

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**ANALYSIS OF MOBILE BIM ADOPTION AT CONSTRUCTION SITE: A
CASE STUDY OF A COMPLEX INFRASTRUCTURE PROJECT**



M. Sc. THESIS

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Department of Civil Engineering
Construction Management Programme

JUNE 2018

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

**İNŞAAT SAHASINDA MOBİL BIM ADAPTASYONUNUN ANALİZİ:
KOMPLEKS ALTYAPI PROJESİ VAKA ANALİZİ**

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To my family,



FOREWORD

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TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	ix
TABLE OF CONTENTS	xi
ABBREVIATIONS	xiii
LIST OF TABLES	xv
LIST OF FIGURES	xvii
SUMMARY	xix
ÖZET	xxiii
1. INTRODUCTION	1
1.1 Background	1
1.2 The Aim and Objectives of the Research	3
1.3 Research Methodology	3
1.3.1 Case study	3
1.3.2 Survey research	4
1.3.3 Interview research	4
1.3.4 Adopted methodology and justification	5
1.4 Research Approach	7
1.4.1.1 Qualitative approach	7
1.4.1.2 Quantitative approach	7
1.4.1.3 Mixed approach (triangulation)	8
1.5 Organization of the Thesis	8
2. LITERATURE REVIEW	9
2.1 Analysis of Market Reports on Site BIM Implementation Issue	9
2.2 BIM Integrated with Mobile Computing to Support On-Site Activities	11
2.3 Literature Analysis for BIM Integrated On-Site Activities	13
2.3.1 Design management enabled through BIM	13
2.3.2 Information management enabled through BIM	15
2.3.3 Quality control and assurance records enabled through BIM	16
2.3.4 Resource management enabled through BIM	17
2.3.5 Performance management enabled through BIM	17
2.4 BIM Implementation for Building and Infrastructure Industries	18
2.5 Comparison of BIM Implementation in Different Procurement Types	18
2.6 Summary of Literature Analysis	20
3. CASE STUDY AND EVALUATION	23
3.1 Introduction	23
3.2 Project Description	23
3.3 BIM Implementation Strategies and Transformation Process	25
3.3.1 Design and engineering	26
3.3.1.1 BIM execution for communication and collaboration	26
3.3.1.2 Information management for data sharing	30
3.3.1.3 BIM model creation & coordination	32
3.3.1.4 Clash reporting format	34

3.3.1.5 2D drawings production procedure	35
3.3.1.6 4D/5D	36
3.3.2 Project management	38
3.3.2.1 Mobile tool set-up	41
3.3.2.2 Model integration process.....	42
3.3.2.3 Mobile BIM practices performed on site.....	43
3.4 Project Participants	51
3.4.1 BIM Production Team.....	52
3.4.2 Designers	53
3.4.3 Construction Subcontractors.....	54
4. SURVEY STUDY OF IGA.....	57
4.1 Introduction	57
4.2 Survey Design.....	57
4.3 Survey Respondent Profile	58
4.4 Results	60
4.4.1 Design management	60
4.4.2 Information management.....	63
4.4.3 Quality control and assurance.....	65
4.4.4 Resource management.....	66
4.4.5 Performance management	67
4.4.6 General questions on BIM use.....	69
4.4.7 Further improvement suggestions.....	71
5. INTERVIEW STUDY OF IGA.....	73
5.1 Introduction	73
5.2 Interview Design.....	73
5.3 Respondent Profile.....	74
5.4 Results	75
5.4.1 Motive to innovate	75
5.4.2 Innovation process	76
5.4.2.1 Adoption strategies for IGA site personnel	77
5.4.2.2 Adoption strategies for subcontractors	78
5.4.3 Main functions of BIM on site.....	78
5.4.4 Main barriers and challenges	80
5.4.5 Main advantage and disadvantages.....	80
5.4.6 Grounds for successful adoption.....	81
5.4.7 Development suggestions and lessons learned.....	82
6. DISCUSSIONS	83
6.1 Case Study of IGA	83
6.2 Survey Study of IGA.....	85
6.3 Interview Study of IGA.....	89
7. CONCLUSIONS AND FUTURE WORK	93
7.1 General Conclusions	93
7.2 Future Work.....	95
REFERENCES	97
APPENDICES	101
CURRICULUM VITAE.....	111

