all sub-processes of A2 are core parts for the proposed SE-BIM integrated information system to support the better industrialised project delivery system. In other worlds, this system integrator is very critical as well as new functions and sub-systems are absolutely necessary to be newly introduced in the current way of working of ModuPark. In the chapter 7.3.3, 8.1.2 and 8.1.3, these issues are more precisely tackled with.

Figure 48. A3 level of IDEF0 process modelling for TO-BE ModuPark:

The above figure illustrates the next process, A3 which is about to make a contract between clients and suppliers. Without any bidding process only depending on the low price, the clients obviously deliver their requirements within pre-defined
parametric design system and the SE-BIM integrated information system automatically and immediately generate all required information such as estimated cost and 3D visualisation. Now clients can leave the ModuPark website to find other providers to meet their uncovered expectation or they can make a contract to build it as if we buy a product at online-shopping mall. Most of these sub-processes in A3 also are automated without any extra mechanism. But, it would be necessary that the client and ModuPark providers participate in a moment to check out all details and to officially make a contract.

Which contract will be used and how? Especially, how detailed information should be shown to clients? Those kinds of research questions are also very attractive and important to implement this supplier-driven and parametric approach to industrialisation in the BC industry. But, this research is not in depth tackled with since it is out of scope and the focus of this research is to link all information each other.

![Figure 49. A4 level of IDEF0 process modelling for TO-BE ModuPark](image)

Lastly, A4 level of IDEF0 process modelling for TO-BE ModuPark is more specified with two sub-processes which are 1) Estimate quantities of all modular components and 2) Order the estimated components to a co-operator. SBS in xBS architectures is the most important because it can be linked to other structures. A system is divided into several sub-systems and this sub-system is also decomposed to several components. Again one step in depth, a component consists of several objects. Quantity-takeoff can be simply conducted through the hierarchal structure of SBS.
Furthermore, the information of each component in the required deliverable can be linked to other type of information by uploading SBS objects to cost information or schedule information.

One thing that I would like to point out is about why a component is more important than an object which could be in the hierarchal lowest level of SBS. Actually, most of the basic functions in the current BIM software work in too object-based way. Even if each objects such as a wall A or a column B has their own information pre-defining the relation each other in geometrically parametric manner, more functional and practical are manually defined by end-users. For instance, the Revit design system has a function to define all related objects as a family. According to BIM Handbook (Eastman et al, 2007), the locally-defined objects are important as BIM experiences are matured. A modeller for ModuPark has already defined their own objects-families to re-use based on standard industrialised concept of ModuPark. Therefore, the component-based approach to the industrialisation in the BC industry such as a prefabricated functional unit would be more suitable than the object-based approach such as each standard material. More discussion related to this component-based design will be practically dealt with in the chapter 8.1.3.

So far, the integrated system for industrialised ModuPark delivery was proposed by reengineering their process and by actively applying xBS technologies as linking structure. In the process of these analysis and proposal, some new information was introduced and set up. Next chapter will deal with these information structure issues in ModuPark delivery system.
7.3 INFORMATION STRUCTURE MODELLING (UML)

Previously, ModuPark business process in terms of design information processing was reengineered by finding out the current situation and analysing some limitations throughout several interviews with ModuPark-involved employees in Ballast Nedam and by proposing the better processes for the industrialised project delivery system facilitated by the complete integration of the existing xBS and Revit model. During the course of developing IDEF0 process modelling, all inputted and outputted information was simply mentioned but how it looks like in the system was not described. Main goal of this chapter is to illustrate the structure of all invited information in the integrated system by means of UML. First of all, chapter 7.3.1 will briefly introduces the purpose, viewpoint and scope of information modelling like chapter 7.2.1. And then, the current structure of ModuPark project delivery system in terms of design-related information will be modelled and analysed based on several interviews in Ballast Nedam. Chapter 7.3.3 will propose the better structure to more properly and fully integrate all information generated by xBS technology and Revit system.

7.3.1 PURPOSE, VIEWPOINT AND SCOPE OF UML MODELING

The main purpose of this information structure modelling by means of UML is to conceptually design the structure of the integrated system for the Better ModuPark project delivery reflecting on the object-oriented system engineering. To do so, first of all, the current information structure in the phases from will be analysed, based the interviews and observation in the Ballast Nedam. (Note: the details can be found in the appendix B, the summary of data collection) And then, UML models illustrating what information should be generated, stored and tracked in the integrated system will be presented in order to support the previously-set TO-BE IDEF0 models. Especially, one of the critical purposes of this modelling is to propose some new parts of information structure for better implementation of the parametric design method linking between clients’ requirements and supplier’s specifications in the ModuPark.
Towards an Industrialised Project Delivery System for the BC Industry

Next, scope of this UML modelling is same as the previous IDEF0 modelling. So, this modelling focuses the phase from clients’ requirement to design development. Other phases in the entire ModuPark project delivery system will be left for further research topics. And, the point-of-view of modelling UML is all on design-related information generating and processing. In this viewpoint, certain person such as a client is regarded as an object that can come up with their requirement information in UML modelling. Furthermore, Ballast Nedam has actively been developing and using the in-house manuals for applying their own xBS technologies. All information which is generated by Excel files and Word file based on in-house xBS manual in Ballast Nedam is also regarded as an object in this modelling.

7.3.2 AS-IS INFORMATION STRUCTURE MODELLING FOR INTEGRATED SYSTEM

![Diagram of Functional needs, Performance Requirement and Solution Concept]

Figure 50. Functional needs, Performance Requirement and Solution Concept (Source: Dik Spekkink, 2005)

Before analysing the AS-IS information structure for ModuPark design system, the definition of the terms that are mainly dealt with in this chapter is determined. Some routinely-used terms such as a requirement and design would be misunderstood. Also in the interviews with ModuPark and discussions, it was discovered that some concepts or definitions of terms are overlapped or differentiated depending on the

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context or people. The most confusing term is ‘Requirement’. Some interviewees sometimes mentioned requirements as a kind of specification. But, in this research focusing on the phases from requirement analysis to design development, design information, which could be both a text-based specification and visualised representation of deliverables, means the outcome information generated based on analysis of requirements that initially received from clients. Moreover, the requirements can be divided into Functional Needs and Performance Requirements as seen in the above figure. (Francoise Szigeti and Gerald Davis, 2005) But unfortunately, clients can never fully describe their own parts such as the performance requirements of the wanted deliverables and even their wishes and needs. In this regard, several tools and methods such as xBS technologies of Systems Engineering have been introduced in order to conduct the integrated delivery such as DB contract-type project. For instance, according to the Dutch handbook on Systems Engineering in the BC industry (RWS, 2009), all three areas are dealt with using FBS (Function Breakdown Structure), RBS (Requirement Breakdown Structure) and SBS (System Breakdown Structure). But, solution providers do not have to fill in all xBS by themselves. It is impossible for provider alone to guess all functional need of clients and required performance of built facilities. Anyhow, we need input from clients to start filling in xBS template. That is the clients’ requirement in this research. This kind of requirements is very dynamic in the context of clients. In every industrialised projects, clients’ requirements should be contextualised by the client themselves by making their own decisions as well as taking their own risks.

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52 Francoise Szigeti and Gerald Davis, 2005, "Performance based building: conceptual framework"
Towards an Industrialised Project Delivery System for the BC Industry

Figure 51. SBS for a normal parking garage project in Ballast Nedam.

An attention-grabbing finding that should be made in definition matter for UML modelling is about the mingling use of FBS, RBS and SBS in practice. In the process of investigating in-house RBS documents, it is discovered that this documents contains not only Requirement (related to performance requirement in the above figure) but also functional wishes, regulations, building codes etc. The too complicated and mixed to handle, manage and track the increasing information in design solution. Ballast Nedam has recently applied the advanced coding system to deal with these issues. But, the coding system cannot treat the complexity of information structure itself. Therefore, it is necessary to set up distinguishable clearly-guided templates for a certain project type.
Another interesting discussion that should be done before this UML modelling is about the links between Requirement Model and Design Model. Arto Kiviniemi in his PhD research \textsuperscript{53} (Title: “Requirement management interface to building product models, 2007) points out that a project in the BC industry generates several different types of models. In the almost every phases of life-cycle, new types of models are set up in the beginning, processed during certain phase and delivered to next models. So, it is very critical factor for a successful integrated project delivery to link the different types of models. His research presented two kinds of linkages between the requirements model and design models, which are direct links and indirect links. And his research applied the internationally-standardised models such as IFC. Not only links between two different models are too simple to apply in practice but also the top-down approach of developing the information model such as IFC models is still to-be to fully cover the whole system in the BC industry. \textsuperscript{54} Therefore, it is necessary to develop the relation-objects as linkages between different models such as requirements, designs, construction, maintenance models etc. in more parametric manner in order to ensure more usability in practice. And for the time being, it would better focus on the bottom-up modelling of in-house development covering the practically certain project types, strategically enabling the re-use of the existing information and sustainably accumulating their knowledge to support their business strategy and to reinforce the in-house system. (Note: In this chapter, terms of top-down and bottom-up are used in the different definition of chapter 3. While

\textsuperscript{53} Arto Kiviniemi, 2007,”Requirement management interface to building product models”

\textsuperscript{54} Sander van Nederveen, 2000 ”Object tree”
the bottom-up approach means more supplier-driven situation in the chapter 3, it means a modelling way to start with explicit representation of distinct part.55)

Based on the above discussions about some definition matter and practical use of Systems Engineering in Ballast Nedam, the following UML models for an AS-IS analysis of ModuPark design-information structure are presented.

![Diagram of Requirement Model and Design Model in Ballast Nedam](image)

**Figure 53. Simply abstracted AS-IS UML: Requirement Model and Design Model in Ballast Nedam general**

The above figure illustrates information structure of the requirement model and design model in Ballast Nedam. In general, the requirements models and design models in a certain project are related to each others. Ballast Nedam has actively applied xBS technologies as one of Systems Engineering tools to meet the needs and requirements of clients and to efficiently manage projects. Both models are developed by Ballast Nedam in the integrated delivery contracts such as Design-Build contract. And xBS technologies are used in both requirement models and design models. For instance, FBS (Function Breakdown Structure) and RBS (Requirement Breakdown Structure) are a part of requirement model which contains all needs, wish

55 Rafael Sacks et al, 2004, “Parametric 3D modelling in the building construction with examples form precast concrete”
Towards an Industrialised Project Delivery System for the BC Industry

as well as the requirements of clients. And SBS (System Breakdown Structure) is a kind of design specification model. WBS (Work Breakdown Structure), OBS (Organisation Breakdown Structure), CBS (Cost Breakdown Structure) and other xBS are developed in these phases if needed. It is necessary to divide the design models into design specification model and design representation model. In the concept of BIM, the design model developed by BIM software could contain all relevant information. For example, ProjectWise is a packaged solution from Bentley Systems aimed at helping manage, find, and share CAD and geospatial content, project data, and Office documents. But, in Ballast Nedam, they have so far separately applied several CAD tools, BIM software and SE tools. Three SE tools, 1) Simple MS Excel spreadsheet, 2) MS Access and 3) Relatics (www.relatics.com) are used in the current practice of Ballast Nedam. Regarding BIM software, Revit packages of Autodesk are mainly used. Based on the general understanding of the requirements model and design models in Ballast Nedam, the following AS-IS information structure of ModuPark design system is modelled by means of UML.

In the above figure, the current information structure of ModuPark project design system is simplified. Design Model and Requirement Model of ModuPark are related to each other. While Requirement Model is usually generated by simple documenting
systems such as MS Excel spreadsheet or MS Word, Design Model is created by a verity of tools such as Revit Structure, AutoCAD, MS Excel, MS Word. According to interviews with ModuPark team, even simple hand-drawings are important in very early moment of developing Design Model. These tools for Design Model are divided into two kinds which are Representation-type Model and Specification-type Model. (Note: There could be also other types of Design Model. But, two main types are invited since the focus of this research is on xBS from SE and Revit from BIM) Main goal of Representation-type Design Models is to visualise the deliverables built so as to easier communicate with other disciplines. Representation-type Design Models in the ModuPark design system are hand-drawings by a initiator in ModuPark team, CAD-drawings by the conceptual modeller using AutoCAD and BIM-type 3D representation by the structural modeller or a drafter using Revit Structure 2010. (Note: The difference of CAD and BIM was discussed in the chapter 4.1) In spite of the difference of the detail level and the phase used, their main goal is to generate the visualised representation of a modular parking garage. Another type of Design Model is the specification information
7.3.3 TO-BE INFORMATION STRUCTURE MODELLING FOR INTEGRATED SYSTEM

As the figure seen in the above, System Integrator consists of two main system, which are the parametric design system and generic model system. First of all, the main function of the parametric design system package is to develop the design of Modular parking garage in the parametric manner based on the client’s functional requirements inputted from the proposed interface of the ModuPark website. In this system part, xBS objects such as requirement objects or system-component objects are called and their pre-established liaisons between RBS and SBS enable the parametric design for ModuPark projects. This part will be more illustrated in the following figure 56. Secondly, the main role of the Generic Model System is to help make the re-use of the existing information from the previously-done ModuPark saving all BIM-integrated information (in this research, Revit-integrated information) in more structured way. Also this system part facilitates the generation of the required information or representation since it coordinates the access authority of the certain information in ModuPark business system as well as it delivers the required information in the required forms. The Generic Model System is a kind of meta-model which pre-define the certain information structures and templates for a modular parking garage and which can be specified and constructed in the context of the
projects and clients. From the parametric design system, some information in the Generic Model System are filled in and revised. This part will also be more concretely explained in the following figure 56.

![Figure 56. Simply abstracted TO-BE UML: Information structure modelling - 02](image)

The above figure simplifies the information structure of the Parametric Design System mentioned in the previous figure 56. Matrix Objects to establish the relation between different xBSs are needed to design a modular parking garage in the parametric method. Matrix Objects are more specified in Matrix Reference Objects. Matrix Reference Object contains some information to establish the Parametric formulation in text. It would be necessary to develop and maintain this kind parametric design system maintain and facilitate to keep adjusting and improving the parameters depending on their business strategy. In the Parametric Formulation Objects, the related xBS Objects with their own properties are called and the values of parameters are generated based on the associated Matrix and Matrix Reference. Parameters are divided into dynamic and static ones. The values of Dynamic parameters for the parametric design of a modular parking garage are every times changed depending on the context of projects and clients’ requirements. The values of these dynamic parameters are filled in by clients or providers. For instance, both the total number of structure units and the arrangement type of parking slots are Dynamic parameters. While the arrangement types such as Vertical type or Angled type are a Dynamic parameter decided by a client’s intention, the total number of structure units is important for the providers. And there are Parametric Computing Objects to actually conduct the information-coding of the Parameters. Finally, all information generated from Parametric Computing Objects is saved as Specification Objects defined.
The Specification Objects presented in the figure 57 let the generic model objects to revise and update their information in pre-defined structural format. And the Specification Objects also can manipulate the Revit Objects Family by updating or revising their information. Prototyping System means an operator to generate the visualised representation with the critical information. All relevant information for prototyping system is provided from Generic Model system consisting of Generic Objects. There are several types of prototyping system as occasion demands arises in practice. For example, the order information of the standard component is collectively generated and managed based on the Generic Model. A prototyping example in this integrated system is the prototyping system using Excel-based Revit design since this research focus on design-information from clients’ requirement to development. In the Client Interface using prototyping system, clients make their decision whether they make a contract of modular parking garage project with ModuPark or not as if they purchase other industrialised products such as cars and electrical goods.
Prototyping system using Excel-based Revit design software needs two main inputs illustrated in the following figure. One is a group of Revit Object Family and another is its coordinator part. To automate this representing function, the value of the coordination for each Revit Objects Families should be automatically generated and given. The current Revit software provides this function to easily manipulate using Excel spreadsheet and Ballast Nedam has already developed this kind of Excel spreadsheet to generate the 3-D representation with all BIM-oriented information for ModuPark design. But, each data in this kind of Excel spreadsheet is manually inputted. Furthermore, the value of the coordination for each Revit Objects Families is manually calculated and given. According to PhD research (Reinout van Rees, 2006), these time-consuming tasks arise some errors and it should be minimised. Therefore, TO-BE integrated system for industrialised ModuPark delivery system proposes the automation of these time-consuming tasks. The value of the coordination for each Revit Objects Families can be parametrically generated by the pre-definition of relations between SBS and SBS presented in the above figure.

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56 Reinout van Rees, 2006, "New instruments for dynamic building-construction: computer as partner in construction"
The above figure illustrated the package of Generic Model System in the simply abstracted manner. This package has at least 5 classes, which are Generic Model, Access Authority Manager, Prototyping system, Generic Model Objects and Generic Model Structure. Generic Model consists of significantly many Generic Model Objects which contains all information covering from SE-oriented Products to BIM-oriented products. The System Breakdown Structure (SBS) for a modular parking garage is hierarchically decomposed into the generic model objects through the component level. These generic model objects are linked to individual pre-defined object in the Revit System or IFC objects as the promising international standard. In this ModuPark system, it is unnecessary and impossible that all objects in BIM are contained. In these issues, there are several solutions. One of them is the Object Tree developed by Sander van Nederveen. (Sander van Nederveen, 2000) The starting point of the Object Tree concept is to directly make an instance model and leave out the idea of instantiating conceptual models. The concept of this Generic model seems to be in line with the Object Tree in that it is a kind of meta-model. The following figure presents the main concept of Object Tree.

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Sander van Nederveen, 2000, “Object tree: Improving electronic communication between participants of different disciplines in large-scale construction project”
Object Tree contains System Objects and Related Objects. These Object includes several different types of characteristics. The concept of Generic Model System follows same principle with Object Tree. Since an instance model for the certain project type (in this research, it is a modular parking garage) could be made in practice, this kind of meta-model enables the industrialised project to directly be usable in the very operational level and possibly reuse them accumulating their information to improve it. Especially, a modular parking garage project, as a pilot project types among many potential industrialized projects, consists of not that many objects or components because the prefabricators in the entire supply chain of the industrialised project delivery provide the limited number of prefabricated solution reflecting on market conditions. Even if much more prefabricators are involved and far more standard components are available in the market, the limited number of participants and options would be taken into account in practice depending on the strategy and business capacity. Therefore, it is more potential and beneficial for the industrialised delivery system to apply the proposed Generic Model.

So far, the information structure in the proposed industrialised project delivery system was discussed with some abstracted UML models. Because the proposed
information structure was illustrated in very static manner and separately with the information process modelling part, the next chapter will illustrate the some important part in more integrated ways by using xPPM modelling and then some prototypes of the propose system will be presented. Based on that, some practical discussion will be addressed.
8. PROTOTYPING: INDUSTRIALISED PROJECT DELIVERY SYSTEM FOR MODUPARK

In the chapter 7, the conceptual models as a representation of the proposed industrialised project delivery system were presented with separately developing information process and structure part. The main goal of this chapter is to present some practical prototypes of the conceptual models and to validate the proposed industrialised project delivery system by implementing it along the earlier-proposed conceptual model.
Towards an Industrialised Project Delivery System for the BC Industry

8.1 PROCESS TO PRODUCT MODELING (XPPM)

So far, two types of information modellings were applied to analyse the present situation of ModuPark project delivery system and to transform the better industrialised approach which theoretically proposed in the chapter 3. The previously-developed conceptual models will be integrated into a single project delivery system. It will be modelled by means of xPPM (or GTPPM) which is a kind of the integrated modelling technique. As some prototypes, its representation will be presented by simple Excel spreadsheet. First, chapter 8.1.1 will set up the purpose, viewpoint and scope of the following modelling technique and briefly introduce the basic syntax of xPPM. And the second sub-chapter will model the integrated (and automated) system by means of xPPM modelling techniques. Finally, chapter 8.1.3 will present some prototypes to show how it looks like.