ABBREVIATIONS

AR	: Augmented Reality
BHS	: Baggage Handling System
BIM	: Building Information Modelling
BOQ	: Bill of Quantities
BOT	: Build-Operate-Transfer
CAD	: Computer Aided Design
CCL	: Collaboration Communication and Learning
CM	: Construction Manager
DCC	: Document Control Center
DM	: Design Management
HVAC	: Heating Ventilation and Cooling
ICT	: Information and Communications Technology
IFC	: Issued for Construction
IGA	: Istanbul Grand Airport
IM	: Information Management
IT	: Information Technology
LoD	: Level of Detail
MAF	: Material Approval Form
MEP	: Mechanical Electrical Plumbing
MS	: Method Statement
NWC	: Navisworks Cache
NWD	: Navisworks Document
PM	: Performance Management
QA/QC	: Quality Assurance/Quality Control
RFI	: Request for Information
RM	: Resource Management
WIP	: Work in Progress
SAS	: Special Airport Systems
SD	: Shop Drawing

2D : Two Dimensional
3D : Three Dimensional
4D : Four Dimensional
5D : Five Dimensional



LIST OF TABLES

	<u>Page</u>
Table 2.1 : Project stage at which BIM provides the greatest value, (Smart Market Report, 2017).....	11
Table 2.2 : Comparison of BIM implementation in different procurement methods	19
Table 4.1 : Participant's age, experience and BIM experience information.....	58
Table 4.2 : Responses on design management questions.....	60
Table 4.3 : Responses on information management questions.....	63
Table 4.4 : Responses on QA/QC questions.....	65
Table 4.5 : Responses on QA/QC questions.....	66
Table 4.6 : PM question responses of overall population.....	68
Table 4.7 : General question responses on BIM functions.....	70
Table 5.1 : Interviewee profile.....	75
Table A.1 : Literature analysis table	102
Table B.1 : Survey questions in turkish.....	104
Table C.1 : Survey responses.....	107



LIST OF FIGURES

	<u>Page</u>
Figure 1.1 : McKinsey global digitization index (Agarwal et al, 2016).	2
Figure 2.1 : Degree of Value of BIM, (Smart Market Report, 2017).	10
Figure 2.2 : Distribution of use cases researched in literature analysis.	20
Figure 2.3 : Distribution of used tools researched in literature analysis.	20
Figure 2.4 : Distribution of used applications in terms of use cases.	21
Figure 2.5 : Distribution of used applications in the implementation type studies. ...	21
Figure 3.1 : Organization schema of IGA BIM department.	24
Figure 3.2 : Meetings that researcher/ senior BIM engineer attended.	25
Figure 3.3 : Flowchart of final product with BIM enabled model.	26
Figure 3.4 : IGA-BIM workshop schedule.	27
Figure 3.5 : IGA-BIM meeting room.	28
Figure 3.6 : IGA-BIM integration workflow.	29
Figure 3.7 : IGA-BIM master model image.	31
Figure 3.8 : Sample of design-construction schedule.	33
Figure 3.9 : IGA-BIM MEP-IT coordination workflow.	34
Figure 3.10 : SD production workflow for MEP-IT.	36
Figure 3.11 : BIM enabled project progress monitoring workflow.	38
Figure 3.12 : Use cases enabled by mobile BIM implementation.	39
Figure 3.13 : Site engineers are using tablets on site.	40
Figure 3.14 : IGA-BIM mobile access guide.	41
Figure 3.15 : Model integration workflow from office to site.	42
Figure 3.16 : Multidisciplinary merged BIM model view on tablets.	43
Figure 3.17 : Project documents are accessible on tablets.	45
Figure 3.18 : Mobile BIM workflow.	46
Figure 3.19 : Improved QA/QC workflow enabled by mobile BIM.	47
Figure 3.20 : Controlling site installation with BIM360 Layout application.	51
Figure 3.21 : Data flow in between project participants.	52
Figure 4.1 : Age distribution of respondents.	59
Figure 4.2 : Experience distribution of respondents.	59
Figure 4.3 : Department distribution of respondents.	59
Figure 4.4 : DM question responses of overall population.	61
Figure 4.5 : DM question responses according to age categories.	61
Figure 4.6 : DM questions responses of MEP department.	62
Figure 4.7 : DM question responses according to departments.	62
Figure 4.8 : IM question responses of overall population.	64
Figure 4.9 : IM question responses of according to departments.	64
Figure 4.10 : IM question responses of QA/QC department.	65
Figure 4.11 : QA/QC question responses of overall population.	66
Figure 4.12 : RM question responses according to age.	67
Figure 4.13 : PM question responses according to age.	68
Figure 4.14 : PM question responses according to department.	69