8.1.1 PURPOSE, VIEWPOINT AND SCOPE OF XPPM AND SYNTAX

As the previous modelling part did, the xPPM modelling in this sub-chapter also start with briefly defining the purpose, viewpoint and scope. First, the purpose of the xPPM modelling is to integrate the previously-presented two different models, one of which is the information process modelling by means of IDEF0 and another of which is the information structure modelling using the abstracted class diagram of UML. In this research, system integrator means a system to automatically conduct the parametric design part and to continuously manage the generic model tracking the revision and updating the information in the proposed industrialised delivery system of the ModuPark project. Actually, the definition and function of the system integrator was in brief introduced in both IDEF0 and UML modelling part. This system integrator is an important SE-BIM integrating part to mainly have to develop in the TO-BE ModuPark. Therefore, the purpose of xPPM is to in depth explore the system integrator part in the proposed system by modelling together with information process and structure.
Towards an Industrialised Project Delivery System for the BC Industry

The above figure presents the scope of this xPPM modelling in this research. While the previous process modelling and product modelling covered from clients’ requirement analysis using the proposed user interface to design development in the industrialised project delivery system, the xPPM in this chapter focus on bridging issues among several applications such as user interface and Revit. (Note: It is assumed that these applications in the prototype part can be manipulated or represented by MS Excel. Actually, it is all possible or already in use in Ballast Nedam to handle Revit design system by using Excel, to generate the information from user interface in Excel format and to establish the xBS information in Excel format.) And the viewpoint of the xPPM modelling is all on design-related information generating and processing, which is same as the previous ones.

The following table summarise some basic syntax in xPPM stencil. As an advanced modelling technique, xPPM provides a verity of sophisticated functions to facilitate to develop the intended system. For instance, the information structure can be actively illustrated and fully developed within xPPM modelling and it can be represented and generated by Excel spreadsheet. Furthermore, SQL code or C++ code can be created from xPPM models. But, the main use of xPPM in this research is not for creating that kind of sophisticated information but for fully illustrating the propose system in the process-product integrated manner.
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<thead>
<tr>
<th>Shape symbol</th>
<th>Name</th>
<th>Description</th>
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<tbody>
<tr>
<td></td>
<td>Initial State/ Final State</td>
<td>They represent the start of a newly created process or completion of a certain process.</td>
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<td></td>
<td>Internal High Level</td>
<td>Conversely, Internal High Activity represents Activities within the scope of the PC Process Model. AS a High-level Activity, it has a name and refers to its more detailed Activities</td>
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<td></td>
<td>Internal Detail</td>
<td>Internal Detail Activity represents Activities within the scope of the PC process modelling effort. As a Detail Level Activity, its information inputs, outputs and processing are important to capture.</td>
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<td></td>
<td>Static Info Source</td>
<td>It represents information coming from a static source. A static information source is static because it cannot be added and removed dynamically. Static information is assumed to be established through an organizational procedure. Examples include building codes, PCI standards, corporate standards, etc.</td>
</tr>
<tr>
<td></td>
<td>Dynamic Info Repository</td>
<td>It represents information coming from a dynamic source. While the above Static Info Source is the fixed information set, Dynamic Info Repository can be updated and revised.</td>
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<td></td>
<td>Decision</td>
<td>It represents states where decisions affect the process. Examples are a bid result or approval of a material sample. It usually has a Yes or No outcome, but it may occasionally have more than 2 alternatives</td>
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<tr>
<td></td>
<td>Information Flow</td>
<td>Represents the flow of information. Each Information flow transfers particular pieces of information between two Activities in one direction.</td>
</tr>
</tbody>
</table>

Table 7. The basic syntax of xPPM (Source: GTPPM User manual<sup>58</sup>)

---

<sup>58</sup> Ghang Lee, 2004, "GTPPM User manual rev 04"
8.1.2 INTEGRATED SYSTEM FOR MODUPARK ILLUSTRATED BY XPPM MODELING

The above figure presents the high level of xPPM modelling, which consists of three processes. The first function in the high level is to tailor the existing design model by parametric design methodology. And the second one is to revise the generic model based on tailoring design model. Then the required information or representation from revised generic model is generated. These processes are derived from the previously-proposed IDEF0 process modelling. While other processes in the IDEF0 models are conducted by the current participants and the existing software, this part with three new processes is totally new and to be developed as an system integrator. And previously, since these processes are all very time-consuming and iterative in spite of the simplicity of tasks, the automation of these processes in the integrated system is highly recommended. Now taking into account on the both process and product modelling, this integrated and automated system will be explored with the following detailed xPPM models.
Towards an Industrialised Project Delivery System for the BC Industry

Figure 63. Detailed level of xPPM modelling for the integrated system of ModuPark - 01

The above figure specifies the first function among three activities presented in the above figure 63. The yellow round boxes represent the detailed activities to receive, generate and output the information. So they are a kind of information-operators. The white rounded boxes mean a dynamic data source. While the above Static Info Source is the fixed information set, Dynamic Info Repository can be updated and revised. (Note: In the perspective of the database management, it could be covered by one single dynamic information repository. But, without that kind of approaches, all dynamic information derived from the previous abstracted UML models are individually dealt with. The blue box in the following figure XX and XX represents the Generic Model which is a sort of Meta-Model containing and controlling all information.) And the arrow means the information flow. In the advanced function of the xPPM modelling, the information flow can describe the information structure and its format. But, this modelling part will be not specified in this research since the focus is on the conceptual modelling of the integrated system.

See more details in the above figure. The input data from the user interface are inputted in the first sub-activity. The input data would be the initial functional requirements of the client. Depending on the company (the business unit, in this research, ModuPark), the different numbers of clients’ requirements would be required. The first sub-activities is to find the related objects using the Matrix Object introduced in abstracted UML modelling part. If available in the current system, the information of the called objects is sent to next sub-activity. If it does not exist, the
matrix Object is modified and the new xBS Object is generated. In the above UML part, you can find the simplified class diagram of xBS Objects and the will be prototyped in the next chapter by means of the simple Excel sheet. Then, next step is to list up the related properties as parameters to be used and send them to the next sub-activity. By Matrix Reference Object, the parametric design formulation is set up. If not available, it would be also newly generated. After listing up input and output information in separately, the Computing Objects conduct the parametric design as pre-formulated. Then, all output information from the Computing Object fill in the rest of specification information for a modular parking garage. By updated all information of the tailored specification in the Specification Object for a ModuPark design, this process in the automated and integrated system is ended and go to the next process.

Figure 64. Detailed level of xPPM modelling for the integrated system of ModuPark - 02

The above figure shows how to revise and update the Generic Model of a ModuPark project delivery system. There are three dynamic information repositories which are the previously-revised Specification Objects, the Generic Model structure and the Generic Model itself. The Generic Model Structure defines the relations among the all generic objects to sustainably accumulate all generated information in order to face and meet the more demanding clients’ requirements and market needs. See the more detailed sub-activities. The first sub-activity is to check whether the previously-revised Specification Objects are within the existing structure of the Generic Model or not. If within the present structure, the Generic Model of ModuPark design system is
updated just by revising new values of properties in all generic objects. If not, it should be added and revised again. So far, the Generic Model of ModuPark is updated. Now the next activity is to generate the required information or representation based on this Generic Model.

![Diagram of the proposed integrated system of ModuPark](image)

**Figure 65. Detailed level of xPPM modelling for the integrated system of ModuPark - 03**

In the above figure, the final process in the proposed integrated system is described. Main function of this process is to generate the required information or representation from the already-updated Generic Model of ModuPark project. But, all design-information with a lot of details does not have to be provided for every participant involved in a ModuPark project such as clients and Ballast Nedam employees. For instance, the clients are interested in the estimated cost information and the schematic design which would be great if 3-D representation is available. As if they don’t ask the very detailed specification when we buy a car, too much information would make them confused. They are more interested in how its deliverables functionally can operate with some images. Furthermore, the estimated cost and the expected delivery time are necessary to let them know. (Note: The above is just an example. So, this issue on what kind of information should be provided for clients and for providers will be mentioned as one of the further research topics) So, system ask users their identifications such as clients or Ballast Nedam employees. Then, Access Authority Object limits the use level of the design-information saved in the Generic Model of ModuPark. Using this function, the providers can order the standard components after making a contract with client or the clients can check the appearance and cost information etc. of the expected deliverable designed by the parametric design methodology.

So far, the concept of the industrialised project delivery system for ModuPark has been illustrated step by step with three modelling techniques which are IDEF0, UML and xPPM. First of all, since the current way of working is too fragmented in
ModuPark project delivery in spite of having many enabling tools, the processes to analyse the clients’ requirements and come up with design solution was reengineered by integrating xBS architectures into Revit design system. The reengineered process was illustrated by means of IDEF0. Secondly, the static information structure was discussed to develop the industrialised project delivery system for ModuPark by proposing to re-structure the current xBS in more object-oriented systems engineering methodology. It was illustrated by means of the abstracted UML modelling. Finally, two conceptual models for the more industrialised ModuPark project delivery system were integrated with the above xPPM modelling. The following sub chapter 8.1.3 will prototype the propose system based on some practical data in the Ballast Nedam.
8.1.3 SOME PROTOTYPES IN THE INTEGRATED SYSTEM

In this sub-chapter 8.1.3, some critical parts in the integrated system proposed by means of xPPM modelling in the previous chapters are prototyped. There are three important assumptions for these prototypes. First, Ballast Nedam already developed their own structured manuals of the normal parking garage projects for the application of systems engineering philosophy and they have the existing experiences and information applied in practice. But, the modular parking garage, ModuPark projects haven’t never specifically applied in practice. (Note: Ballast Nedam Engineering did some pilot projects to apply it in ModuPark business unit. And they are still struggling and discussing it with ModuPark team to use in practice.) More important thing is that the existing SE manuals and information for the normal parking garage project such as SBS templates, WBS coding system and requirements verification documents should be modified to fit the concept of a modular parking garage in ModuPark. (Note: Developing all new SBS and RBS for ModuPark is out of scope. But, it is very essential as a critical background to fully and properly realise SE philosophy in practice of ModuPark as well as to transform the current limited industrialised concepts into the better business concepts) In this consideration, a limited number of Requirement objects in RBS and Components Objects in SBS will be chosen to prototype the critical part of the integrated system in order to show the previously-proposed system great possibility and working logic as an example represented.

The following table 8 describes 5 main standard components derived from the existing Revit of ModuPark. Each standard component which consists of several objects such as columns and plates is defined as an object-family in Revit design system by a drafter. Even though the detailed and realistic design representation of a ModuPark deliverable is needed to add more components and objects, the prototypes that will present in this research is based on these limited number of components.
<table>
<thead>
<tr>
<th><strong>Standard components derived from the existing Revit of ModuPark</strong></th>
<th><strong>Components and sub-objects</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Structural Unit" /></td>
<td>Component level: Structural Unit</td>
</tr>
<tr>
<td><img src="image" alt="Ramp" /></td>
<td>Component level: Ramp</td>
</tr>
<tr>
<td><img src="image" alt="Stair Hall" /></td>
<td>Component level: Stair Hall</td>
</tr>
<tr>
<td><img src="image" alt="Elevator Hall" /></td>
<td>Component level: Elevator Hall</td>
</tr>
<tr>
<td><img src="image" alt="Exit" /></td>
<td>Component level: Exit</td>
</tr>
</tbody>
</table>

*Table 8. List of the standard components derived from the existing Revit of ModuPark*
Towards an Industrialised Project Delivery System for the BC Industry

Second assumption is related to the way of representing the proposed SE-BIM integrated system. There are several ways of prototyping. The important thing in terms of the prototyping in this chapter is that the integrated system is to propose the automation of the parametric design and generic modeling functions, which are extremely iterative and time-consuming. Therefore, MS Excel and VBA will be fictively tooled to represent the information generating, revising, processing and saving in the proposed integrated system. In other words, it might be unnecessary to use MS Excel and VBA as a kind of information-processor in the information system physically developed as modelled by means of xPPM.

Third assumption is about the validation matter of data collections and their analyses in scientifically. Most of the prototypes presented in the following chapter are based on the interviews conducted several times and in-house surveyed documents and files during the prototyping period of this MSc research. The purpose of the coming prototyping as well as previously-done conceptual modelling is not to develop the practical integrated information system but to explore some possibilities and to propose the better way of transforming the current ModuPark to the theoretically-proposed industrialisation with integration of enabling technologies. In this regards, the prototypes will be a represented example of the proposed system based on the qualitative analysis of the data gathered. Quantitative analysis and method to verify whether the following prototypes work as proposed in practice are left as the topics of further research. All summarised back-up data of this qualitative analysis will be appended in the end of this report.
PARAMETRIC DESIGN USING XBS

Table 9. A represented example-01: Matrix Object for relation-reference between RBS and SBS

The above table outlined in red prototype a Matrix Object. More specifically, the main function of the above Matrix Object is to predefine the relations between RBS objects and SBS object. As previously mentioned, 5 main components of SBS and 5 main functional requirements for a ModuPark project are tabled. (Note: During the interview with Modeller and engineer in Ballast Nedam, the relations in the Matrix Object was presented and checked. More importantly, based on their engineering knowledge, the Matrix Objects could be developed in more detailed with more accuracy in practice.)

See more details. For instance, the requirement about parking space is referred to three standard components of SBS such as the structural unit, ramp and stair hall. As you can guess, the Matrix Object does not describe the relation in the parametric manner. The relations between two different objects are marked in existence or nonexistence in order to call the marked objects for the coming parametric design.
Towards an Industrialised Project Delivery System for the BC Industry

Table 10. A represented example-02: Matrix Object for relation-reference between RBS and RBS

The above tables prototype two different types of Matrix Objects. One is the Matrix for allied objects that is derived from the same categorised xBS. Another is the Matrix Object with different types. The previous figure is a prototype of the latter one. This type of Matrix Object is important to define in parametric design since it describes how to link the different categories of xBS which are Cost, Organisation, System, Requirement, Work Breakdown Structure etc. To create the real synergies in BIM as well as SE, the integration of the different information typologies is so essential. This Matrix Object enables the different xBS to bridge each other. Another type is to define the relations within the same categorised xBS.

There are at least two functions of this type of Matrix Object. First, it is necessary to fully design a modular parking garage in parametric way. A requirement in RBS is not only linked to the several components in SBS but also interrelated to the other requirements in same category. All related objects in the different information categories should be called to provide their parameters in order to completely come up with the design solution in parametric way. In other word, all associated objects in all different xBS fully called in the parametric design arena, based on this type of Matrix. For instance, if you start with ‘Available land’ requirement, not only ‘Ramp’ ‘Stair hall’ components in SBS but also ‘Parking space’ ‘Floor’ ‘Arrangement’ requirement in RBS are called at the same time in this logic.
The second function of this type of Matrix Object is to generate the advanced information. By analysing the relation in the same categories and defining the bridging ways, the information to accumulate is getting valuable and improved. For instance, the complex knowledge (what requirements are the most important to design or which relation should be more carefully controlled etc.) could be figured out by analysing the objects-links within RBS. This advanced information is very vital intangible asset for sustainably running their industrialised business as well as the critical strategic decision in the design process would be made based on it. Moreover, this function is important within SBS as the following table presents.

Table 11. A represented example-03: Matrix Object for relation-reference between SBS and SBS

One of the most challenging parts for the parametric design is to locate the certain component in the right place and with the right relation, which is called ‘coordination problem’. Normally, most of all commercial BIM software provides a part of this function, which is to facilitate to place them with the right relation. But, the more advance function such as automated location of should be manually done or the extra add-on software programming for this function is needed. Based on the above table, we can develop the function of automatically-locating the called components.
Towards an Industrialised Project Delivery System for the BC Industry

<table>
<thead>
<tr>
<th>Reference in text</th>
<th>Matrix type</th>
<th>Called xBS objects</th>
<th>Called Object properties</th>
<th>Parametric formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS01</td>
<td>Structural Unit (F)</td>
<td>( f_1 ): Structural unit Area ( f_2 ): Total number of Structural Units ( f_3 ): Width ( f_4 ): Length ( f_5 ): Height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RS02</td>
<td>Ramp (G)</td>
<td>( g_1 ): Ramp Area ( g_2 ): Ramp type ( g_3 ): Ramp Installation type ( g_4 ): Total number of Ramps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RS03</td>
<td>Hall with stair (J)</td>
<td>( j_1 ): Hall Area ( j_2 ): Hall type ( j_3 ): Hall Installation type ( j_4 ): Number of Stair-Halls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR01</td>
<td>Available land (C)</td>
<td>( c_1 ): Area of available land from client</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR02</td>
<td>Floors (D)</td>
<td>( d_1 ): Total number of floors ( d_2 ): Usability of ground floor ( d_3 ): Floor Area ( d_4 ): Width ( d_5 ): Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR03</td>
<td>Arrangement of parking slot (E)</td>
<td>( e_1 ): Arrangement type ( e_2 ): Number of parking slot per structural unit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The number of parking slots in ModuPark system is directly proportional to the number of structural unit. Space for functional units such as Ramp and Hall with stair should be separately considered if they are located in space of structural units. The number of structural units per floor is limited by Available land. Also the number of parking slot per Structural unit is related to Arrangement types which are Vertical or Angled.

Table 12. A represented example-04: Matrix Reference Object

The above table represents the Matrix Reference Object and Parametric Formulation Object. The first column of the table generally describes relations among the called objects in text. There are at least two functions of this first column. First, it would facilitate to the communication between the parametric designer for ModuPark and the system developer in further system development. In practice, the different participants use their own vernacular languages in working. While the system developer or managers are familiar with the programming language such as C++ or Java, it would be too difficult for the design or modeller to communicate with them in this language. Therefore, the textual reference information derived from the knowledge of the designers or modeller with many experiences can help the system developers having without any background of a ModuPark projects to develop and the parametric formulation. Second, as reference book for the parametric design of ModuPark, the designer, modeller and other employees can continuously and easily check, manage and update it depending on their business environments and strategic decisions.
The textual reference might be not the best solution that the parametric formulation for a modular parking garage by using his kind of the textual reference is developed by the system manager or developer.

In my opinion, there are three expected approaches to develop the parametric formulation in practice. First of all, it is ‘Push Strategy’ that Ballast Nedam as a client to purchase their software actively asks the software vendors (in this research, Revit software provider, Autodesk) to develop this kind of the advanced parametric function. In this approach, the willingness of the software developers is very important to realise in practice. And the assignment to fit the generally-developed function to ModuPark would be an additional issue to be faced. Secondly, it is ‘Pull strategy’ that Ballast Nedam try to develop the add-on program for this kind of parametric design methodology. Actually, since the CAD age, many users were not fully satisfied with the basic functions provided by the big software vendors and they developed their own add-on program using VBA, which is enabled to use CAD applications in the interoperable way. Many BIM users develop the small add-on programs to reduce the iterative design tasks and to fit the standard software to their design process. Revit software is also possible to add the customised function by programming in VBA. Therefore, if really willing to use this function in ModuPark, they can develop it by themselves. The third approach as the most realistic solution, in my opinion, is that the new enabling software from IT Market is introduced. Currently, the construction IT market provides many applications covering a verity of technical specifications. There are also several applications specialised in the parametric design methodology. One of them is the grasshopper in the above figure. Many parametric designers model their product by this grasshopper. Many of the

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59 The grasshopper Primer, second edition 2009
grasshopper users focus on the freeform or complicated-facade design, rather than the industrialised parametric design presented in this research. (The grasshopper Primer, 2009) But, it is believe that the more user-friendly interface of the grasshopper realise the industrialised parametric design as well. More importantly, there are some trials to link these grasshoppers to Revit system online.