ANALYSIS OF MOBILE BIM ADOPTION AT CONSTRUCTION SITE: A CASE STUDY OF A COMPLEX INFRASTRUCTURE PROJECT

SUMMARY

This research is a case study of a real-world project to implement BIM-related tools and tablets for mobile computing use on-site and its analysis in terms of advantages/disadvantages, challenges/barriers, and lessons learned. This implementation has been examined not as the technology itself but managing the utilization of right technologies and people transformation. The study focuses on construction phase but also generates an overlook for design, test& commissioning and operations. This study presents mobile BIM as a pioneering and innovative management concept of construction Information and Communications Technology-ICT. The aim of this research is to illustrate BIM adoption at site and to identify barriers/ challenges, advantages and disadvantages of implementing BIM at the construction site in a complex infrastructure project.

Recently interest in BIM has been raised with the technological developments for construction projects. 3D design tools are getting popular within design teams. But there are very limited effort to carry the models designed in the office to site. It has been seen as a major challenge to change the traditional processes followed during construction for adoption of BIM at site. There are also lack of softwares and tools that can be used cross-projects with compliance. In order to extend mobile BIM use, there is a need for strategies and outputs comes from an experience. These type of implementations would lead the other projects in terms of management strategies, problems faced and benefits observed.

In order to identify on site BIM processes, a comprehensive literature research has been performed. Various BIM applications used for on site management purposes have been summarized into 5 use cases with references from 40 literature studies. These use cases are named as design management, information management, quality control and assurance, resource management and performance management. This literature analysis is aimed to reveal state-of-art for site BIM processes by introducing possible mobile BIM operations on site and relevant outcomes proposed by the literature. According to literature analysis most of the studies performed for mobile BIM use on site is limited with prototypes tested for only specified activities. There is a need for research on broad implementation of mobile BIM on-site in a real project.

Istanbul New Airport construction project has been selected to review the processes of mobile BIM implementation in a real project. At the time of the research design and construction was well progressed and commissioning for the first phase of the project was ongoing. It has been planned to complete Istanbul New airport in 4 phases and to start operating the airport at the end of the first phase will be finalized towards the end of 2018.

Design and construction of airport is a very complex characteristic since it consists of many different assets as terminal building, runways, passenger bridges, car parks,

railway structure and roads. In order for timely and on budget completion there is a need for a platform that integrates the participant parties of the project. For this reason involvement of BIM department to the project has been determined and planned it to bring alternative solutions to the project's challenging features.

A case study that utilized participatory research approach was conducted to examine how mobile BIM is implemented during construction. This research is conducted by a researcher who also has taken responsibility in the company's BIM department as BIM engineer to examine and elaborate on the BIM implementation in IGA project. The data used in this research derived from literature analysis, project documents, observations, and survey results collected by the researcher who involved to organization in daily activities.