<table>
<thead>
<tr>
<th>Reference code</th>
<th>Called Object property</th>
<th>Property Name</th>
<th>Dynamic/ Static</th>
<th>Input/Output</th>
<th>Value</th>
<th>Parameter design function</th>
</tr>
</thead>
<tbody>
<tr>
<td>f1</td>
<td>Structural unit Area</td>
<td>Static</td>
<td>Input</td>
<td>80 standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f2</td>
<td>Total number of Structural units</td>
<td>Dynamic</td>
<td>Output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f3</td>
<td>Width</td>
<td>Static</td>
<td>Input</td>
<td>5 standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f4</td>
<td>Length</td>
<td>Static</td>
<td>Input</td>
<td>16 standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f5</td>
<td>Height</td>
<td>Static</td>
<td>Input</td>
<td>2.85 standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g1</td>
<td>Ramp Area</td>
<td>Dynamic (f)</td>
<td>Input</td>
<td>150 standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g2</td>
<td>Ramp type</td>
<td>Dynamic (f)</td>
<td>Input</td>
<td>20 m x 7.5m standard</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>g3</td>
<td>Ramp Installation type</td>
<td>Dynamic (f)</td>
<td>Input</td>
<td>External Installation</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>g4</td>
<td>Number of Ramps per floor</td>
<td>Dynamic (f)</td>
<td>Input</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g5</td>
<td>Total number of Ramps</td>
<td>Dynamic</td>
<td>Output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>j1</td>
<td>Hall Area</td>
<td>Dynamic (f)</td>
<td>Input</td>
<td>25 standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>j2</td>
<td>Hall type</td>
<td>Dynamic (f)</td>
<td>Input</td>
<td>5m x 5m standard</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>j3</td>
<td>Installation type</td>
<td>Dynamic (f)</td>
<td>Input</td>
<td>External Installation</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>j4</td>
<td>Number of Star-Hills</td>
<td>Dynamic (f)</td>
<td>Input</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>j5</td>
<td>Total number of Star-Hills</td>
<td>Dynamic</td>
<td>Output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a1</td>
<td>Number of parking space</td>
<td>Dynamic</td>
<td>Input</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c1</td>
<td>Area of available land from client</td>
<td>Dynamic</td>
<td>Input</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d1</td>
<td>Total number of floors</td>
<td>Dynamic</td>
<td>Input</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d2</td>
<td>Usability of ground floor</td>
<td>Dynamic</td>
<td>Input</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d6</td>
<td>Number of floors for parking</td>
<td>Dynamic</td>
<td>Output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e1</td>
<td>Arrangement type</td>
<td>Dynamic</td>
<td>Input</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e2</td>
<td>Number of parking slot per structural unit</td>
<td>Dynamic</td>
<td>Output</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13. A represented example-05: Computing Parameters Object

The above table XX show you a Computing Parameters Object represented by Excel sheet. All called properties in the related objects including the requirement and component objects are listed up. These listed-up properties are finally the parameters to generate the new information in parametric design method. See more details in the third and forth columns. The way of being given the value of the properties is divided into two categories. One is dynamic or static. Another is input or output. An example of the dynamic and input information is the required number of parking space. This kind of the information value is revised every time and given by clients or employees in ModuPark. And an example of the static information is given.

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60 The grasshopper Primer, second edition 2009

61 http://cafe.naver.com/revitbim.cafe?iframe_url=/ArticleRead.nhn%3Farticleid=2831
the fixed values by this proposed system itself. If necessary, it also revised and updated. But, its access to do so is different with the above table. Regarding this issues, the system manager interface was presented in the previously-shown UML models. Another type is the dynamic and output information, an example of which is the expected total number of the structural units in yellow cells of the above table. But, although the properties marked by Dynamic (F) in the above table are changeable in practice, they are given the fixed value to simplify the parametric formulations in this prototyping phase.

<table>
<thead>
<tr>
<th>Level</th>
<th>Base</th>
<th>Family</th>
<th>Type</th>
<th>Material</th>
<th>Coordinates</th>
<th>Offsets</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$x_0$</td>
<td>$y_0$</td>
<td>$x_1$</td>
</tr>
<tr>
<td>1e</td>
<td>Verdieping</td>
<td>BN_28_balk_IPE-profiel</td>
<td>IPE 400</td>
<td>Metal (system)</td>
<td>0.000</td>
<td>0.230</td>
<td>5.000</td>
</tr>
<tr>
<td>1e</td>
<td>Verdieping</td>
<td>BN_28_balk_IPE-profiel</td>
<td>IPE 400</td>
<td>Metal (system)</td>
<td>5.000</td>
<td>0.230</td>
<td>10.000</td>
</tr>
<tr>
<td>1e</td>
<td>Verdieping</td>
<td>BN_28_balk_IPE-profiel</td>
<td>IPE 400</td>
<td>Metal (system)</td>
<td>10.000</td>
<td>0.230</td>
<td>15.000</td>
</tr>
<tr>
<td>1e</td>
<td>Verdieping</td>
<td>BN_28_balk_IPE-profiel</td>
<td>IPE 400</td>
<td>Metal (system)</td>
<td>15.000</td>
<td>0.230</td>
<td>20.000</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>0.000</td>
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<td>15.770</td>
<td>10.000</td>
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<td>10.000</td>
<td>15.770</td>
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<td></td>
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<td></td>
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<td>5.000</td>
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<td></td>
<td></td>
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<td>5.000</td>
<td>16.230</td>
<td>10.000</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
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Table 14. A represented example-06: Excel-based Revit-Family Coordinator
The above Excel spreadsheet presents the lists of the called components that can generate the Revit representation with the detailed information. A Revit modeller in Ballast Nedam Engineering developed the above Excel file to easily manipulate all standard components of a modular parking garage in the Revit system. As an add-on program provided by Autodesk, Revit can generate the BIM-oriented representation based on the Excel-based Revit-Family Coordinator presented in the above table 14. To use the Excel-based Revit-Family Coordinator in practice, many objects should be grouped as the families. In the beginning, it would take a lot of time and effort to prepare this Excel sheet in more realistic fashion. But, it is possible as well as helpful to realise the industrialised project delivery system since it plays the key connecting role between the different information and BIM-oriented representation. (Note: More practically speaking, this add-on program provides the limited number of Excel spreadsheets to handle the object-family. The modellers and BIM manager in the Ballast Nedam Engineering is discussing it with Autodesk as far as I know.)

So far, the parametric design part in the conceptual models of the proposed industrialised project delivery system was explored with some prototypes represented by simple Excel sheets containing the practical data. Next, user interface will be prototyped with arising some practical issues and providing some recommendation on them.
There are at least two strategies to come up a representation prototyping of the ModuPark website or ModuPark information system presented in the following table.

**Table 15 Two strategies: The Representation Prototyping using Revit**

These two strategies are differentiated with the direction of the information flow. One concept derives from the information flow from SBS to RBS. In this strategy, a catalogue with a lot of the pre-developed and possibly-deliverable ModuPark products is given in the website or in-house information system. In this parametric design, the input information would be the available components in SBS and their structure to interrelate to each other. The output information is the expected and requirements fulfilled by ModuPark design solutions to be generated in the parametric way. As the existing information accumulated from the previous project experiences and the available components are growing, this catalogue, which is a kind of available industrialised products list, would be more and more valuable and useful in the BC market. Another concept is a questionnaire-type interface which of information mechanism is from RBS to SBS. In this case, this integrated design
system can immediately generate some requirement-based alternatives by using the predefined parameters and their formulations.

Figure 67. a example of questionnaire-type representation prototyping

See more details in the questionnaire-type representation prototyping. 5 questions are asked to the perspective clients. As you can see and we discussed in the earlier chapters, all question is not about the technical requirements, specifications or building codes but about the very basic functional requirements. In the above example, the only one question is asked for each requirement for RBS of ModuPark project delivery. One requirement object in RBS contains several properties that could be used as the parameter in the parametric formulation. So, the several specified questions could be asked for the individual properties. Some practical issues on what kind of requirements should be tackled with and what questions we have to ask to the future clients etc. are left as the further research topics.
Figure 68. A example of catalogue-type representation prototyping

The above figure presents a example of the catalogue-type representation prototyping. By conducting the parametric design method from SBS to RBS, the requirements information that could be met by the visualised ModuPark product is presented as the above seen. For instance, a ModuPark deliverable in the above figure meet the functional capacities such as 150 parking slots, 2 Exit in opposite direction, etc. furthermore, by using the System Engineering Architecture, they can simply generate some other information such as the estimated cost and possible delivery time etc. More issues on the user-friendly interface or the category and amount of the information to be provided for the healthy trades between clients and providers should be discussed in the further research.

So far, two conceptual models were incorporated by modelling xPPM in the chapter 8.1.2. The chapter 8.1.3 has been so far presented some prototypes in some critical part of the integrated system. Next chapter is for the validation of the integrated system that has been proposed so far.
This chapter will validate the proposed integrated system by exploring how to support the industrialised project delivery system. The validation process in this chapter will explore two strategies to apply, which were questionnaires-type and catalogues-type presented in chapter 8.1.3. First of all, the chapter 8.2.1 will present the proposed procedures to generate the required information from an initial requirement of RBS to a standard component of SBS and to present 3-D representation by means of Revit system. In other words, the integrated system of the questionnaires-type designs some alternatives of the modular parking garage from RBS throughout SBS to Revit generating the related information and representation. So, the validation process of the questionnaires-type in this research will start with one specific requirement object from the RBS for the modular parking garage, which information is provided by the clients themselves. This initial input will be tracked in each processes and structure of proposed integrated system in order to prove how to support the industrialised project delivery system.

On the other hands, the chapter 8.2.2 will track the specific information revising in the parametric manner passing through three main procedures of the integrated system of the questionnaires-type, which are from 3-D Revit representation throughout SBS to RBS. By the component coordinators (Note: there is no such job position in ModuPark team of Ballast Nedam. But, it will be necessary to properly use the integrated system in the strategy of the catalogue-types. It will be briefly introduced in the chapter 8.3.3.), many 3-D representations using countless combinations of the available standard components in SBS can be discussed and made in advance to develop the ModuPark catalogues with many alternatives. In other words, based on the already-designed Revit representations by combinations of the standard industrialised components, all relevant information of the component objects in the SBS is extracted. This information is linked to the met requirements, which consist of the capacity information of the delivered catalogues for the ModuPark business. The above two processes using the proposed integrated system will be explored step by step being on the track of the very specific and limited information in the entire integrated system in order to validate how this proposed system can facilitate the industrialised project delivery system.
8.2.1 FROM A TO Z IN THE APPROACH OF THE QUESTIONNAIRES-TYPE

The following figure presents how to use the proposed integrated system from A to Z in the approach of the questionnaires-type. Looking into all details step by step, the way of supporting the industrialised project delivery system using the integrated system will be shown. The exploration of the integrated system in this chapter consists of 6 steps.

Figure 69. From A to Z in the approach of the questionnaires-type
[STEP 1] USER INTERFACE

Suppose that the suggested system is developed and supported in the real business of ModuPark. In the website of ModuPark, the perspective clients are visited with some interests and needs of a modular parking garage. In the approach of questionnaires-type, the first thing to be done by clients is to fill in the questionnaires delivering their initial requirements to the integrated system. As the step 1 represented, the client A inputs 80 regarding the needed number of parking spaces in the expected ModuPark deliverable. One of the interesting issues is what questions should be asked to the clients. It is totally up to the strategic decision of their business unit. Also, regarding this issue, one of the best solutions in the theoretical perspective would be the knowledge-based system to extract the best questions from the previous works. One thing I would like to highly suggest is that the number of questions should be limited for both clients’ usability and providers’ capabilities. In other words, the user interfaces with too many detailed questions would be never useful for the client’s involvement and too many input data from too many detailed questions would make the parametric design system too complicated to handle in proper and efficient way. So, the limited number of the critical questions should be pre-defined by the solution providers such as ModuPark. By means of the parametric matrix in the proposed system, these important questions can be chosen. For instance, the parametric matrix to describe the relations between RBS and RBS can provide some insights of the importance order among the several functional requirements. The more detailed discussion will be left as the further research. As you can see in the above figure, the client A expressed their expected requirement by 80 parking spaces. Now this chapter will mainly explore how this initial requirement (the number of parking spaces: 80) is used in the parametric design system and generate the new information for a design of the modular parking garage.

[STEP 2] RBS IN THE GENERIC MODEL SYSTEM

In the approach of the questionnaire-type, all inputted information from the user interface, the main goal of which is to receive the functional initial requirements from the perspective clients, revises the related xBS object in the generic model system. As previously explained in the chapter 7.3 and 8.1, the generic model system is a kind of meta-model for a modular parking garage, which can contain all information generating and processing in the structured way based on the Object-Oriented Systems Engineering. In the above figure, a class of the xBS objects, which is a very particular part of the generic model, is presented in UML diagram. Since this research mainly focuses on the phase from requirements analysis and design development,
two kinds of xBS objects which are Requirement and System are specified. The integration of the other xBS architectures such as Cost, Work, Organisation, Documentation etc. should be discussed as the further researches. And now on we will look into the parametric design system with the revised xBS objects.

[STEP 3] PARAMETRIC DESIGN SYSTEM

The first sub-step of this parametric design system is to call the related objects from the generic model. The parametric matrix object in the proposed system can check the relationship between different or same xBS architectures. The called-xBS objects by the parametric matrix objects are specified and revised with the following objects;

- Parametric Reference Objects
- Parametric Formulation Objects
- Parametric Computing Objects

More detailed information on these related objects was already presented in the chapter 7.3 and 8.1.

Now the focus of the validating exploration is on two particular xBS objects, which are the Parking space object from RBS and the structural unit from SBS. As the following figure presents, two objects are related to each other. The relationship between two different objects should be predefined in the parametric design way as seen in the following.

*Figure 70. Step 3 of the questionnaire-type approach in the proposed integrated system.*
Towards an Industrialised Project Delivery System for the BC Industry

Based on the parametric formulation, the integrated system can recognise that at least 20 structural units are needed to fulfill the client’s requirement which is 80 parking spaces. The following examples present how to use the parametric matrix and formulation in the proposed system.

Table 16. An example of the parametric design for ModuPark - 01

The above table is an example of the summarised information inputting and outputting in the process of the parametric design system. In total, 22 properties in the 10 selected objects from RBS and SBS are called to parametrically design a modular parking garage. In the above example, a client asks a modular parking garage of 100 parking slots within 1000 m². Also the client wants 2 floors garage including the ground floor. The arrangement of the parking slots is the vertical type that means a car draws along side of another one. Based on these Dynamic information received from clients, some detailed information of the related requirements for the parametric design is generated. For instance, since the clients want to use the ground floor as the parking space, total floors account for parking space. Another example is about the number of parking spaces per the structural unit. The vertical arrangement of parking spaces provides averagely more rooms than the angled or horizontal arrangements. (Note: The number of parking spaces per one structural unit is schematically estimated throughout the interview with the relevant. In case of the vertical type, one unit is available for 4 normal cars. And In case of the angled type, it is accounted by 3.5 cars per one unit. These figures are based on the knowledge of the related business actors. It is necessary to exactly
estimate them in the further research. At least, two main further research topics are presented here; 1) the average number of parking spaces per the several standard structural units depending on arrangement type and 2) the differentiated average numbers depending on the different installation location of the structural units)

So far, the parameters (properties of the called objects) being given by the clients’ intention and expectation were described. Now see the parameters from SBS filled in the darker blue in the above table. Since the SE-BIM integrated system uses the existing and available components grouped into the families in the Revit System, some parameters are static, rather than dynamic. (Note: In this example, the information of the standard structural unit is specified mainly by the shape information such as length, width etc. But, in practice, more parameters should be dealt with. These parameters to be analysed are left for the further research as well.) For the parametric design of ModuPark in this example, the static parameters inputted from SBS are 5,000mm*16,000mm*2,850mm (width*length*height) of the structural unit. There are some more dynamic parameters which are used to generate the alternatives. For instance, the ramps to bridge the upper and lower decks vary from the spiral type to the rectilinear type. Also, where to install the additional functional unit such as the ramps and stair-hall is an example of the dynamic parameters from SBS. With these dynamic parameters, the several alternatives to meet the clients’ functional requirements are automatically generated. (Note: In this research, some of these dynamic parameters from SBS are fixedly valued to simplify the parametric formulation. But, it is very crucial to study the constraints and alternatives conditions of the standard SBS components in more detailed in order to realise this system.)

Finally, some dynamic parameters are outputted based on the predefined parametric formulation. For instance, the number of standard structural unit is 26. In this instance, one thing that you can importantly recognise is that these parameters are not enough to finish the design since the above table16 is assumed as a part of the total parametric design. Especially, the additional parametric formulation should be predefined between SBS and SBS. One of the important information expected to be generated by the parametric formulation between SBS and SBS is the coordination of the accounted components of SBS. For instance, there are the 23 standard structural units and 1 ramp. Where components are automatically located in the certain X, Y, Z coordination and how certain components are arrayed side by side etc.
Towards an Industrialised Project Delivery System for the BC Industry

In the previously-presented example, one more important thing is that the parametric design solution with the inputted information is impossible to finish since some requirements provided by a client in the above table XX have clashed with each other. For instance, the client asks 100 parking spots on only 2 floors but the client have less land. Therefore, the message ‘You need more land to meet your previously-provided requirements’ is returned in the interface of integrated system. The above table XX presents an example of the complete parametric design without any clash among inputted information from RBS and SBS. For instance in the above, clients want to see some alternatives of a modular parking garage. Their initial functional expectations are approximately 50 parking spots, 3 floors for parking excluding the ground floor and the angled arrangement of the parking bays with 1000 m$^2$. The integrated system for ModuPark can come up with some alternatives for a modular parking garage with 13 standard structural units, 2 prefabricated externally-installed ramps and staircase and some additional joint components.

So far the step 3 of the questionnaire-type approach in the proposed integrated system was explored in the very detailed.
**[STEP 4] SBS IN THE GENERIC MODEL SYSTEM**

Throughout the parametric design system in the above step 3, the rest of information in the generic model of a modular parking garage was generated. See the following figure. 20 structural units were generated by outcomes of the parametric design system. There are several properties such as area, number, width, length, height and coordination values.

![Diagram of Standard Structural Unit - System Object](image)

**Figure 71. System information generated by outcomes of the parametric design system**

Now that only two types of objects, which are the structural unit of SBS and the parking spaces of RBS, are being dealt with in order to explore the proposed integrated system, the other objects are all ignored. More detailed study of the generic model system is left for the further research.
This step will explore how to generate the required information or representations from the integrated generic model with some enabling functions of the current Revit system. Especially, two enabling function of the current Revit system for ModuPark Ballast Nedam will be discussed in this research. And in the end of this sub-chapter, the Excel spreadsheet for the generation of 3-D representation will be shown.

Figure 72. Excel Based Model Generation in the Revit Structure

The extension of the Excel Based Model Generation is one of add-on pre-customised programs in the current Revit system. This add-on small application enables user defined MS Excel data to automatically define the geometry of some critical structural objects in Revit Structure. The add-on application mainly generates the limited number of objects which are beams, columns, levels, walls and footings. In the proposed integrated system, this function facilitates to seamlessly link the SE-based
data to the Revit-based representation model. The more practical example that is developed by an employee in the Ballast Nedam will be introduced in the following table XX.

![Image of Grid Generation in the Revit Structure]

Figure 73. Grid Generation in the Revit Structure

Another extension to enable the proposed integrated system is the Grid Generator that enables the definition and generation of axes grids and levels in Revit Structure projects because they can provide the generated grids to facilitate to array the called standard components in the integrated system. By using this add-on application, we can easily create four major structural elements at characteristic places of a generated grid. More interestingly, two different grid types which are ‘Cartesian’ and ‘Cylindrical’ are available in the current extension of the Revit system. Both are very useful for the proposed integrated system to support the bottom-up, parametric and dynamic project delivery system. In the case of the Cartesian grid type, we can array all structural units called from the previously-discussed parametric design system along with the generated Cartesian grids. And in the case of the Cylindrical grid type, the components or objects for a modular parking garage derived from the integrated

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63 [www.extensions4revit.com](http://www.extensions4revit.com)
Towards an Industrialised Project Delivery System for the BC Industry

system can be arranged in the right coordination following the related building codes. For instance, in NEN 2443, the Dutch building codes for the parking facilities, any place in the designed parking garage should reach one of emergency exits within 30m and the cylindrical grids enable this building code to automatically be met in the integrated system.

![Image of Excel model generator](image)

Table 18. Input data in the Excel Based Model Generator of Revit Structure 2010

Finally, the above table presents a part of Input data in the Excel Based Model Generator of Revit Structure 2010. The information layout is very similar with the objects of the structural units previously-mentioned. But, there are several limitations to directly use this extended function of the current Revit system for the proposed system. These limitations will be mainly discussed in the next chapter 8.3.
[STEP 6] MODUPARK DESIGN ALTERNATIVES

Lastly, the ModuPark design solution will be presented in this step. Especially, as an example of the user interface to deliver the final outcome meeting the initial requirements, 3-D representations of the available ModuPark solution will be come up by using ‘Excel Based Model Generator’ in the extended version of current Revit application. The client can check out the 3-D representation or the other types of information such as 2-D drawing for arragement plan of the parking spaces.

![UserForm1](image)

*Figure 74. An example of the user interface for the generated representation*

According to the interview with ModuPark actors, not only 3-D representation but also 2-D drawing are useful to present the expected deliverables since the modular parking garage itself is the functional product, rather than the aesthetic ones. In other words, 2-D drawings that represented the functional values such as the flow of the
traffic of the humans as well as cars are as valuable as to be shown together with the 3-D representations. This kind of strategic decisions of the user interface layout require more study. These issues will be also left as the interesting further researches.

Figure 75. Extendable system architectures

So far, the information process and structure in the approach of the questionnaire-type were explored throughout 6 steps in total. Since the scope of this research is limited by the phases from requirements analysis and design development focusing on the design-related information, the other system architectures was not tackled with. But, there are more possibilities with the others such as CBS and WBS. Especially, if SBS is integrated with WBS, 4-D simulation would be possible. In the same regard, the additional integration of CBS would provide 5-D approach covering the entire BIM world. These issues are unfortunately left as the further research topics.

Till now, one of the promising approaches in the use of the integrated system, the questionnaire-type, was thoroughly looked into. The chapter 8.2.2 will explore the catalogues-type in the use of the integrated system.
8.2.2 FROM A TO Z IN THE APPROACH OF THE CATALOGUES-TYPE

The following figure presents how to use the proposed integrated system from A to Z in the approach of the catalogues-type. Looking into all details step by step, the way of supporting the industrialised project delivery system using the integrated system will be shown. The exploration of the integrated system in this chapter consists of 5 steps.

As the well-summarised flowchart seen in the above, 5 main steps in the approach of the catalogues-type are as followings;

1. A group of ModuPark design solutions in Revit are designed in advance, based on the SBS components.
2. SBS information is extracted by the generic model system.
3. The parametric design system is conducted.

Figure 76. from A to Z in the approach of the catalogues-type
Towards an Industrialised Project Delivery System for the BC Industry

4. RBS information is generated

5. By using all information generated, the catalogues are developed.

From now on, each step will be explored in the very detailed with figuring out some possibilities and limitations.

[STEP 1] SBS-BASED REVIT ALTERNATIVES

First of all, the person or automated system that can coordinate the available components and design the new products is necessary to realise this idea. A group of ModuPark design solutions in Revit are designed in advance by ModuPark designer or the certain system. The most important thing in this step is that all design alternatives are fully and properly based on the SBS components. Otherwise, extra task time-consuming will be required to link the each other information architectures.

Figure 77. Two ways of extracting SBS information

One more possibility to realise this idea in practice is to re-use the information of ModuPark products that have already delivered or will be developed. As the accumulated information is increasing, the catalogues would cover more area of the client’s expectation. So it would be great idea to develop the new SBS for a modular parking garage as soon as possible.
[STEP 2] SBS IN THE GENERIC MODEL SYSTEM

This step is about extracting SBS information from the representation model, which is Revit model in this research. The extracted SBS is delivered to the Generic Model System. The use of the Generic Model System was amply introduced in the previous chapter 8.2.1.

[STEP 3] PARAMETRIC DESIGN SYSTEM

This step is exactly same logic with the questionnaire-type but just the other way around. In other words, while the previous chapter generates output information from RBS to SBS, the catalogue-type approach check out the components information from SBS and generate the requirements met. See more details in the [Step 3] of the previous chapter.
[STEP 4] RBS IN THE GENERIC MODEL SYSTEM

The main purpose of this step is that RBS information is generated.

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Table 19. Some examples of the Catalogue-type interface derived from Revit System.

The above table presents some examples to partially but automatically generate the information of the requirement to be met for a modular parking garage. The above three 3D representation are based on the standard industrialised components as the very abstracted SBS. In other words, the standard structural units, ramp, staircase etc established in SBS for a modular parking garage are visualised in the above. Then, the requirements information can be extracted from 3D representation in the case that each component represented are based on SBS with the industrialised concept. As seen in the above table, the information regarding the number of parking space, which is an example of the functional requirement to be met, is extracted. See the first example in the above. There are 85 parking spots in the ground floor, 77 in the first floor, 74 in the second floor and 40 in the top floor of a modular parking garage. In this regard, catalogue-type strategy, which means to generate the information from SBS to RBS, can be applied in ModuPark business practice. Therefore, a possibility of the proposed integrated system is shown with catalogue-type strategy to support the industrialised project delivery system.
As seen in the above example, the standard structural unit consists of four standard steel columns, two prefabricated span objects and some joint objects importantly including the parallel line object for one parking bay. These parallel lines are directly related to the number of parking spaces. It is possible to extract the RBS information from SBS-based design representation by simply counting the number of these parallel lines for a parking. But, unfortunately, there are several limitations in the current system. One of the most practical issues is that the very limited requirements can be extracted in this way because the parametric relations between SBS and RBS would be very complicated in real practice. Furthermore, the non-standard objects are newly defined by themselves since the current Revit and other BIM software provides the limited number of standard objects. (Note: But, most of them provide the customised function to add their own object and make them a family.)
Figure 79. An example of the user interface for the catalogues-type

Client A just checks out these kinds of catalogues to choose one of ModuPark solution. Each solution is explained well with the requirements met and capacity ensured. Also, as previously-mentioned, more detailed requirements such as cost and delivery time etc. can be delivered by integrating the other information architectures.

So far, by exploring two proposed approaches in use, which are the questionnaires-type and the catalogue-types, the integrated system was thoroughly tackled with the practical possibilities and limitations to support the industrialised project delivery system. In next chapter, the further arguments based on the findings will be discussed in the one-level higher, strategic level.
8.3 FURTHER DISCUSSION

Along the integration solution framework that was presented in chapter 6, three main modelling techniques have so far been tackled with. In chapter 7.2, ModuPark business process for the industrialised project delivery system, which was based on theoretical research in chapter 2 and mainly proposed in 3, was reengineered by means of IDEF0 process modelling. In the chapter 7.3, the information structures of the xBS-Revit integrated system were proposed. The previous chapter is about Process to Product modelling by means of xPPM with some prototypes of the important parts. And by the chapter 8.2, two practical approaches using the proposed integrated system were validated by showing how to use in practice from A to Z. Now on the one step further discussion will be made in this chapter.

8.3.1 POSSIBILITIES & LIMITATIONS OF THE PROPOSED INTEGRATED SYSTEM

In this chapter, so far, some very practical possibilities available in the current system or simply developed in the MS Excel were dealt with to validate the proposed integrated system. Especially, some prototypes of the suggested concepts were presented. For instance, how to apply the parametric design system by simply dealing with 22 parameters and by being represented by Excel sheets was shown step by step along the proposed processes. And, more practically, some possibilities the prototyping system to generate the required information or representation from the Generic Model were explored in the extensions of Revit Structure application. For example, the Excel Based Model Generation or Grid Generator would be the suitable add-on function to facilitate information exchange between the different hierarchical objects or between the specification model and the representation model.

This SE-BIM integrated system opens several possibilities in practice. First of all, in this research, main concern is on design-information linking requirement objects in RBS and component objects in SBS. And since the components in SBS are based on the objects-families in Revit design model, BIM-oriented 3D representation would be automatically generated by simply adjusting the Excel spreadsheet. In other words, well-defined SBS for a modular parking garage plays a key role to connect other-type information. In this regard, SBS can be connected to other xBS such as CBS, WBS,
Towards an Industrialised Project Delivery System for the BC Industry

OBS etc. (Ballast Nedam, 2008\textsuperscript{64}) and other Expert systems as well. For instance, the individual tasks and practical activities can be allocated to each component in SBS. Then, the current Revit design model would be a 4D modelling interacting with scheduling system. Therefore, well-prepared and predefined SBS for a certain project types such as a modular parking garage is critical as well as necessary to fully realise BIM and SE.

Another possibility is that the industrialised facilities themselves are not required to use that many number objects of SBS or RBS. Definitely, only 5 requirements objects and 5 components in the previous prototyping and case of ModuPark is not enough to fully realise the concept of the proposed industrialised project delivery. But, it is also true that it is impossible that the clients can develop the very sophisticated requirement documents. Furthermore, the existing standard components already are within the building codes and the related regulations. If the industrialised business unit focus on the fundamental functional requirements and the associations between SBS and RBS or between FBS and RBS are well predefined to parametrically design the specification, the proposed industrialised project delivery system would be fully and properly realised in the near future. More positively, during some additional interviews with real business actors in ModuPark, they are also technically positive at least in terms of the potentials of an industrialised modular design and construction. They pointed out that (See more in the appendix of the interview summary) Therefore, by keeping accumulating the existing information and extending the new available possibilities such as the new combination of the standard components and as the coming ModuPark projects go on.

Furthermore, there are already enough existing information to develop this industrialised concept in practice of ModuPark and Ballast Nedam. The only assignment to be realised is how to link each other so as to work together creating the synergy and immediately ensuring the profits in their industrialised business unit. In the case of Ballast Nedam or ModuPark, many BIM-oriented and SE-oriented information has been established throughout the previous project deliveries. The amply existing information enables the current ModuPark business to be transformed to the industrialised project system. That is why we have to more focus on the bottom-up approach, rather than the top-down approach to start with the complete definition. So it is necessary to change their strategy to focus on how to use, rather than what to develop.

With the above possibilities so far, there are several limitations in the proposed integrated system to support the industrialised project delivery system. First of all, the complexity of the parametric formulation for the integrated system would be one

\textsuperscript{64} Ballast Nedam, XXXX “In-house document non-published”
Towards an Industrialised Project Delivery System for the BC Industry

of the critical limitations that should be overcome in the further development. In the process of the prototyping using the proposed integrated system discussed in the chapter 8.1 and 8.2, the only 5 critical requirement objects in RBS and 5 prefabricated standard component objects were called to establish the idea and validate it. (Note: Actually, one requirement and component-oriented objects were mainly tracked in the phase of the validation.) But, the formulations with few parameters are already quite complex. If more parameters are involved, it would be too complicated to handle in the system. Therefore, it is very necessary to study further on how to cope with this complexity of the parametric formulation and how to extract them from the invisible knowledge of the employees involved in the ModuPark projects.

Secondly, some practical limitations in the currently-used applications were discovered. For instance, the Excel Based Model Generator that mainly presented in the chapter 8.2 is the very necessary function to enable the proposed integrated system. But, unfortunately it has some critical limitations to implement in practice. The current add-on program of the Revit Structure 2010 which is Excel Based Model Generator provides the limited number of Excel spreadsheets and objects to be manipulated. More specific specking, it has only 5 spreadsheets which are Levels, Beams, Columns, Walls and Footings as the table seen in the following. Actually that is one of reasons why only the standard structural unit consisting of the beams and columns was dealt with in the validation phase of this research. Even if the user manually adds more spreadsheets, the Revit system cannot read any information with error messages. Therefore, the currently-used application should be improved to make up for these limitations.

Table 20. Practical limitation of Excel Based Model Generator in the Revit system

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<th>Column 3</th>
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</tbody>
</table>

Table 20. Practical limitation of Excel Based Model Generator in the Revit system
8.3.2 DISCUSSION TO ENHANCE AND DEVELOP THE PROPOSED SYSTEM

“...London’s new Olympic stadium will be boxed and shipped after use to the next host of the games...”

- From an article ‘Modern Living’ in the Holland Herald

One of the hottest argumentation in this research is the coupling problem between demander’s expectation and supplier’s deliverables. In the proposed industrialised project delivery system theoretically presented in the chapter 3, some of the clients’ requirements are not coupled with their deliverables because they are not customised to fulfil all clients’ requirements but industrialised within the suppliers’ solution area to maximise the use of the existing information and components by saving the cost and time. This situation is schematically illustrated based on the previously-presented systems thinking as seen in the following.

Figure 80. Uncovered requirements/ Requirements to be met/ Residual capacity for specification

The coupling problem between the demander’s and supplier’s system should be discussed. According to the interview with Director of Ballast Nedam, his opinion on this uncoupled issue between the required and available solutions is simple but clear in that the client should find the other providers in case that the uncovered requirements exists in the ModuPark to be enabled by the proposed integrated. In macro perspective, ModuPark also try to find the other clients within their own
solution area. And In the long term viewpoint, the solution area of a modular parking garage will be enlarged by accumulating their knowledge, by keeping developing the sophisticated system and then by covering the more and more requirements to be met. In short-term point-of-view, I propose the following two recommendations that can be useful in practice.

1. Seek the clients within solution area.

Following the rules of the market economy, the bottom-up approach can earn more value to the demanders as well as suppliers. Motto ‘The quicker, the cheaper adding more value’ is possible in the industrialised project delivery system. Therefore, the suppliers should emphasis on the more attractive factors that can understand the clients to stick to the industrialised solution area.

2. Extend the capacity of the industrialised concept.

At the same time, the efforts should be made to extend the solution capacity using more available components and developing more combinations. More importantly, for the time being, both should be used.

So far, the conceptual models and some prototypes for the development of the integrated system to support the bottom-up, parametric and dynamic industrialisation were presented in the above chapters. Furthermore, some findings on the expected limitations and possibilities of the proposed integration in practice were discussed with real business actors in Ballast Nedam. Based on these arguments, I would like to shortly recommend a roadmap to enhance the proposed system by briefly pointing out some critical parts of further practical system developments and implementation in ModuPark of Ballast Nedam.

First, I recommend that the current design-related information structure for the ModuPark project be modified fitting the proposed industrialised concept and the SE-BIM integrated system. As previously mentioned several time, the Ballast Nedam already have the well-structure information template for a parking garage project based on the Systems Engineering Manuals in Ballast Nedam. One of the urgent to-do’s is to re-structure them using Object-Oriented Systems Engineering methodology and the existing components information, which are reusable and extensible. (Jeffrey L. Whitten et al, 2004) For, instance, what kind of the functional requirements should be asked to the clients, what system-objects should be grouped as the objects-family that is seen as a standard component in SBS, what components are available in the market etc. should be re-studied and re-formulated to be fitted in the industrialised delivery system. Also, a library of the standard components available

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for a modular parking garage project should be developed in the near future. As we have so far looked through, other architectures of xBS technologies such as WBS and CBS should be re-developed in the reusable and extensible way in order to seamlessly integrate the whole life cycle of the ModuPark deliverables. In other words, the issues of the interoperability between different system architectures or between different applications that are used in the Ballast Nedam should be more analysed to automate some functions in the proposed system, even if this research mentioned some of parts.

The second thing for the further practical development is to re-analyse and re-design the whole industrialised project delivery system or specifically the SE-BIM integrated system based on more data collections and more detailed interviews. One thing very important is to look more into the interface problems between several different software and application currently used.

Finally, I would like to recommend the following new task owners for the ModuPark design team. Because the proposed system is the new way of working fully reflecting on the industrialised project delivery system, the additional or different tasks are required as followings;

1. Component designer: He or she specialise in the design of components fitting for the industrialised product such as a modular parking garage. As this research several times pointed out, objects or components of SBS should be fitted for the certain This works are directly related to the capacity of their solution area and it is very critical to run their business in profitable way.

2. Components coordinator: With the importance of role of the above component designer for the industrialised product, someone who can coordinate the combination of a lot of the standard components available. Actually, his or her main task is to develop the parametric formulation for the use of the standard components available.

3. System engineer for certain industrialised product: Currently system engineers in construction companies, at least in Ballast Nedam are involved in the new project or new biding phase every times. By accumulating their experiences and facilitating to reuse them, the generic model of the certain industrialised product as a core part of the proposed system can be reinforced.

So far, all argumentations in the different levels surrounding the industrialized project delivery system to use the proposed integrated system were made. By next chapter, this research will be concluded and closed.
9. CONCLUSION

The main goal of this MSc research was to analyse and design the system by integrating two different enabling tools from Systems Engineering and Building Information Model in order to support the proposed industrialised project delivery system which is bottom-up, parametric and dynamic with system thinking. In more detailed, some prototyping to show the practical link between xBS technology (as one of tools in SE) and Revit Structure 2010 in Ballast Nedam was tackled with. Although the research scope, especially project type, was limited to modular parking garage project in Ballast Nedam, I believe that many of practical logics and critical factors to support ‘the bottom-up, parametric and dynamic’ project delivery system for better industrialisation in the BC industry were studied in depth.

This MSc research presented some scientific contributions. First, one of the main scientific findings is that some limitations and opportunities of the current industrialisation in the BC industry was analysed with two research-based projects such as FutureHome and ManuBuild and business-based projects such as BoKlok and Corus Living Solution. Especially, ModuPark of Ballast Nedam in the Netherland was case-studied in the very detailed. And secondly, another scientific contribution is that some critical requirement for better industrialised delivery system in the BC industry was proposed based on the theoretical research. Thirdly, two enabling technologies which are System Engineering and Building Information Modelling were revisited by mentioning some possible contributions for the proposed industrialised project delivery system. Fourthly, one important issue in practice is integration between SE and BIM. To solve the integration problem, this research set up the Model-driven framework. As technologies-integration is regarded as a critical factor of the successful application in practice, this model-driven framework is one of main scientific contributions in this research since it provides a good guideline for other technologies-integration issues. Finally, the SE-BIM integrated system to underpin the proposed project delivery system was analysed and designed along with the previously-mentioned model-driven framework. More detailed description will be found in the following chapter 9.1.

The major practical implications are 1) To discover the pitfall of the fragmented application of enabling technologies in the BC industry, 2) To propose one of possible solutions to integrate SE and BIM, 3) To find out the importance and role of Business Process Reengineering using IDEF0 in the integration issue, 4) To discover the limitation of the current SE and to introduce Object-Oriented System Engineering, 5) To present the very practical prototyping of the integrated information system fully.
covering the phases from Requirement Model to Design Model, 6) To practically present possibilities and limitations of the proposed delivery system enabled by integration of BIM and SE in several interviews and discussions with relevant real business actors. The following chapter 9.2 will more specifically elaborate the above-mentioned main practical implication of this MSc research.

Since the scope of this MSc research was limited and the research goal was specified, there are some uncovered research areas. Although this research opens a wide range of further research topics, chapter 9.3 will categorise possible further researches into 2 main-groups and 6 topic sub-groups. 2 main-groups are 1) Further practical researches with more development in practice and 2) Further theoretical researches extending the current focus to the whole BC industry and other methodologies. The further practical researches consist of 1-1) Extended scopes such as construction phase and maintenance phase, 1-2) Other types of BC projects in the industrialised delivery system, 1-3) More detailed case study on ModuPark Business unit to lead to physical development of the integrated information system. And the further theoretical researches are divided into as followings; 2-1) More enabling technologies should be invited and integrated in the near future, 2-2) More requirements for better industrialised project delivery system in the BC industry should be found out and studied in more detailed and 2-3) Other research branches of Living Building Concept should be dealt with to maximise synergy effects in practice. All these topics will be more explicitly presented in the following chapter 9.3.