A survey has been conducted with fifty-one site engineers who are involved in mobile BIM system to identify cultural& technical barriers/challenges, advantages and disadvantages of the system. The survey questions have been categorized according to the use cases identified through literature research.

A semi-structured interview has been conducted with twelve engineers aiming to gain an understanding of the case who were actively involved. Key actors who are knowledgeable. The interviews followed a schedule motive to innovate, innovation process, main BIM functions, barriers/ challenges, advantages/ disadvantages, grounds for successful adoption, future developments and lessons learned; but participants were allowed freedom to discuss their experiences and thoughts about BIM in their own terms.

For discussion case study, survey and interview results have been summarized in order to reveal lessons learned and innovative solutions provided. It has been identified that through the use of technology enabled by BIM practices; workflows of construction activities are improved. Even though it was the first BIM experience for the survey participants they were stated that BIM use on site eased their daily activities by saving time; increasing efficiency, constructability, decreasing rework. When the benefits of site-BIM is experienced by the professionals, they would like to use the same system for the next projects independent from their age and experience. It has been also found that use of mobile devices instead of papers are highly preferred onsite independent from age and experience. The weakest use case of the implementation is identified as resource management, which is also the least researched issue in the literature. Technical issues such as WI-FI connection on-site or tablet capacity are raised as the main barriers during site implementation of BIM. There has to be a formal plan/workflow implemented to transform traditional way of doing an activity to the digital way by all means. The data collected throughout site-BIM implementation found to be significant for project's operations phase

It has been identified through the interviews that motivations for innovation has been seem as the complexity and size of the project, distance between site and office, easy access to most accurate project documentation and limited project time. In order to transfer BIM implementation site, BIM site team has been set up and tasked with different locations in the project as the adoption strategy. Resistance of the site personnel has been overcome when they have experienced the benefits of using BIM and this led a passage to full transformation from traditional method to innovative way of performing work on site. Subcontractors they have been obliged to perform inspections digitally and also resolve any issues raised by BIM site engineers in order to receive their monthly progress payments. Main functions of BIM has been stated by

the interviewees that instruction of construction with BIM model, registration of inspection forms, creating observation; supervision reports for the problems on site, progress monitoring, registering punch lists, and registration of test and commissioning reports. Main challenges has been identified as cultural change of the site engineers in the projects by site BIM engineers. It was also identified as challenge that construction on site cannot be performed with the same precision as BIM model. Main advantages of the system access to most updated and coordinated project information. It was founded very practical to conduct installation according to coordinated BIM model and reworks are avoided. Formal procedures has been eliminated through supervision of BIM due to common digital environment. Main disadvantage for site engineers was to learn a new technology and get used to it in a short period of time. It was also a disadvantage for them that their work had to be accountable to site BIM engineers during construction. Disadvantage of site BIM engineers was that they had to spend very long time for training and adopting site staff to the new system. They had to break the unwelcoming environment to their existence because of site personnel's resistance to change.

The success of the project is achieved with having an on-site BIM team and their close follow-up on daily activities. Successful personal connections of BIM site engineers and managerial support has also big impact on successful implementation.



İNŞAAT SAHASINDA MOBİL BIM ADAPTASYONUNUN ANALİZİ: KOMPLEKS ALTYAPI PROJESİ VAKA ANALİZİ

ÖZET

Bu çalışma gerçek bir inşaat projesinde BIM ile ilgili uygulamaların ve tabletlerin inşaat sahasında kullanılmasının vaka çalışması ve bu uygulamanın avantaj/dezavantaj, karşılaşılan zorluklar/ engeller ve öğrenilen dersler açısından analizidir. İnşaat sahasında BIM uygulamasının yapılması yalnızca teknolojik açıdan değil aynı zamanda doğru teknolojilerin seçimi ve çalışanların geleneksel çalışma yöntemlerinden yeni çalışma düzenine geçişleri açısından da değerlendirilmiştir. Vaka çalışması projenin inşaat aşamasına odaklı olmasına rağmen tasarım, test ve devreye alma ve işletme aşamaları için de bakış açıları geliştirmiştir. BIM uygulaması inşaat bilgi teknolojileri konusunda öncü ve yenilikçi bir yöntem anlayışı olarak sunulmuştur.