Finally, this report of MSc thesis will be closed with some personal remarks self-answering the motivating questions asked in the chapter 1.
Among the scientific contributions of this MSc thesis, the most valuable thing that I suppose is the effort on developing the industrialised project delivery system supported by the integration of SE and BIM. This is more specified as followings.

First of all, some limitations and opportunities of the current industrialisation in the BC industry were presented in the chapter 2 and chapter 7. Chapter 2.1 analysed two research-driven approaches, FutureHome and ManuBuild that were recently done and European researches. Chapter 2.2 theoretically investigated two industrialised business model which are BoKlok run by a consortium with IKEA and Skanska and Corus Living Solution operated by Corus steel group. The most detailed-dealt industrialised case in this research was ModuPark initiated by Ballast Nedam Parking. One of limitations in the current industrialisation of the BC industry is too limited project-type to be applied. While we can find many cases of the modular or industrialised housing project as a whole delivery concept, still rare to be applied in other projects. As many business modes running on the market are proven, the modular or industrialised housing project is definitely feasible for both clients and providers to apply the industrialisation. But, the other type of products in the BC industry also has a lot of possibilities on it. Furthermore, as the standard components are more and more available in market, how to link each other standard components are getting more important. Even if several different models such as requirement model, design model, construction model etc in terms of information management have to be used in the whole life cycle of the industrialised facilities, most of the businesses and researches too focus only on the use of a design model. The most important thing to improve the current industrialisation in the BC industry is to integrate several models derived from the life cycle of the industrialised products or projects.

Secondly, another scientific contribution is that some critical requirement for better industrialised delivery system in the BC industry was proposed based on the theoretical research. Three requirements which are the bottom-up, parametric and dynamic approach, were presented in the chapter 3.3. Bottom-up approach can stimulate to reuse the existing information and accumulate their knowledge to improve the industrialised system in the BC industry. And the parametric approach is vital to realise a industrialised system and enhance the productivity in the BC industry. In parametric concept, most of information could be automatically generated by filling in the pre-defined parameters. Furthermore, the dynamic approach can improve the above-mentioned bottom-up and parametric system.
Thirdly, two enabling technologies which are System Engineering and Building Information Modelling were revisited by mentioning some possible contributions for the proposed industrialised project delivery system. BIM is one of the critical enabler to support the proposed industrialised project delivery system because the visualisation of the industrialised deliverables using BIM provides the better communications between the clients and the suppliers as well as between the currently-fragmented suppliers. Furthermore, in this highly-fragmented supply chain in the current project delivery system of the BC industry, the collaboration is the very important factor for the successful delivery of the certain industrialised construction project as well as the sustainability of the industrialised business model in the certain company. Moreover, with BIM, the industrialised base should be reinforced by accumulating all reusable information. Finally, by using SE philosophy, the contractors such as Ballast Nedam ensure that more satisfaction of clients can be delivered to clients in the integrated project delivery system, one example of which is Design-Build.

Fourthly, one important issue in practice is integration between SE and BIM. To solve the integration problem, this research set up the Model-driven framework. As technologies-integration is regarded as a critical factor of the successful application in practice, this model-driven framework is one of main scientific contributions in this research since it provides a good guideline for other technologies-integration issues.

Finally, the SE-BIM integrated system to underpin the proposed project delivery system was analysed and designed along with the previously-mentioned model-driven framework. Along the integration solution framework that was presented in chapter 6, three main modelling techniques have so far been tackled with. In chapter 7.2, ModuPark business process for the industrialised project delivery system, which was based on theoretical research in chapter 2 and mainly proposed in 3, was reengineered by means of IDEF0 process modelling. In the chapter 7.3, the information structures of the xBS-Revit integrated system were proposed. The previous chapter is about Process to Product modelling by means of xPPM with some prototypes of the important parts. And by the chapter 8.2, two practical approaches using the proposed integrated system were validated by showing how to use in practice from A to Z.
9.2 PRACTICAL IMPLICATIONS

The most valuable practical implication, in my opinion, is to open the new possibility that the statically generated information throughout the current project delivery system is transformed to the more dynamically available one by integrating each other, by predefined their parametrical relations based on the knowledge they have already accumulated and by actively reusing them for their coming projects. In other words, this new way of working together with BIM and SE was proposed focusing on the question “How can we use these new market-leading technologies, especially BIM and SE as the prime perspective driver of paradigm shift in construction industry?”, rather than simply “What is new technology in construction industry?” More specifically, the major practical implications are as followings.

1) To discover the limitation of the fragmented application of enabling technologies in the BC industry: This can be mainly found in the chapter 4.3.

2) To propose one of possible solutions to integrate SE and BIM: This can be mainly found in the chapter 6.3

3) To find out the importance and role of Business Process Reengineering using IDEF0 in the integration issue: This can be mainly found in the chapter 7.2

4) To discover the limitation of the current SE and to introduce Object-Oriented System Engineering: This can be mainly found in the chapter 7.3

5) To present the very practical prototyping of the integrated information system fully covering the phases from Requirement Model to Design Model: This can be mainly found in the chapter 8.2.

6) To practically present possibilities and limitations of the proposed delivery system enabled by integration of BIM and SE in several interviews and discussions with relevant real business actors: This can be mainly found in the chapter 8.3.
9.3 SUGGESTED FURTHER RESEARCH

Many topics for the further research were mentioned in the body of this MSc report. Although all pop-up topics during the theoretical and practical research are interesting and necessary enough to study in depth, many of them should be left as the further research due to time constraints of the MSc research. The phases from the requirement analysis to design development in the project delivery were mainly tackled with, the SE-BIM integration (More specifically, xBS technology and Revit software in the design of a modular parking garage) was focused and the only design-related information was dealt with in depth. Because of these limitations of this research, many questions are still to be in spite of its importance and necessity. In this regard, this research opens a wide range of the further research topics. Based on the initially-mentioned structure of this research, they are categorised into 2 main groups, which are the further practical research with more analysis and development in practice and the further theoretical research expending the scope and viewpoint.

In the further practical research, one of the important topics is related to the more detailed case study on ModuPark business unit to lead to the physical development of the integrated system. In this research, many interviews did with staffs in charge not only in ModuPark but also in the other Ballast Nedam. But, many detailed and comprehensive case study was missed. This group of the further research topics are the most important in that it can lead the further development of the proposed system. So, it is introduced in the more detailed as the following detailed topics are suggested;

1. The full System Breakdown Structure for a modular parking garage: This should be differentiated with the current SBS for the normal parking garage. As the ModuPark projects are more delivered, it is definitely necessary that the SBS for a modular parking garage should keep updating them and reflecting new market condition and business strategy. But, since the concept of the normal parking garage is totally different with one of the ModuPark, it is crucial to revise it fitting the industrialised concept and using the standardised prefabrication available in market. In this topic, the application of Object Oriented SE is highly recommended. Also, the important level of SBS is not in objects as the lowest level but in components which consist of several related objects as a meaningful and available unit.

2. The full Requirement Breakdown Structure for a modular parking garage: This is also very urgent to implement the proposed system. Many system engineers in the Ballast Nedam have already established the RBS for the normal parking garage and have knowledge and expertise enough to reformulate it to the more industrialised
Towards an Industrialised Project Delivery System for the BC Industry

one. But, as several time pointed out in the previous, the more important thing in this topic is the clear-cut distinction between the functional and technical requirements or between dynamic and static requirements. The providers do not have to expect that the clients come up with technical requirements. Like the other industries do, the business actors should actively offer the room of the available but limited alternatives to clients. To do so, the standard functional requirements for certain industrialised project is indispensable. And regarding the dynamic input, the amount of information from clients should be restrictively allowed. Otherwise, this system with too many dynamic input or alternatives would make both clients and providers more and more complicated. According to the above research, ‘Choice and Focus’ is the most suitable strategy for the industrialised project delivery system.

3. The matrix and formulation of the parametric design system for a modular parking garage: Whenever the question on the expected technical problems of the parametric design system in the interviews was asked to the ModuPark participants in Ballast Nedam, an even answer was that they strongly believe there are not that much technical problems for modular parking garage projects. As a matter of fact, even if the technical problems to develop the proposed parametric design system are not that challenges, the development is in general time-consuming. Moreover, the parametric design system would be a kind of the knowledge-based system, which is flexibly developed depending on the business strategies and experts’ preferences and experiences. Therefore, the most critical part is that the iterative tasks manually done by experts can be automated by means of the knowledge-based system. For instance, one of the possible methodologies or research areas related to the formulation of the parametric design system for the automation is to apply the methods of ‘Neural Networks’ in order to figure out the parametric formulation between input and output.

4. The BIM-oriented Components library for a modular parking garage: This is not only necessary but also very interesting topic for the detailed further research. As mentioned in the body of this MSc report, the BIM-oriented library should focus their effort not on gathering the innumerable and independent objects but on the limited and market-available components, which are a group of individual objects and more meaningful in practice. In the process of doing this research, the top-down approach of the standardisation is even a barrier to fully implement the BIM in certain company such as Ballast Nedam since they provide too many information. Many researchers have pointed out that the top-down approach such as IFC is very promising in the near future. (Reza Beheshti et al, 2010) But, in terms of the business-oriented perspective, more effort should be made to develop the BIM-oriented Components library for a modular parking garage.

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5. The development of add-on program to bridge each other in the proposed integrated system for a modular parking garage: The current ICT environment in the ModuPark or Ballast Nedam is fragmented with many different applications. Also, the other firms would be same as well. One of the interesting topics for the further researches is about the development of the add-on application to link each other in the proposed integrated system.

6. User-friendly interface of the website or operating system for a modular parking garage: The user interface is very necessary to be discussed in more detailed manner. The human and computer interface is, actually, one of the very critical success factors in the industrialised project delivery system. What information will be delivered and how user-friendly? These research questions in the further research should be asked for the industrialised project delivery of ModuPark business.

One of the other groups of the further research topics is to deal with the other types of projects for the industrialised delivery system. As you know, this research developed the integrated system for the modular parking garage to support the industrialised delivery system. But, there are more possible types of construction projects. These possibilities would be interesting topics for the further research.

Another group of the further research in practice is to extended scopes such as construction phase and maintenance phase. Basically, the Systems Engineering provides the life-cycle approach. Also, you can use the BIM-oriented information in the whole life cycle since it is interoperable with the natures of the object-oriented and parametric technology. But, this research focused on the phase from the requirement analysis to the design development. So, the other scope of the same researches can be necessary. In the other words, the integration framework such as business process reengineering etc in the construction, operation and maintenance phase would be necessary to be conducted in the near future.

And the further theoretical researches for the industrialised project delivery system are divided into three main categories which are 1) More enabling technologies should be invited and integrated in the near future, 2) More requirements for better industrialised project delivery system in the BC industry should be found out and studied in more detailed and 3) Other research branches of Living Building Concept should be dealt with to maximise synergy effects in practice.

First of all, BIM and SE are the enabling technologies revisited in this research. But, the other enabling technologies (or concepts) such as knowledge technology and robotics etc can add the more value on the industrialised project delivery system. More importantly, the integration issues or the interface issues between these enabling technologies would be the attention-grabbing topics for the further research.
Towards an Industrialised Project Delivery System for the BC Industry

Secondly, more detailed analysis of the industrialised project delivery system should be done by figuring out more requirements. This research pointed out three requirements of the industrialised project delivery system, which are bottom-up, parametric and dynamic. But, the other requirements can be found out in the further research. In the perspective of the system thinking, then, the industrialised project delivery system would be influenced making some additional discussion points. So, these requirements should be very carefully dealt with. Moreover, three requirements that this research presented could be more specified to deliver the more detailed and clear messages to the practitioners in the BC industry.

Finally, other research branches of Living Building Concept should be dealt with to maximise synergy effects in practice.
9.4 CLOSING REMARK

“Don’t compete with rivals. Make them irrelevant.”

- In the website of a book ‘Blue Ocean Strategy’

<table>
<thead>
<tr>
<th>Red Ocean Strategy</th>
<th>Blue Ocean Strategy</th>
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</thead>
<tbody>
<tr>
<td>Compete in existing market space</td>
<td>Create uncontested market space</td>
</tr>
<tr>
<td>Beat the competition</td>
<td>Make the competition irrelevant</td>
</tr>
<tr>
<td>Exploit existing demand</td>
<td>Create and capture new demand</td>
</tr>
<tr>
<td>Make the value-cost trade-off</td>
<td>Break the value-cost trade-off</td>
</tr>
<tr>
<td>Align the whole system of a firm’s activities with its strategic choice of differentiation or low cost</td>
<td>Align the whole system of a firm’s activities in pursuit of differentiation and low cost</td>
</tr>
</tbody>
</table>

Table 21. Red Ocean and Blue Ocean (Sources: www.blueoceanstrategy.com)

Closing this report of my MSc project, I would like to address the above sentence as my personal answer of the broadly-jumped question with personal motivation in the chapter 1. The book ‘Blue ocean strategy’ written by W. Chan Kim and Renee Mauborgne (2005) in terms of the business strategy presents a new strategic way to make the competition irrelevant by creating a leap in value for both the company and its customers.\(^{67}\) I highly believe that the industrialised project delivery system that this research suggested is to open ‘Blue Ocean’ in the BC industry. More interestingly, the BC industry must go through this full and proper industrialisation as the other industries did. An issue to grab all attention in the course of the paradigm shift towards the industrialisation is how to make it. Therefore, this research is hurling a profound question to all business actors in the BC industry. Are your project on the Blue Ocean or Red Ocean?

\(^{67}\) www.blueoceanstrategy.com
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Table of Appendix

Appendix A. Terminology in this research
Appendix B. Summary of data collection
Appendix C. SWOT analysis of 4 previous typical efforts on an industrialisation
Appendix D. Detailed IDEF0 report
Appendix E. MSc committees’ evaluations
This appendix defines some terms which are critical and iteratively-used in this research.

<table>
<thead>
<tr>
<th>Words</th>
<th>Definition</th>
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<tbody>
<tr>
<td><strong>BC (Building and Construction) Industry</strong></td>
<td>As commonly-used acronym for the entire industry related to the construction projects such as housings, urban developments, infrastructures, it can be consider a synonym to AEC. (Reinout van Rees, 2006) While the term of AEC is more specific to Architecture, Engineering and Construction, BC is the more exclusive term covering all relevant parties and disciplines.</td>
</tr>
<tr>
<td><strong>Building Information Modelling or Building Information Models (BIM)</strong></td>
<td>Building Information Modelling (BIM) is a set of interacting policies, processes and technologies generating a “methodology to manage the essential building design and project data in digital format throughout the building's life-cycle”. (H. Penttilä, 2006) BIM includes processes by which the right information is made available to the right person at the right time. BIM adds intelligence to project data to allow data to be interpreted collectively removing attribution errors and assumptions. (Finith E. Jernigan, 2007) More detailed definition was discussed in the chapter 4.</td>
</tr>
<tr>
<td><strong>Systems Engineering (SE)</strong></td>
<td>This research is based on the following definition of SE defined by INCOSE. Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product</td>
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Towards an Industrialised Project Delivery System for the BC Industry

<table>
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<th>That meets the user needs.</th>
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<tr>
<td>More specifically, the following definition by Menno et al (2010) is fully in line with my definition.</td>
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<tr>
<td>Systems Engineering is the methodology used to acquire and execute projects in a standardized way. Systems Engineering is a structured method that guarantees that one gets what one is asked for. It establishes a relationship between problems (requirements) and solutions (designs) and includes all aspects that play a role in the projects life cycle. Systems Engineering ensures that clear design choices are made.</td>
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</table>

**Client**

A person or party who in the BC industry initiate the project that is delivered certain products with the certain expectations and needs. While the general contractor such as Ballast Nedam or specifically ModuPark is major player in the proposed supply system, the client is a main player of the demand system in this research.

**Requirement**

This research uses the following definition of SE defined by Andrew P et al.

A requirement is a statement that identifies a capability or function that is needed by system in order to satisfy its customer’s needs. A functional requirement defines what, how well, and under what condition’s one or more input must be converted into one or more outputs at the boundary in question in order to satisfy the customer’s needs. A customer’s need might be to solve a problem, achieve an objective, or satisfy a contract, standard, or specification.

In this research, it is regarded more as the functional requirement that can be derived from the client.

**Model**

See appendix A.

**System**

A System is a set of physical or virtual objects whose interrelationships enable a (set of) desired function(s). (MIT Open Course Ware) Or it is an interacting combination of elements viewed in relation to function (INCOSE, 2004)

**eXtensible Breakdown Structure (xBS)**

As one of the important tool for the structured way of working of System Engineering, xBS means extensible Breakdown Structure of the generated information in the project delivery system. There are several examples of
Towards an Industrialised Project Delivery System for the BC Industry

<table>
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<tr>
<th>xBS used in practice as followings;</th>
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<tr>
<td>- Work Breakdown Structure (WBS)</td>
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<td>- Cost Breakdown Structure (CBS)</td>
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<td>- System Breakdown Structure (SBS)</td>
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<td>- Requirement Breakdown Structure (RBS)</td>
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<tr>
<th>Process Model</th>
<th>This research uses the following definition of SE defined by Guy Redding et al (2007).</th>
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<tr>
<td>Process models are structured in terms of activities (Which may be decomposed into sub-processes), events, control and data-flow dependencies, and associations between activities and resources. BPMN, UML activity diagrams, BPEL and YAWL are examples of notations that capture the behaviour of a system in a process-oriented manner at various levels of details. Process models provide a holistic view on the activities and resources required to achieve a goal. Accordingly, they lend themselves to analysis through simulation and other quantitative analysis techniques, and they have proven instrumental in enabling communication between business and IT stakeholders.</td>
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<th>Computer Aided Design (CAD)</th>
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<th>Information System (IS)</th>
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<th>Object Oriented Systems Engineering (OOSE)</th>
<th>See appendix A.</th>
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<tr>
<th>Information and Communication Technology (ICT)</th>
<th>As an general term for the computer- and communication-related technologies, (Reinout van Rees, 2006)</th>
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Towards an Industrialised Project Delivery System for the BC Industry

Knowledge Management (KT)  See appendix A.
APPENDIX B. SUMMARY OF DATA COLLECTIONS

This chapter is to present the summary of some important interview heavily influenced on the outcomes of this research.

B-1. Interview summary 01. (ModuPark team)

<table>
<thead>
<tr>
<th>Specified open-questions for interview with ModuPark</th>
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<tbody>
<tr>
<td><strong>Statement of purpose</strong></td>
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<tr>
<td><strong>Contents</strong></td>
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<tr>
<td><strong>Additional information and references</strong></td>
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<td><strong>1st distribution</strong></td>
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<td><strong>2nd distribution</strong></td>
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Towards an Industrialised Project Delivery System for the BC Industry

1. Interview Process

To do the effective interview with ModuPark, interviewees and interviewers need to understand each other. Interviewers looked through ModuPark website and some in-house documents regarding ModuPark, especially regarding information system approach. Also some ModuPark projects were studied with assistances from Modeler in Ballast Nedam Engineering. Based on previous and this documents that were sent from the interviewer would provide some specific information on what is this research goal and what information from your side is necessary. If you didn’t check out, please ask interviewer to provide the short presentation on these issues. Interview is arranged on 3rd May. You can find expected open questions in following chapters. During this interview, all discussion and dialogues will be recorded and documented. During the process of documentation, some relevant in-house documents from ModuPark could be surveyed and some additional questions could be asked. The final documents will be sent to interviewees to check out and be validated in order to use.