Teknolojik gelişmeler ile birlikte BIM uygulamasının son yıllarda inşaat projelerinde kullanılması gündeme gelmiştir. Uygulama ile birlikte değerlendirilen 3 boyutlu modelleme programları ile dizayn öncesi ve dizayn sırasında bazı tasarımcılar tarafından kullanılmaktadır. Fakat ofislerde tasarlanmış bu modellerin sahaya aktarımı konusunda çok sınırlı sayıda uygulama mevcuttur. Sahada uzun yıllardır aynı geleneksel yöntemler ile yapılan işin yönteminin değiştirilmesi özellikle karşılaşılabilecek direnç yüzünden mümkün olmamaktadır. Bunun yanı sıra saha koşullarında kullanılabilecek araç ve tasarlanan yazılımların her proje için uyumlu olmaması gibi başlıca sorunlar da bulunmaktadır. Sahada BIM uygulamasının yaygınlaştırılabilmesi için bunun başarı ile tecrübe edildiği projelerdeki verilere ihtiyaç duyulmaktadır. Örnek teşkil edecek bu projeler sistemin uygulanmasının istendiği diğer projelere yol gösterecek ve sürecin nasıl yönetilmesi gerektiği, ne tür sorunlar ile karşılaşılabileceği ve ne gibi avantajların elde edileceği gibi sorulara cevap olacaktır.

Öncelikli olarak akademik çalışmalarda bahsi geçen saha BIM süreçlerinin belirlenmesi için detaylı bir literatür analizi yapılmıştır. Çeşitli mobil BIM çalışmalarının anlatıldığı 40 adet literatür çalışmasından referans alınarak sahaya yönelik olarak uygulanan BIM süreçleri 5 ana başlık altında toplanmıştır. Bu ana başlıklar tasarım yönetimi, bilgi yönetimi, kalite kontrol ve güvence, kaynak yönetimi ve performans yönetimi olarak belirlenmiştir. Literatür çalışması yapılırken sahada mobil olarak kullanılan BIM uygulamalarının bugünkü durumunun ortaya çıkarılması amaçlanmış ve bu yöntemle de literatür tarafından sunulan inşaat aşamasına yönelik BIM fonksiyonları ve bunların sonuçları belirlenmiştir. Literatür araştırmalarına göre bu konuda yayınlanan çoğu çalışma sahada BIM uygulanmasına yönelik oluşturulmuş prototiplerin yalnızca belirli inşaat aktivitelerinde kısıtlı amaçlarda test edilmesini anlatmaktadır. Bunlar prototipin doğrulanması için küçük çaplarda yapılan testler veya yalnızca tek bir proje ihtiyaçlarının giderilmesi için yapılan uygulamalardır. Oysa ki birçok farklı projede uygulanabilir bir sistemin eksikliği söz konusudur. Gerçek bir projede kapsamlı bir şekilde saha BIM uygulamaları ile ilgili oldukça kısıtlı çalışma bulunmuştur.

Gerçek bir projede inşaat sahasında BIM uygulamasının süreçlerinin analiz edilebilmesi için İstanbul Yeni Havalimanı Projesi seçilmiştir. Bu araştırmanın yapıldığı süreçte tasarım ve inşaat işleri ilerlemiş ve projenin ilk aşaması için devreye alma ve teslimler yapılmaya başlanmıştır. İstanbul Yeni Havalimanı projesinin 4 aşamada tamamlanması ve ilk aşamasının bitimi olan 2018 yılının sonlarında işletmeye açılması planlanmıştır.

Havalimanı tasarımı ve inşaatı binalar, terminal binası, uçak pistleri, yolcu köprüleri, otoparklar, demiryol yapıları ve yol gibi farklı yapıları içermesinden dolayı oldukça karmaşık bir özelliğe sahiptir. Projenin doğru bir şekilde tamamlanması, yerel ve uluslararası birçok firmanın işbirlikçi ve koordinasyon içinde çalışmasını gerektirmektedir. Projenin zamanında ve belirlenen bütçede tamamlanabilmesi için bütün bu partileri entegre eden bir platforma ihtiyaç duyulmuştur. BIM departmanının bu şekilde projeye dahil olması kararlaştırılmış ve proje karakteristiklerinin getirdiği zorlu koşullara alternatif çözümler sunması planlanmıştır.

Vaka çalışmasında katılımcı araştırma yöntemi benimsenmiştir. IGA projesinde sahadaki BIM uygulamasının incelenip detaylandırmasını yapan araştırmacı tez çalışmasını yürütürken aynı zamanda projede yüklenici konumundaki firmanın BIM departmanında 2 yıl süre ile BIM Mühendisliği görevini üstlenmiştir. Araştırmacı firmaya günlük olarak katılmış ve araştırması için bu şekilde gözlem yapma ve proje dökümantasyonlarına erişme yetkisine sahip olmuştur. Katılımcı araştırma yönteminin yanı sıra sahada sistemi kullanan mühendisler ile bir anket çalışması yapılmış ve onların uygulanan sistem ile ilgili tecrübeleri hakkında daha detaylı bilgi edinebilmek adına sonrasında yarı yapılandırılmış röportajlar yapılmıştır. Araştırmada literatür analizi, proje dökümanları, araştırmacının gözlemleri, tecrübeleri, anket ve röportaj sonuçları firmadaki günlük aktivitelere katılımda bulunan araştırmacı tarafından kaynak olarak kullanılmıştır.

Katılımcı vaka analizi sırasında öncelikle projede BIM'in tanıtılma stratejilerinde izlenen süreçlerden bahsedilmiştir. Projedeki diğer departmanların BIM ile ilgili bilgi paylaşımlarını standartlaştırmak için günlük ve haftalık workshoplar düzenlenmiştir. Her departmandan BIM departmanına bilgi akışını sağlayacak kilit kişiler belirlenip onlara BIM sisteminin nasıl yürüyeceği ile ilgili bilgiler verilmiştir. Projedeki çoğu kişi ilk kez BIM uygulamasına dahil olduğu için BIM kapsamında ilerletilecek süreçleri ve standartları belirtmek için BIM Uygulama Planı hazırlanmış ve şirket bünyesinde dağıtılmıştır. Departmanlardan gelen farklı formatlardaki tasarım bilgileri 3 boyutlu model haline getirilmiştir. Bu modeller konsolide olarak tüm disiplin sistemlerini içerecek şekilde kurgulanmıştır. Tasarımdaki uyumsuz veya sorunlu alanların tesbiti için çakışma kontrolleri yapılarak konular haftalık toplantılarda gündeme alınarak çözüm amaçlanmıştır. BIM adaptasyonu yalnızca yüklenici firma çapında değil aynı zamanda sahada fiili işi yapacak ve inşai çizimlerin tamamlanmasından sorumlu altyükleciler çapında da uygulanmıştır. Çakışma kontrolleri sonucu koordine edilmiş BIM modelleri altyükleniciler ile paylaşılıp modellere uygun olarak inşai çizimlerini üretmeleri şart koşulmuştur. Altyüklenicilerden gelen tüm inşai çizimler BIM departmanı tarafından BIM modeline uygunluk açısından kontrol edilip onaylandıktan sonra sahaya dağıtımına izin verilmiştir. Koordinasyonun yanı sıra iş programı da BIM modeline entegre edilmiş ve haftalık periyotlarda üst yönetim ile sahadaki mevcut durum karşılaştırılarak paylaşılmıştır. Koordine edilmiş BIM modellerinden metrajlar alınarak ilgili departmanların teknik ofislerine altyüklenicinin imalatının kontrolü için dağıtımı yapılmıştır.