2. Open Questions

Open questions consist of three main categories, which are general questions on interviewees and ModuPark, detailed questions on the current situation and anticipated future.
2.1 General questions

These general questions will be answered within 30 minutes. These questions would be asked in more general and overall manner. Main goal of this part is that previous survey on ModuPark is valid and modified by getting some general information from interviewees.

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<th>Questions</th>
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<tbody>
<tr>
<td>To get some general information on interviewees</td>
<td>What is your main task? Could you introduce your background?</td>
<td>Interviewees’ general information</td>
<td>1. Fred Groot: Director of Ballast Nedam Parking which started in 2010, more than 20 years working experience in Ballast Nedam infra. As company manager, He was involved in several infrastructural projects which were 1~20 million euro. 2. Jaap Schreiber: Commercial manager of Ballast Nedam Parking, He was Business developer manager that was dealing with ModuPark. He also have some working experience from different Ballast Nedam companies such as Pre-Fab company.</td>
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<tr>
<td>To check out if the previous survey on ModuPark is valid and modified</td>
<td>Could you briefly introduce ModuPark? Is there any news of ModuPark that didn’t update at website? What kind of client do you have? What companies are involved in? etc.</td>
<td>ModuPark business Recent news</td>
<td>1. ModuPark started their business focusing on temporality use of parking garage. Main concept of ModuPark derived from the needs of short-term use of parking garage. Since most of components such as foundations and standard units are reusable, ModuPark concept is feasible enough. Now ModuPark can offer temporarily or permanently available parking garages to clients in very short time. 2. 6 ModuPark projects were done and now 7th ModuPark project is dealing with. 7 ModuPark projects so far are divided to three types of clients; Local governments, hospitals and real-estate firms. 7th project is for hospital and recently started up. 3. Clients of ModuPark could be quite different</td>
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Towards an Industrialised Project Delivery System for the BC Industry

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<td>It is supposed that ModuPark is very innovative and prospective business unit. Especially, the industrialized approach and supplier-driven project delivery are main reasons why we want to do casestudy.</td>
<td>How have you run business of ModuPark? What were the main challenges in this kind of business model?</td>
<td>ModuPark business (AS-IS) Current Problems</td>
<td>1. Clients can ask ModuPark to solve the problem of parking facilities. But, main concept of ModuPark is usually to find the opportunities for their business using network of Ballast Nedam. In other words, ModuPark recognizes the clients’ problems and they present some solutions one of which is a ModuPark. And if clients are not that satisfied with their solution, then they try to offer another solutions. So, it is very important to find out possibilities of ModuPark using Ballast Nedam network, newspapers or internet etc. So it is somehow different concept with the traditional tendering projects. Also that’s why Systems Engineering is so critical to deal with this new type of business model since it can provide a good solution to meet client requirements, wishes and needs within their solution area.</td>
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<td>Questions</td>
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<tr>
<td>What is main strategy of ModuPark business in these days? What General strategy for ModuPark business (TO-BE)</td>
<td>Interesting for them.</td>
<td>1. They want that their ModuPark business is sustainable by making a good balance between selling products and renting</td>
<td></td>
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<td></td>
<td>3. ModuPark is cooperating with Grontmij Park Consult which has extensive expertise in the parking garage projects as an engineering firm. In the process of this business, Grontmij can officially offer consultant services to government organization but Ballast Nedam cannot involve in this process. That’s one of main reasons why Grontmij Park Consult should be cooperated with this project.</td>
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<td>4. Another cooperator for ModuPark is Oostengh which is a steel production company. They provide all steel components and structural engineering solution.</td>
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<td></td>
<td>5. So far this type of new business model is not that familiar with client in construction market. They have not that much understood a lot of advantages and possibilities of ModuPark products. That’s main challenge to run this ModuPark business. Technical challenges are not that much so far because the parking facilities are not that hard to design and build comparing to other construction project. So using existing information and knowledge from all relevant actors can just modify in the context of client.</td>
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<td>6. Connection or links between two different standard components should be the most careful thing to tackle with but it is a just challenge, rather than a problem.</td>
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Towards an Industrialised Project Delivery System for the BC Industry

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<td>these industrialized approach has faced a lot of challenges to realize in practice.</td>
<td>positive possibilities are expected? What technologies or enablers will be the most critical to achieve this?</td>
<td>future</td>
<td>2. In general, the expected end-product in this MSc research is in line with their expectation in terms of better project delivery system.</td>
<td></td>
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</table>

2.2 Detailed questions for AS-IS situation

This interview part will take around 30 minutes. Main focus of it is on understanding AS-IS situation in more detailed. This research is dealing with by the following viewpoint, purpose and scope. Please explain your answers in the following viewpoint, purpose and scope.

1. Viewpoint: All things considered in this research are “information” generating, processing, and managing. Especially, this research is considering information of requirements and specifications and is describing their interrelations.

2. Purpose: The end-product of this research would be the analysis and design of the integrated information system (semi-automated) to support the new project delivery system which are bottom-up(provider-driven), parametric and dynamic.

3. Scope: This integrated issue would be huge research project. So, this MSc project focuses only on the phase from requirements analysis and design development. In this regards, you can provide your answers considering the steps from capturing the clients’ requirements and developing your design specifications in ModuPark.

5 categories of open questions in this interview are as the above; Activity/ Input information/ output information/ software and tools/ the way of controlling or managing.
Towards an Industrialised Project Delivery System for the BC Industry

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<tr>
<td>To analyze the information structure and process of AS-IS situation</td>
<td>What kind of software, systems or methods do you use in order to capture the clients requirements? How do you develop your design specification? And what is your task during this phase?</td>
<td>The current use of software, system and tools</td>
<td>1. There are two main stages; before making a contract with client and after it. 2. Before making a contract with client, they don’t use sophisticated tools and software such as Revit. They just use hand-drawings and Excel spreadsheet in this phase. They receive verbal and basic information from clients, even just Google map and develop</td>
<td></td>
</tr>
<tr>
<td>To analyze the information structure and process of AS-IS situation</td>
<td>Could you let me know what input data you receive when starting your task? From whom? What type of information? What do you think on this process? Any recommendation to make this process or the way of working better and more efficient?</td>
<td>The current input information</td>
<td>1. ModuPark first ask how many parking spaces and how many layers (floors) clients want. Surrounding constraint information such as boundary conditions and some special regulations are also asked. Those are the most important input from client at that moment. 2. Also some minor requirements from clients are gathered. For instance, do you prefer to install some elevator, have additional special fire escape or to have a nice-looking facade? But, those are not ModuPark standardized concept because it is open garage and uses natural ventilation focusing on structural components, rather than considering all HVAC or decoration.</td>
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<tr>
<td>To analyze the information structure and process of AS-IS situation</td>
<td>How do you produce your information during your task? By which software? With whom? By which methodology? And Why?</td>
<td>The current process model</td>
<td>1. Clients have a problem on their parking facilities. 2. ModuPark visit the clients and have a just very basic information regarding boundary conditions such as Google map. 3. With these initial input data, ModuPark develop the conceptual draft by hand. Without any use of software and system, the first drawing is developed. 4. Based on this first and conceptual hand-</td>
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Towards an Industrialised Project Delivery System for the BC Industry

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<td>drawing, a cost estimation by ModuPark is roughly calculated using simple Excel spreadsheet and some their own knowledge.</td>
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<td>5. With these outcomes from the above processes, ModuPark visit again client and propose their conceptual plan and estimated cost etc.</td>
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<td>6. If the above process is accepted by client, then ModuPark starts the real engineering for modular parking garage.</td>
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<td></td>
<td>7. Ballast Nedam Engineering is involved at this moment in order to develop the detailed specification using Revit software.</td>
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</table>

To analyze the information structure and process of AS-IS situation

| To analyze the information structure and process of AS-IS situation | What output data do you deliver when finishing your task? To whom? What type of information? And why? | The current output information | 1. Final outcomes such as all kind of shop drawings are made by Ballast Nedam Engineering. | 2. Revit and Excel are main tool to generate all related information. |

2.3 Detailed questions for TO-BE expectation

This interview part will takes around 30 minute focusing on TO-BE expectation. Three perspectives in the integrated system which are information process, information structure and enabling software in existing information system will be discussed. The scope, viewpoint and purpose of this interview part is same with the above chapter. Main question of this part is What kind of design options you consider, what type of requirements (changeable or fixed) you consider, and what pre-conditions and technical possibilities you consider. This question is for development of parametric matrix in this research.

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<tr>
<td>In this research, one of the critical findings would be a linkage between client</td>
<td>What requirements should be asked to clients? In my point-of-view, there are two</td>
<td>Requirements from clients</td>
<td>1. In the current ModuPark, the important decision making is too highly based on the clients’ impression (feeling) and providers’ intangible knowledge. But, this is still</td>
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**Towards an Industrialised Project Delivery System for the BC Industry**

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<tr>
<td>requirements (from RBS or even SBS) and supplier specification (from Revit model). To integrate these two different information structures, the parametric design methodology is dealing with.</td>
<td>types of requirements. One is client-driven requirements which mean that it is totally based on the context, wish and needs of client. What do you think of it? And if agreed, what kinds of requirement is client-driven requirement?</td>
<td>sometime too risky as well as unreliable. Therefore, it would be great for ModuPark if an information system or software to support their decision and reduce mismatching problem is developed and applied in their business.</td>
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1. I explain the integrated system and user interface that I want to develop using parametric design method. Their approach

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<tr>
<th>In this research, the user interface using parametric design</th>
<th>Do you have any idea or expectation on user interface? What is the User interface</th>
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Towards an Industrialised Project Delivery System for the BC Industry

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<th>Keywords</th>
<th>Answers</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>methodology would be proposed to support the ModuPark business in supplier-driven project delivery.</td>
<td>most important requirements from clients and the vital perspectives for suppliers?</td>
<td></td>
<td>for better performance of ModuPark is also in line with my development.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. User interface would better provide some alternatives to choose, rather than propose the best solution based on the integrated system.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. We can divide two types of requirements. One is changeable and another is fixed. The changeable requirement is mostly from clients. So we can ask changeable requirements to clients using User interfaces in ModuPark website.</td>
<td></td>
</tr>
</tbody>
</table>

In this research, most of iterative and routine works in requirement analysis and design development would be automated by pre-defining the relations and their logics.

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Questions</th>
<th>Keywords</th>
<th>Answers</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>To automate the current iterative and routine works, the clear analysis on the process and its logic should be define. What do you think of the proposed TO-BE process and product model? And any comments to improve it?</td>
<td>TO-BE process expectation, Automation(semi)</td>
<td>1. In the current business process, ModuPark takes all risks after making a contract only based on the conceptual design and estimation. So, if the more detailed design and estimation are available in the very early phase, they can reduce a lot of risks.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Mostly it takes 3~4weeks to generate the conceptual design of ModuPark. In the near future, they are expected to produce it within few days saving a lot of time and effort.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. But, they are not sure if it is possible to develop fully-knowledge-based system that automatically generate all relevant information and provide the best solution in any cases. It is not because this process is fussy but because all relations among requirements and specifications are too complicated to describe. All are related each other. They think that design development process itself is too difficult to describe on the paper since a lot of variables should be considered.</td>
<td></td>
</tr>
</tbody>
</table>
## Towards an Industrialised Project Delivery System for the BC Industry

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Questions</th>
<th>Keywords</th>
<th>Answers</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>To analyze the requirement of the integrated system. If they provide some requirements or ideas for their software or systems that they are using, they are reflected on the conceptual modeling of the integrated system.</td>
<td>I am developing (or designing) the integrated system (BIM+SE) for a better industrialization in the BC industry. What do you think of it? Do you have any requirement on it? Why?</td>
<td>Additional requirements for the integrated system</td>
<td>1. An industrialized project delivery system based on standardized components and reusable existing information has a lot of possibilities but also there are definitive boundaries to apply it. For instance, the maximum number of layers (floors) in ModuPark is 5 using the existing standard components. So, you would better find out these constraints and boundaries. 2. ModuPark want to use a system to immediately generate some alternatives of design solution, rather than depending on hand-drawings and invisible knowledge.</td>
<td></td>
</tr>
</tbody>
</table>
Towards an Industrialised Project Delivery System for the BC Industry

B-2. Interview summary 01. (Strategic information manager in Ballast Nedam)

<table>
<thead>
<tr>
<th>Preparation for Interview with Menno (Strategic information manager in BN)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statement of purpose</strong></td>
</tr>
<tr>
<td>An interview with Menno is arranged at Ballast Nedam on 25th May, 2010. This is one of additional interviews, based on the other interview team and what this MSc research have found so far. Main goal of this interview is to understand the current situation of SE and BIM in Ballast Nedam and validate findings from this MSc research. Main interview question is how Ballast Nedam have individually applied SE and BIM in practice, why integration between SE and BIM is so critical in Ballast Nedam and what possibilities and limitation in the proposed system are expected in practice.</td>
</tr>
<tr>
<td><strong>Contents</strong></td>
</tr>
<tr>
<td>1. Interview Process</td>
</tr>
<tr>
<td>2. General question</td>
</tr>
<tr>
<td>3. Detailed open questions for the parametric design for ModuPark</td>
</tr>
<tr>
<td><strong>Additional preparations</strong></td>
</tr>
<tr>
<td>The following documents will be also prepared to discuss during meeting. These will be printed out for interviewee.</td>
</tr>
<tr>
<td>1. Draft final MSc report</td>
</tr>
<tr>
<td>2. Process modeling rev.07</td>
</tr>
<tr>
<td>3. Product modeling rev.02</td>
</tr>
<tr>
<td>4. Some prototyping</td>
</tr>
<tr>
<td>5. Other interview summaries</td>
</tr>
<tr>
<td><strong>1st distribution</strong></td>
</tr>
<tr>
<td>On 19th May and To interviewee and all MSc committee [interview preparation]</td>
</tr>
<tr>
<td><strong>Expected 2nd distribution</strong></td>
</tr>
<tr>
<td>On 30th May and To interviewee and all MSc committee [Interview validation]</td>
</tr>
</tbody>
</table>

* The overview and background of this MSc research is omitted in this document, since it is supposed that the interviewee as one of the MSc committee already understood well. If required, please contact me.

1. Interview Process

Before interview, I suppose I will send the draft MSc report (or part of it) to interviewee since it would contain some background of this interview. On 25th May, an interview will be done with the following open-questions. On 30th May, an interview summary document will be delivered to the interviewee to validate information in it.
2. General questions

Open questions consist of two main categories, which are general questions on interviewees’ background and his task and detailed questions on the current situation of SE and BIM in Ballast Nedam. These general questions will be answered within 15 minutes. These questions would be asked in more general and overall manner. Main goal of this part is to formally underpin some relevant chapters of final MSc report.

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Questions</th>
<th>Keywords</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>To get some general information on interviewees</td>
<td>What is your main task? Could you introduce your background?</td>
<td>Interviewees’ general information</td>
<td>Could be skipped</td>
</tr>
<tr>
<td>To more practically support findings in chap. 4.1</td>
<td>Why BIM is so important in BN? What possibilities of BIM are important for BN?</td>
<td>AS-IS situation of BIM in BN</td>
<td>Main reason to implement and use BIM is, they believe, to ensure the better construction and the more profitable project management by reducing the error and by preventing the failures in the design and construction phases. BIM has a lot of potentials in the current BC industry. Depending on the strategy and situation, it would be more useful for a certain project in certain aspect of BIM. For instance, it is very important for ModuPark to use BIM since it provide a good tool to manage the whole logistic plan of the industrialized components including how to prefabricate and assembly. Furthermore, BIM enable ModuPark to quickly generate design representation in order to discuss with the clients in the very earlier design phase. Also, we can easily, correctly and quickly estimate the cost of the product built. Therefore, BIM provide good solutions for the construction project management of 3D, 4D and 5D aspects. (3D means a visualization of the design, 4D means a better scheduling technology including the whole logistics plan and 5D is cost management.)</td>
</tr>
<tr>
<td>To more practically</td>
<td>How have BN applied</td>
<td>AS-IS situation of BIM</td>
<td>BIM has been actively applied in Ballast Nedam,</td>
</tr>
</tbody>
</table>

Towards an Industrialised Project Delivery System for the BC Industry
Towards an Industrialised Project Delivery System for the BC Industry

<table>
<thead>
<tr>
<th>support findings in chap. 4.1</th>
<th>so far? Are there any problems to implement BIM in practice?</th>
<th>in BN</th>
<th>especially in these days. But, BIM has been not that much used for the ModuPark so far as far as he knows. While there are some actively-applied cases the normal parking garage projects such as Kralingese zoom project not only in 3D visualisation but also in 4D time management, the ModuPark is not that much applied so far in spite of the more potential. He pointed out that even if there are some technical problems to implement BIM, it is never main problem to confront. Main challenges to use BIM in Ballast Nedam is more organizational, rather than technical. For example, Ballast Nedam are asking their employees to use for some ongoing projects. But, unfortunately the capacity of BIM specialist in Ballast Nedam is not enough. Furthermore, the way of working in the current Ballast Nedam is too difficult to change. Those kinds of the organisational issues exist in practice. Even if there are some problem in BIM technologies and system itself, it is minor but solvable.</th>
</tr>
</thead>
<tbody>
<tr>
<td>To more practically support findings in chap. 4.2</td>
<td>Why SE is so important in BN? What possibilities of SE are important for BN?</td>
<td>AS-IS situation of SE in BN</td>
<td>There are several reasons to use SE in Ballast Nedam. First of all, SE ensures their design solution the better fitting the clients’ requirement. And SE provide a good solution of establishing, managing and tracking all project information in the more structured way by using the standard method to manage the process in the entire project management. More importantly, their clients such as the Dutch governmental organisation are more and more demanding them to apply the public construction project such as highway project or railroad construction. Actually, Dutch BC market is quite often mandatory to use this SE philosophy. Especially, the large clients such as Prorail and RWS ask them to actively use SE in their project. SE provides a good guideline of the lifecycle</td>
</tr>
</tbody>
</table>
Towards an Industrialised Project Delivery System for the BC Industry

management for the facilities built. In practice, SE has more been applied to come up the better design solution in the design phase and check it out in the construction phase.

To more practically support findings in chap. 4.2

<table>
<thead>
<tr>
<th>Questions</th>
<th>Keywords</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>How have BN applied so far? Are there any problems to implement SE in practice?</td>
<td>AS-IS situation of SE in BN</td>
<td>SE in design phase defines the clients’ requirements and establishes the design solution and in construction phase proof to fit the clients’ requirements and their design. SE has a lot of enabling tools and methods. The most interesting tool for Ballast Nedam is xBS technologies, which are enabled to conduct their project in more structured manner. There are some problems to properly implement SE in Ballast Nedam. First of all, SE methodology is quite complex and unfamiliar in the BC industry.</td>
</tr>
</tbody>
</table>

3. Detailed open questions for the integration and its further development

Detailed questions consist of two main categories, which are the integration and its further development in Ballast Nedam. These general questions will be answered within 15 minutes. These questions would be asked in more general and overall manner. Main goal of this part is to formally underpin some relevant chapters of final MSc report.

<table>
<thead>
<tr>
<th>Backgrounds</th>
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<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>To more practically support findings in chap. 4.3</td>
<td>I suppose these two different concepts, BIM and SE, are more and less overlapped in theoretically due to similar goals, broadly speaking. What do you think of it? At the same time, in practice, they have fragmentally applied due to individual application of</td>
<td>Overlapped concepts in theory/ Fragmented application in practice</td>
<td>Since both SE and BIM concepts cover the whole life cycle and their goals of the better construction project are generally similar, they are interactive with each other and overlapped in theory. But, in practice, both are individually used. In other words, system engineer is involved to contribute the project in certain phase and BIM modeller also separately develops their design in certain phase. He also mentioned about information system architecture in engineering and construction sector. Ballast Nedam has several information system architectures such as ERP for financial and logistics</td>
</tr>
</tbody>
</table>
## Towards an Industrialised Project Delivery System for the BC Industry

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Questions</th>
<th>Keywords</th>
<th>Answers</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>software etc. What do you think of it?</td>
<td>part, Document Managing System, BIM, SE etc.</td>
<td>Now Ballast Nedam is trying to interlink each other architectures. Especially, an inter-link between BIM and document part or an inter-link between BIM and SE are been actively studying and developing in Ballast Nedam.</td>
<td></td>
</tr>
<tr>
<td>To more practically support findings in chap. 4.3</td>
<td>Why do you think the integration between SE and BIM? What’s the most critical and necessary to achieve this integration? What efforts have so far been made to tackle with this issue?</td>
<td>BIM and SE in Ballast Nedam</td>
<td>The most interesting part in the integration issues of SE and BIM in the current Ballast Nedam is to load SBS in-house codes to objects in the BIM environment in order to</td>
<td></td>
</tr>
<tr>
<td>To more practically support findings in chap. 8.3.1</td>
<td>During several modelling processes for the integrated system, some interesting possibilities &amp; limitations was discovered and mentioned in draft MSc report. What do you think of it? And Any other additions?</td>
<td>possibilities &amp; limitations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To more practically support findings in chap. 8.3.3</td>
<td>Please let me know the plan and strategy of further development.</td>
<td>Strategy to enhance the proposed system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## APPENDIX C. SWOT ANALYSIS OF 4 PREVIOUS INDUSTRIALSAED APPROACHES

### SWOT Analysis for FutureHome

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal</strong></td>
<td><strong>Negative</strong></td>
</tr>
<tr>
<td>- It covers almost all supply chain process from off-site factory system through transportation system to on-site assembly.</td>
<td>- They didn’t much take into account on conditions of commercial business in the BC industry.</td>
</tr>
<tr>
<td>- It was quite specifically developed with certain prototype in process and product modeling.</td>
<td>- Comparing to experiences of other industries, design phase was too client-driven, rather than producer-driven for mass customization.</td>
</tr>
<tr>
<td>- At that time, existing and emerging ICT solutions were actively applied.</td>
<td>- Although some specific prototypes were presented, no fully-integrated structure and process were developed.</td>
</tr>
<tr>
<td>- In long-term plan, they provide a good guideline for fully Integrated Construction Automation (ICA)</td>
<td>- It focused only on residential and office building.</td>
</tr>
<tr>
<td><strong>External</strong></td>
<td></td>
</tr>
<tr>
<td>- Robotics technology has been attained more growth for last decades in the BC industry</td>
<td>- Since there is no active initiator and no commercially successful case so far, most of actors just are observing each others.</td>
</tr>
<tr>
<td>- As Information technology quite developed and commonly applied in our society,</td>
<td>- Although a lot of effort for standardization concept has been made, some of them is still in development and others is turned away.</td>
</tr>
<tr>
<td>- With numerous trials and errors in the BC industry, a group of producer have enough experience on ICT and ICA.</td>
<td>- Still an initial investment on it is not that feasible for producers.</td>
</tr>
<tr>
<td>- Positive market and governmental environment on ICT such as BIM has been built up.</td>
<td>- A conservative characteristic of the BC industry</td>
</tr>
</tbody>
</table>
### SWOT Analysis for ManuBuild

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal</strong></td>
<td></td>
</tr>
<tr>
<td>- It is very good systems thinking and holistic approach to lead the fully-integrated industrialization to the BC industry.</td>
<td>- Too research-oriented project (wide-range of theoretical solutions but narrow-range of practices)</td>
</tr>
<tr>
<td>- The openness on the manipulating issues and to external actors enabled their approach to be spread including business models and education.</td>
<td>- Like most of similar project, main focus of the industrialization is on housing market, not overall BC industry including several type of infrastructure project.</td>
</tr>
<tr>
<td>- They provided well-distributed and wide-ranged research basement with some tangible achievements on industrialization concept.</td>
<td>- In spite of having some tangible achievements on industrialization concept, fully-integrated prototyping from a to z was not presented.</td>
</tr>
<tr>
<td><strong>External</strong></td>
<td></td>
</tr>
<tr>
<td>- Clients are asking this kind of concepts more and more by experiences from other industries as well as producers are accumulating their knowledge from some pilot projects.</td>
<td>- Since there is no active initiator and no Due to conservative characteristic of the BC industry, traditional delivery system would be adhered.</td>
</tr>
<tr>
<td>- ICT has more developed in the BC industry and common people as well as project participants are get used to it. (BIM environment)</td>
<td>- It is too difficult and too time-consuming to develop the relevant standardization, legal system and policy to support and realize the industrialization.</td>
</tr>
<tr>
<td>- Available benchmarking</td>
<td>- it is too difficult to shift due to absence of market leader (world-wide initiator) in this field.</td>
</tr>
</tbody>
</table>
# SWOT Analysis for BoKlok

<table>
<thead>
<tr>
<th>Internal</th>
<th>Positiva</th>
<th>Negativa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- A lot of tactical knowledge from IKEA concept on systematic component production and a lot of experience from Skanska on constructability and construction project delivery.</td>
<td>- Uncertainty and weakness on their collaboration relation</td>
</tr>
<tr>
<td></td>
<td>- The process of user interaction and strategy accumulating knowledge by means of the phases of communications and evaluations.</td>
<td>- Limitation on extending their business up to other industrialized construction project due to the current too specific target group, particular at cheap housing.</td>
</tr>
<tr>
<td></td>
<td>- Win-win strategy by opening new market that they hasn’t conducted in spite of their willingness.</td>
<td>- No effective methods for internal knowledge sharing in the firm and between the firms</td>
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<td></td>
<td></td>
<td>- Limitation on flexibility in their solutions</td>
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</table>

<table>
<thead>
<tr>
<th>External</th>
<th>Positiva</th>
<th>Negativa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- A good condition for stable market of industrialized buildings because construction boom is over and a recession will be stayed for the time being. (Worse economical situation, better condition for this market)</td>
<td>- The hesitating reactions and slow transformation of the governmental organization and policy might be a challenging issues</td>
</tr>
<tr>
<td></td>
<td>- IT progress are positive and user’s learning curve on IT is promising.</td>
<td>- Differences in regulations between different countries and in cultures regarding housing style and life style</td>
</tr>
<tr>
<td></td>
<td>- Robust and world-leading name-value from both initiators, IKEA and Skanska</td>
<td>- A conservative characteristic of project organization involved in the BC industry negatively influences a lot.</td>
</tr>
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</table>
### SWOT Analysis for Corus Living Solutions

<table>
<thead>
<tr>
<th>Internal</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Innovative and well-prepared ‘forward integration’ strategy based on material(Metal) background.</td>
<td>- Limitation of design flexibility, particularly container-box based unit design</td>
</tr>
<tr>
<td></td>
<td>- Already sustainable development and market i.e. MOD living quarters and student halls etc.</td>
<td>- Weak collaboration and knowledge-sharing in the internal process</td>
</tr>
<tr>
<td></td>
<td>- Annual capacity of up to 3000 units</td>
<td>- Still most of profits are from very specific building market (i.e. MoD) Not that well-balanced business portfolio</td>
</tr>
<tr>
<td></td>
<td>- Some efforts and achievements in terms of legal and policy for suitable business i.e. ISO 14001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Not only housing but also civil engineering solutions i.e. Modular Rail Platforms system and BT-Steel</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>External</th>
<th>Positive</th>
<th>Negative</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>- Demanding an industrialization as a solution due to a number of challenges of traditional BC industry such as ever-escalating, a shortage of skilled labor and tighter regulation etc.</td>
<td>- A conservative characteristic of project organization involved in the BC industry negatively influences a lot.</td>
</tr>
<tr>
<td></td>
<td>- Already initial investment was made with a good of profits</td>
<td>- Due to steel or metal company image, weak name -value compared to IKEA</td>
</tr>
<tr>
<td></td>
<td>- IT progress are positive and user’s learning curve on IT is promising</td>
<td>- Weak partnership with contractors</td>
</tr>
<tr>
<td></td>
<td>- Industrialized and modular building are demanding</td>
<td>- Standardization problem</td>
</tr>
</tbody>
</table>
APPENDIX D. DETAILED IDEF0 REPORT

AS-IS process modelling (IDEF0) rev. 06 Report

Statement of purpose
As we discussed during last plenary meeting, the detailed AS-IS process modelling based on more specific data such as interview are necessary. Based on interviews with Modeller for modular parking garage in Ballast Nedam(on 28th and 29th April, 2010), this process model was developed.

Distributed
On 30th April and To Arjen, Menno, Reza, Sander and Hennes

Created by
Park Jae Hyuk

Full IDEF0 Report for AS-IS process modelling (IDEF0) rev. 06

[Diagram: A-0] Top-level
Activity: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Standard components information g garage system
Input From: Standard components information g garage
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Existing Revit information (Design Model) g garage system
Input From: Existing Revit information (Design Model)
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Requirements and constraints information g garage system
Input From: Requirements and constraints information
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Regulation & Policy/ Building codes
Control From: Regulation & Policy/ Building codes
Control To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Structural Modeller
Mechanism From: Structural Modeller
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Tailored BIM information (Design Model) g garage system
Output From: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)
Output To: Tailored BIM information (Design Model)

Arrow: Revit software (BIM)
Mechanism From: Revit software (BIM)
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Specification Specialists
Mechanism From: Specification Specialists
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Conceptual Modeller
Mechanism From: Conceptual Modeller
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Project Manager
Mechanism From: Project Manager
Towards an Industrialised Project Delivery System for the BC Industry

Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: AutoCAD software (CAD)
Mechanism From: AutoCAD software (CAD)
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Excel & Word software
Mechanism From: Excel & Word software
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Business Rule
Control From: Business Rule
Control To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)

Arrow: Tekla software (BIM)
Mechanism From: Tekla software (BIM)
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark: AS-IS rev. 06)
[Diagram: A0] Design modular parking garage system

Activity: [A1] Analyze the program of parking garage system

Activity: [A2] Re-design parking garage system

Activity: [A3] Develop detailed drawings

Arrow: Requirements and constraints information g garage system
Input From: {I3} Requirements and constraints information
Input To: [A1] Analyze the program of parking garage system

Arrow: Existing Revit information (Design Model) g garage system
Input From: {I2} Existing Revit information (Design Model) for the modular parking
Input To: [A2] Re-design parking garage system

Arrow: Regulation & Policy/ Building codes
Control From: {C1} Regulation & Policy/ Building codes
Control To: [A3] Develop detailed drawings

Arrow: Regulation & Policy/ Building codes
Control From: {C1} Regulation & Policy/ Building codes
Control To: [A2] Re-design parking garage system

Arrow: Standard components information g garage system
Input From: {I1} Standard components information g garage
Input To: [A2] Re-design parking garage system
Towards an Industrialised Project Delivery System for the BC Industry

Arrow: Tailored BIM information (Design Model) g garage system
Output From: [A3] Develop detailed drawings
Output To: {O1} Tailored BIM information (Design Model)

Arrow: Structural Modeller
Mechanism From: {M3} Structural Modeller
Mechanism To: [A2] Re-design parking garage system

Arrow: Structural Modeller
Mechanism From: {M3} Structural Modeller
Mechanism To: [A1] Analyze the program of parking garage system

Arrow: Defined requirements and constraints information
Output From: [A1] Analyze the program of parking garage system
Input To: [A2] Re-design parking garage system

Arrow: Draft Revit information (Draft design model)
Output From: [A2] Re-design parking garage system
Input To: [A3] Develop detailed drawings

Arrow: Request information to re-tailoring & re-programming
Output From: [A3] Develop detailed drawings
Input To: [A1] Analyze the program of parking garage system

Arrow: Revit software (BIM)
Mechanism From: {M6} Revit software (BIM)
Mechanism To: [A2] Re-design parking garage system

Arrow: Revit software (BIM)
Mechanism From: {M6} Revit software (BIM)
Mechanism To: [A3] Develop detailed drawings

Arrow: Request information to re-programming
Output From: [A2] Re-design parking garage system
Input To: [A1] Analyze the program of parking garage system

Arrow: Request information to re-tailoring
Output From: [A3] Develop detailed drawings
Input To: [A2] Re-design parking garage system

Arrow: Conceptual shape model
Output From: [A1] Analyze the program of parking garage system
Input To: [A2] Re-design parking garage system

Arrow: Excel & Word software
Mechanism From: {M5} Excel & Word software
Mechanism To: [A1] Analyze the program of parking garage system

Arrow: Excel & Word software
Mechanism From: {M5} Excel & Word software
Mechanism To: [A3] Develop detailed drawings
Towards an Industrialised Project Delivery System for the BC Industry

Arrow: Conceptual Modeller
Mechanism From: {M2} Conceptual Modeller
Mechanism To: [A1] Analyze the program of parking garage system

Arrow: Project Manager
Mechanism From: {M8} Project Manager
Mechanism To: [A1] Analyze the program of parking garage system

Arrow: AutoCAD software (CAD)
Mechanism From: {M4} AutoCAD software (CAD)
Mechanism To: [A1] Analyze the program of parking garage system

Arrow: Specification Specialists
Mechanism From: {M1} Specification Specialists
Mechanism To: [A3] Develop detailed drawings

Arrow: Business Rule
Control From: {C2} Business Rule
Control To: [A1] Analyze the program of parking garage system

Arrow: Business Rule
Control From: {C2} Business Rule
Control To: [A2] Re-design parking garage system

Arrow: Project Manager
Mechanism From: {M8} Project Manager
Mechanism To: [A3] Develop detailed drawings

Arrow: Tekla software (BIM)
Mechanism From: {M7} Tekla software (BIM)
Mechanism To: [A3] Develop detailed drawings

Arrow: AutoCAD software (CAD)
Mechanism From: {M4} AutoCAD software (CAD)
Mechanism To: [A3] Develop detailed drawings

Arrow: Structural Modeller
Mechanism From: {M3} Structural Modeller
Mechanism To: [A3] Develop detailed drawings
[Diagram: A1] Analyze the program of parking garage system

Activity: [A11] Pre-analyze the programs and requirements

Activity: [A12] Discuss and Analyze constraints and requirements

Activity: [A13] Develop a conceptual model

Activity: [A11] Pre-analyze the programs and requirements

Activity: [A12] Discuss and Analyze constraints and requirements

Activity: [A13] Develop a conceptual model

Arrow: Requirements and constraints information for the modular parking garage system
Input From: {I1} Requirements and constraints information
Input To: [A11] Pre-analyze the programs and requirements

Arrow:
Output From: [A11] Pre-analyze the programs and requirements
Input To: [A12] Discuss and Analyze constraints and requirements

Arrow:
Output From: [A12] Discuss and Analyze constraints and requirements
Input To: [A13] Develop a conceptual model

Arrow: Request information to re-tailoring & re-programming
Input From: {I2} Request information to re-tailoring & re-programming
Towards an Industrialised Project Delivery System for the BC Industry

Input To: [A12] Discuss and Analyze constraints and requirements

Arrow: Request information to re-programming
Input From: {I3} Request information to re-programming
Input To: [A12] Discuss and Analyze constraints and requirements

Arrow: Excel & Word software
Mechanism From: {M4} Excel & Word software
Mechanism To: [A11] Pre-analyze the programs and requirements

Arrow: Excel & Word software
Mechanism From: {M4} Excel & Word software
Mechanism To: [A12] Discuss and Analyze constraints and requirements

Arrow: Structural Modeller
Mechanism From: {M5} Structural Modeller
Mechanism To: [A12] Discuss and Analyze constraints and requirements

Arrow: AutoCAD software (CAD)
Mechanism From: {M1} AutoCAD software (CAD)
Mechanism To: [A13] Develop a conceptual model

Arrow: Conceptual Modeller
Mechanism From: {M2} Conceptual Modeller
Mechanism To: [A13] Develop a conceptual model

Arrow: Conceptual shape model
Output From: [A13] Develop a conceptual model
Output To: {O1} Conceptual shape model

Arrow: Defined requirements and constraints information
Output From: [A12] Discuss and Analyze constraints and requirements
Output To: {O2} Defined requirements and constraints information

Arrow: Business Rule
Control From: {C1} Business Rule
Control To: [A12] Discuss and Analyze constraints and requirements

Arrow: Business Rule
Control From: {C1} Business Rule
Control To: [A11] Pre-analyze the programs and requirements

Arrow: Project Manager
Mechanism From: {M3} Project Manager
Mechanism To: [A12] Discuss and Analyze constraints and requirements

Arrow: Project Manager
Mechanism From: {M3} Project Manager
Mechanism To: [A11] Pre-analyze the programs and requirements
Towards an Industrialised Project Delivery System for the BC Industry

[Diagram: A2] Re-design parking garage system

Activity: [A21] Plot layout conditions
Activity: [A22] Adjust levels for floors
Activity: [A23] Array components for slabs
Activity: [A24] Array other components (ramp and hall)
Activity: [A25] Adjust all components as a final touch

Arrow: Conceptual shape model
Input From: {I1} Conceptual shape model
Input To: [A21] Plot layout conditions

Arrow: Existing Revit information (Design Model) g garage system
Input From: {I4} Existing Revit information (Design Model) for the modular parki
Towards an Industrialised Project Delivery System for the BC Industry

Input To: [A21] Plot layout conditions

Arrow: Standard components information g garage system
Input From: {I2} Standard components information g garage
Input To: [A22] Adjust levels for floors

Arrow: Standard components information g garage system
Input From: {I2} Standard components information g garage
Input To: [A23] Array components for slabs

Arrow: Standard components information g garage system
Input From: {I2} Standard components information g garage
Input To: [A24] Array other components (ramp and hall)

Arrow: Defined requirements and constraints information
Input From: {I3} Defined requirements and constraints information
Input To: [A21] Plot layout conditions

Arrow: Defined requirements and constraints information
Input From: {I3} Defined requirements and constraints information
Input To: [A23] Array components for slabs

Arrow: Defined requirements and constraints information
Input From: {I3} Defined requirements and constraints information
Input To: [A24] Array other components (ramp and hall)

Arrow: Defined requirements and constraints information
Input From: {I3} Defined requirements and constraints information
Input To: [A25] Adjust all components as a final touch

Arrow: Request information to re-tailoring
Input From: {I5} Request information to re-tailoring
Input To: [A25] Adjust all components as a final touch

Arrow: Structural Modeller
Mechanism From: {M1} Structural Modeller
Mechanism To: [A21] Plot layout conditions

Arrow: Structural Modeller
Mechanism From: {M1} Structural Modeller
Mechanism To: [A22] Adjust levels for floors

Arrow: Structural Modeller
Mechanism From: {M1} Structural Modeller
Mechanism To: [A23] Array components for slabs

Arrow: Structural Modeller
Mechanism From: {M1} Structural Modeller
Mechanism To: [A24] Array other components (ramp and hall)

Arrow: Structural Modeller
Mechanism From: {M1} Structural Modeller
Mechanism To: [A25] Adjust all components as a final touch
Towards an Industrialised Project Delivery System for the BC Industry

Mechanism To: [A25] Adjust all components as a final touch
Arrow: Revit software (BIM)
Mechanism From: {M2} Revit software (BIM)
Mechanism To: [A21] Plot layout conditions

Arrow: Revit software (BIM)
Mechanism From: {M2} Revit software (BIM)
Mechanism To: [A22] Adjust levels for floors

Arrow: Revit software (BIM)
Mechanism From: {M2} Revit software (BIM)
Mechanism To: [A23] Array components for slabs

Arrow: Revit software (BIM)
Mechanism From: {M2} Revit software (BIM)
Mechanism To: [A24] Array other components (ramp and hall)

Arrow: Revit software (BIM)
Mechanism From: {M2} Revit software (BIM)
Mechanism To: [A25] Adjust all components as a final touch

Arrow: Business Rule
Control From: {C1} Business Rule
Control To: [A22] Adjust levels for floors

Arrow: Business Rule
Control From: {C1} Business Rule
Control To: [A23] Array components for slabs

Arrow: Business Rule
Control From: {C1} Business Rule
Control To: [A24] Array other components (ramp and hall)

Arrow: Business Rule
Control From: {C1} Business Rule
Control To: [A25] Adjust all components as a final touch

Arrow: Regulation & Policy/ Building codes
Control From: {C2} Regulation & Policy/ Building codes
Control To: [A25] Adjust all components as a final touch

Arrow: Revit with layout information
Output From: [A21] Plot layout conditions
Input To: [A22] Adjust levels for floors

Arrow: Revit with levels information
Output From: [A22] Adjust levels for floors
Input To: [A23] Array components for slabs

Arrow: Revit with slab components information
Output From: [A23] Array components for slabs
Towards an Industrialised Project Delivery System for the BC Industry

Input To: [A24] Array other components (ramp and hall)

Arrow: Revit with all component information
Output From: [A24] Array other components (ramp and hall)
Input To: [A25] Adjust all components as a final touch

Arrow: Draft Revit information (Draft design model)
Output From: [A25] Adjust all components as a final touch
Output To: {O1} Draft Revit information (Draft design model)

Arrow: Request information to re-programming
Output From: [A25] Adjust all components as a final touch
Output To: {O2} Request information to re-programming

Arrow: Regulation & Policy/ Building codes
Control From: {C2} Regulation & Policy/ Building codes
Control To: [A21] Plot layout conditions

Arrow: Defined requirements and constraints information
Input From: {I3} Defined requirements and constraints information
Input To: [A22] Adjust levels for floors
[Diagram: A3] Develop detailed drawings

Activity: [A31] develop initially detailed drawings under conditions, rules, and constraints

Activity: [A32] Discuss some issues and find solution

Activity: [A33] Finalize the detailed drawings with relevant specification

Activity: [A31] develop initially detailed drawings under conditions, rules, and constraints

Activity: [A32] Discuss some issues and find solution

Activity: [A33] Finalize the detailed drawings with relevant specification

Arrow: Regulation & Policy/ Building codes
Control From: {C1} Regulation & Policy/ Building codes
Control To: [A31] develop initially detailed drawings under conditions, rules, and constraints

Arrow: Regulation & Policy/ Building codes
Control From: {C1} Regulation & Policy/ Building codes
Control To: [A32] Discuss some issues and find solution

Arrow: Regulation & Policy/ Building codes
Control From: {C1} Regulation & Policy/ Building codes
Control To: [A33] Finalize the detailed drawings with relevant specification
Arrow: Draft Revit information (Draft design model)
Input From: \{I1\} Draft Revit information (Draft design model)
Input To: \[A31\] develop initially detailed drawings under conditions, rules, and constraints

Arrow:
Output From: \[A32\] Discuss some issues and find solution
Input To: \[A31\] develop initially detailed drawings under conditions, rules, and constraints

Arrow:
Output From: \[A32\] Discuss some issues and find solution
Input To: \[A33\] Finalize the detailed drawings with relevant specification

Arrow:
Output From: \[A31\] develop initially detailed drawings under conditions, rules, and constraints
Output To: \{O2\} Request information to re-tailoring

Arrow: Excel & Word software
Mechanism From: \{M4\} Excel & Word software
Mechanism To: \[A31\] develop initially detailed drawings under conditions, rules, and constraints

Arrow: Excel & Word software
Mechanism From: \{M4\} Excel & Word software
Mechanism To: \[A32\] Discuss some issues and find solution

Arrow: Specification Specialists
Mechanism From: \{M6\} Specification Specialists
Mechanism To: \[A31\] develop initially detailed drawings under conditions, rules, and constraints

Arrow: Project Manager
Mechanism From: \{M2\} Project Manager
Mechanism To: \[A31\] develop initially detailed drawings under conditions, rules, and constraints

Arrow: Project Manager
Mechanism From: \{M2\} Project Manager
Mechanism To: \[A32\] Discuss some issues and find solution

Arrow: Request information to re-tailoring
Output From: \[A31\] develop initially detailed drawings under conditions, rules, and constraints
Output To: \{O2\} Request information to re-tailoring

Arrow: Request information to re-tailoring & re-programming
Output From: \[A31\] develop initially detailed drawings under conditions, rules, and constraints
Output To: \{O3\} Request information to re-tailoring & re-programming
Towards an Industrialised Project Delivery System for the BC Industry

Arrow: Tailored BIM information (Design Model) g garage system
Output From: [A33] Finalize the detailed drawings with relevant specification
Output To: {O1} Tailored BIM information (Design Model)

Arrow: Request information to re-tailoring
Output From: [A32] Discuss some issues and find solution
Output To: {O2} Request information to re-tailoring

Arrow: Request information to re-tailoring & re-programming
Output From: [A32] Discuss some issues and find solution
Output To: {O3} Request information to re-tailoring & re-programming

Arrow: Specification Specialists
Mechanism From: {M6} Specification Specialists
Mechanism To: [A32] Discuss some issues and find solution

Arrow: Revit software (BIM)
Mechanism From: {M5} Revit software (BIM)
Mechanism To: [A33] Finalize the detailed drawings with relevant specification

Arrow: Structural Modeller
Mechanism From: {M3} Structural Modeller
Mechanism To: [A33] Finalize the detailed drawings with relevant specification

Arrow: AutoCad software (CAD)
Mechanism From: {M1} AutoCad software (CAD)
Mechanism To: [A31] develop initially detailed drawings under conditions, rules, and constraints

Arrow: Tekla software (BIM)
Mechanism From: {M7} Tekla software (BIM)
Mechanism To: [A31] develop initially detailed drawings under conditions, rules, and constraints
Statement of purpose
As we discussed during last plenary meeting, the detailed TO-BE process modelling based on more specific data such as interview are necessary. Based on interviews with Modeller for modular parking garage in Ballast Nedam (on 28th and 29th April, 2010), this process model was developed.

Distributed
On 30th April and To Arjen, Menno, Reza, Sander and Hennes

Created by
Park Jae Hyuk

Full IDEF0 Report for TO-BE process modelling (IDEF0) rev. 07

Activity: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Standard components information for the modular parking garage system
Input From: Standard components information for the modular parking garage
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Existing SBS/ WBS/ RBS for modular parking garage system
Input From: Existing SBS/ WBS/ RBS for modular parking garage system
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Existing Revit information (Design Model) for the modular parking garage system
Towards an Industrialised Project Delivery System for the BC Industry

Input From: Existing Revit information (Design Model) for the modular parking garage
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Requirements and constraints information for the modular parking garage system
Input From: Requirements and constraints information for the modular parking garage system
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Business rules
Control From: Business rules
Control To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Systems Engineering methodology
Control From: Systems Engineering methodology
Control To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Regulation & Policy/ Building codes for the modular parking garage system
Control From: Regulation & Policy/ Building codes for the modular parking garage system
Control To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Provider
Mechanism From: Provider
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Contract information for the modular parking garage system
Output From: [A0] Design modular parking garage system (Ballast Nedam ModuPark)
Output To: Contract information for the modular parking garage system

Arrow: Integrated BIM Design Model for the modular parking garage system
Output From: [A0] Design modular parking garage system (Ballast Nedam ModuPark)
Output To: Integrated BIM Design Model for the modular parking garage system

Arrow: Revised SBS/ WBS/ RBS for modular parking garage system
Output From: [A0] Design modular parking garage system (Ballast Nedam ModuPark)
Output To: Revised SBS/ WBS/ RBS for modular parking garage system

Arrow: Order information for components/ assembly
Output From: [A0] Design modular parking garage system (Ballast Nedam ModuPark)
Output To: Order information for components/ assembly

Arrow: Client
Mechanism From: Client
Mechanism To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: Client basic information
Input From: Client basic information
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: ModuPark basic information
Input From: ModuPark basic information
Towards an Industrialised Project Delivery System for the BC Industry

Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

Arrow: General conditions and terms for contract
Input From: General conditions and terms for contract
Input To: [A0] Design modular parking garage system (Ballast Nedam ModuPark)

[Diagram: A0] Design modular parking garage system

Activity: [A1] Use parameter design tool

Activity: [A2] Use System Integrator (SE+BIM)

Activity: [A3] Make a contract with client

Activity: [A4] Specify specification of components and assembly

Arrow: Requirements and constraints information for the modular parking garage system
Input From: {I7} Requirements and constraints information for the modular parking garage
Input To: [A1] Use parameter design tool

Arrow: Input data for parametric design
Output From: [A1] Use parameter design tool
Input To: [A2] Use System Integrator (SE+BIM)

Arrow: Existing Revit information (Design Model) for the modular parking garage system
Towards an Industrialised Project Delivery System for the BC Industry

Input From: {I6} Existing Revit information (Design Model) for the modular parking garage
Input To: [A2] Use System Integrator (SE+BIM)

Arrow: Business rules
Control From: {C1} Business rules
Control To: [A3] Make a contract with client

Arrow: Regulation & Policy/ Building codes for the modular parking garage system
Control From: {C2} Regulation & Policy/ Building codes for the modular parking garage
Control To: [A3] Make a contract with client

Arrow: Regulation & Policy/ Building codes for the modular parking garage system
Control From: {C2} Regulation & Policy/ Building codes for the modular parking garage
Control To: [A2] Use System Integrator (SE+BIM)

Arrow: Client
Mechanism From: {M1} Client
Mechanism To: [A3] Make a contract with client

Arrow: Provider
Mechanism From: {M2} Provider
Mechanism To: [A3] Make a contract with client

Arrow: Contract information for the modular parking garage system
Output From: [A3] Make a contract with client
Output To: {O1} Contract information for the modular parking garage system

Arrow: Client
Mechanism From: {M1} Client
Mechanism To: [A1] Use parameter design tool

Arrow: Systems Engineering methodology
Control From: {C3} Systems Engineering methodology
Control To: [A4] Specify specification of components and assembly

Arrow: Order information for components/ assembly
Output From: [A4] Specify specification of components and assembly
Output To: {O4} Order information for components/ assembly

Arrow: Integrated BIM Design Model for the modular parking garage system
Output From: [A2] Use System Integrator (SE+BIM)
Output To: {O2} Integrated BIM Design Model for the modular parking garage system

Arrow: Provider
Mechanism From: {M2} Provider
Mechanism To: [A4] Specify specification of components and assembly

Arrow: Standard components information for the modular parking garage system
Towards an Industrialised Project Delivery System for the BC Industry

Input From: {I1} Standard components information for the modular parking garage
Input To: [A2] Use System Integrator (SE+BIM)

Arrow: Existing SBS/ WBS/ RBS for modular parking garage system
Input From: {I2} Existing SBS/ WBS/ RBS for modular parking garage system
Input To: [A2] Use System Integrator (SE+BIM)

Arrow: Contracted draft Revit design model
Output From: [A3] Make a contract with client
Input To: [A4] Specify specification of components and assembly

Arrow: Request information to re-tailoring
Output From: [A3] Make a contract with client
Input To: [A1] Use parameter design tool

Arrow: Revised SBS/ WBS/ RBS for modular parking garage system
Output From: [A2] Use System Integrator (SE+BIM)
Output To: {O3} Revised SBS/ WBS/ RBS for modular parking garage system

Arrow: Systems Engineering methodology
Control From: {C3} Systems Engineering methodology
Control To: [A2] Use System Integrator (SE+BIM)

Arrow: Specification information (Based on draft Revit design model)
Output From: [A2] Use System Integrator (SE+BIM)
Input To: [A3] Make a contract with client

Arrow: Client basic information
Input From: {I3} Client basic information
Input To: [A1] Use parameter design tool

Arrow: ModuPark basic information
Input From: {I5} ModuPark basic information
Input To: [A1] Use parameter design tool

Arrow: General conditions and terms for contract
Input From: {I4} General conditions and terms for contract
Input To: [A3] Make a contract with client
[Diagram: A1] Use parameter design tool

Activity: [A11] Visit the ModuPark website and log-in

Activity: [A12] Open the parametric design tool in the website

Activity: [A13] Fill in User interface sheet for parametric design

Activity: [A11] Visit the ModuPark website and log-in

Activity: [A12] Open the parametric design tool in the website

Activity: [A13] Fill in User interface sheet for parametric design

Arrow: Client basic information
Input From: \{I2\} Client basic information
Input To: [A11] Visit the ModuPark website and log-in

Arrow: ModuPark basic information
Input From: \{I3\} ModuPark basic information
Input To: [A11] Visit the ModuPark website and log-in

Arrow:
Output From: [A11] Visit the ModuPark website and log-in
Input To: [A12] Open the parametric design tool in the website

Arrow:
Output From: [A12] Open the parametric design tool in the website
Input To: [A13] Fill in User interface sheet for parametric design
Towards an Industrialised Project Delivery System for the BC Industry

Arrow: Client
Mechanism From: {M1} Client
Mechanism To: [A11] Visit the ModuPark website and log-in

Arrow: Client
Mechanism From: {M1} Client
Mechanism To: [A12] Open the parametric design tool in the website

Arrow: Client
Mechanism From: {M1} Client
Mechanism To: [A13] Fill in User interface sheet for parametric design

Arrow: Requirements and constraints information for the modular parking garage system
Input From: {I1} Requirements and constraints information for the modular parking system
Input To: [A13] Fill in User interface sheet for parametric design

Arrow: Request information to re-tailoring
Input From: {I4} Request information to re-tailoring
Input To: [A13] Fill in User interface sheet for parametric design

Arrow: Input data for parametric design
Output From: [A13] Fill in User interface sheet for parametric design
Output To: {O1} Input data for parametric design

Arrow:
Output From: [A13] Fill in User interface sheet for parametric design
Output To: [A13] Fill in User interface sheet for parametric design
Towards an Industrialised Project Delivery System for the BC Industry

[Diagram: A2] Use System Integrator (SE+BIM)

Activity: [A21] Tailor Revit design model by parametric design system

Activity: [A22] Revise generic prototyping system based on Revit design model

Activity: [A23] Generate all relevant information from System Integrator

Activity: [A21] Tailor Revit design model by parametric design system

Activity: [A22] Revise generic prototyping system based on Revit design model

Activity: [A23] Generate all relevant information from System Integrator

Arrow: Input data for parametric design
Input From: {I1} Input data for parametric design
Input To: [A21] Tailor Revit design model by parametric design system

Arrow: Standard components information for the modular parking garage system
Input From: {I2} Standard components information for the modular parking garage system
Input To: [A21] Tailor Revit design model by parametric design system

Arrow: Existing Revit information (Design Model) for the modular parking garage system
Input From: {I4} Existing Revit information (Design Model) for the modular parking garage system
Input To: [A21] Tailor Revit design model by parametric design system

Arrow: Existing SBS/ WBS/ RBS for modular parking garage system
Input From: {I3} Existing SBS/ WBS/ RBS for modular parking garage system
Input To: [A22] Revise generic prototyping system based on Revit design model
Towards an Industrialised Project Delivery System for the BC Industry

Arrow: Regulation & Policy/ Building codes for the modular parking garage system
Control From: \{C1\} Regulation & Policy/ Building codes for the modular parking garage
Control To: [A21] Tailor Revit design model by parametric design system

Arrow: Systems Engineering methodology
Control From: \{C2\} Systems Engineering methodology
Control To: [A22] Revise generic prototyping system based on Revit design model

Arrow: Systems Engineering methodology
Control From: \{C2\} Systems Engineering methodology
Control To: [A23] Generate all relevant information from System Integrator

Arrow: Integrated BIM Design Model for the modular parking garage system
Output From: [A23] Generate all relevant information from System Integrator
Output To: \{O1\} Integrated BIM Design Model for the modular parking garage system

Arrow: Specification information (Based on draft Revit design model)
Output From: [A23] Generate all relevant information from System Integrator
Output To: \{O3\} Specification information (Based on draft Revit design model)

Arrow: Revised SBS/ WBS/ RBS for modular parking garage system
Output From: [A23] Generate all relevant information from System Integrator
Output To: \{O2\} Revised SBS/ WBS/ RBS for modular parking garage system

Arrow: Revit information
Output From: [A21] Tailor Revit design model by parametric design system
Input To: [A22] Revise generic prototyping system based on Revit design model

Arrow: Integrated information
Output From: [A22] Revise generic prototyping system based on Revit design model
Input To: [A23] Generate all relevant information from System Integrator

Arrow: Revised Integrator (UML)
Output From: [A22] Revise generic prototyping system based on Revit design model
Output To: [A22] Revise generic prototyping system based on Revit design model
[Diagram: A3] Make a contract with client

Activity: [A31] Set up format of contract

Activity: [A32] Check out all details and make an agreement

Activity: [A33] Export all contracted information

Arrow: Regulation & Policy/ Building codes for the modular parking garage system
Control From: {C1} Regulation & Policy/ Building codes for the modular parking garage
Control To: [A31] Set up format of contract

Arrow: Regulation & Policy/ Building codes for the modular parking garage system
Control From: {C1} Regulation & Policy/ Building codes for the modular parking garage
Control To: [A32] Check out all details and make an agreement

Arrow: Business rules
Control From: {C2} Business rules
Control To: [A32] Check out all details and make an agreement

Arrow: General conditions and terms for contract
Input From: {I2} General conditions and terms for contract
Input To: [A31] Set up format of contract
Towards an Industrialised Project Delivery System for the BC Industry

Arrow: Specification information (Based on draft Revit design model)
Input From: {I1} Specification information (Based on draft Revit design model)
Input To: [A32] Check out all details and make an agreement

Arrow:
Output From: [A31] Set up format of contract
Input To: [A32] Check out all details and make an agreement

Arrow:
Output From: [A32] Check out all details and make an agreement
Input To: [A33] Export all contracted information

Arrow: Client
Mechanism From: {M1} Client
Mechanism To: [A32] Check out all details and make an agreement

Arrow: Provider
Mechanism From: {M2} Provider
Mechanism To: [A32] Check out all details and make an agreement

Arrow: Contract information for the modular parking garage system
Output From: [A33] Export all contracted information
Output To: {O1} Contract information for the modular parking garage system

Arrow: Request information to re-tailoring
Output From: [A33] Export all contracted information
Output To: {O3} Request information to re-tailoring

Arrow: Contracted draft Revit design model
Output From: [A33] Export all contracted information
Output To: {O2} Contracted draft Revit design model

Arrow: Specification information (Based on draft Revit design model)
Input From: {I1} Specification information (Based on draft Revit design model)
Input To: [A33] Export all contracted information
[Diagram: A4] Specify specification of components and assembly

Activity: [A41] Estimate quantities of all components, based on SBS and Revit d

Activity: [A42] Order estimated components

Activity: [A41] Estimate quantities of all components, based on SBS and Revit d

Activity: [A42] Order estimated components

Arrow: Contracted draft Revit design model
Input From: {I1} Contracted draft Revit design model
Input To: [A41] Estimate quantities of all components, based on SBS and Revit d

Arrow: Systems Engineering methodology
Control From: {C1} Systems Engineering methodology
Control To: [A41] Estimate quantities of all components, based on SBS and Revit d

Arrow: Systems Engineering methodology
Control From: {C1} Systems Engineering methodology
Control To: [A42] Order estimated components

Arrow: Provider
Mechanism From: {M1} Provider
Mechanism To: [A41] Estimate quantities of all components, based on SBS and Revit d

Arrow: Provider
Mechanism From: {M1} Provider
Mechanism To: [A42] Order estimated components
Towards an Industrialised Project Delivery System for the BC Industry

Arrow: Order information for components/assembly
Output From: [A42] Order estimated components
Output To: {O1} Order information for components/assembly

Arrow: Estimated information
Output From: [A41] Estimate quantities of all components, based on SBS and Revit
Input To: [A42] Order estimated components