Ofiste sarfedilen bu çabaların sahada uygulaması ve takibi adına Autodesk'in BIM360 Field uygulaması tabletlerden kullanılmak üzere satın alınmıştır. Bu uygulama ile ofisten koordineli BIM modelleri, onaylanmış uygulama çizimleri, kalite kontrol dökümanları sahadaki tabletlerle paylaşılmıştır. Bunun yanı sıra denetleme formlarının da tablet üzerinden bu uygulama aracılığı ile doldurulması kararlaştırılmıştır. Bu uygulamanın takibinin yapılması adına BIM saha ekibi oluşturulmuş ve projenin farklı alanlarında görevlendirilmiştir. Başlangıçta saha ekiplerinin dirençleri ile karşılaşan bu ekip sonradan kişisel iletişimler ve üst yönetimin baskısı sayesinde sistemin uygulanması konusunda çalışmışlardır. Altyüklenicilerin de aylık ödemelerini almalarında BIM ile ilgili gereklilikleri yerine getirme koşulu öne sürüldüğünden onların da sisteme adaptasyonu sağlanmıştır.

Uygulamada sahada uygulanan BIM fonksiyonları literatür analizi sonucunda belirlenen 5 kategori altında detaylandırılmış ve bu projedeki uygulama stratejileri ve kapsamaları hakkında bilgi verilmiştir.

IGA projesinde inşaat aşamasındaki mobil BIM çalışmalarına katılmış olan 51 saha mühendisinin katılımı ile bir anket çalışması yapılmıştır. Bunun ile kültürel ve teknik bariyer ve zorlukların, avantaj ve dezavantajların belirlenmesi amaçlanmıştır. Anket soruları literatür çalışmasının sonucunda belirlenen 5 kategoriye göre bölünmüş ve firmada bu yönde yapılan çalışmalar ile ilgili mühendislerin görüşleri toplanmıştır.

Projede saha BIM uygulamasında aktif görev alan 12 mühendis ile uygulamanın detayları ve onların bakış açılarını öğrenmek adına yarı yapılandırılmış röportajlar yapılmıştır. Röportaj için konuşulması gereken konulara göre açık uçlu sorular belirlenmiş ve bir program takip edilmiştir. Röportajlarda sırasıyla yenilik için motivasyon, yenilik süreçleri, başlıca BIM fonksiyonları, engeller/ zorluklar, avantajlar/dezavantajlar, başarılı uygulamanın başlıca etkenleri, geliştirme önerileri ve öğrenilen dersler konuları takip edilmiştir. Fakat katılımcıların kendi tecrübeleri ve düşünceleri hakkında konuşmasına da olanak sağlanılmıştır.

Son olarak vaka çalışması gözlemleri, anket ve röportaj sonuçları birarada özetlenmiştir. Teknolojik gelişmelere bağlı olarak uygulanmış BIM sistemi inşaat aşamalarındaki iş akışları geliştirdiği tespit edilmiştir. Vaka analizindeki tüm mühendislerin ilk BIM deneyimleri olmasına rağmen, sahadaki BIM uygulamasının zaman kazanımı, artırılmış verim ve inşa edilebilirlik ve tekrar çalışmayı azaltarak günlük inşaat aktivitelerini kolaylaştırdığı belirlenmiştir. Çalışanların saha BIM uygulamalarının avantajlarını tecrübe etmeleri, sonraki projelerinde de aynı sistemi yaş ve tecrübelerinden bağımsız olarak kullanmak istemelerine sebep olmuştur. Saha BIM uygulamasının en zayıf kullanımı kaynak yönetimi olarak belirlenmiştir. Literatür analizi çıktılarında da kaynak yönetimi ile ilgili çalışmaların çok kısıtlı olması o alanda hala araştırma ve geliştirme yapılması gerektiğini göstermektedir. Sahadaki internet bağlantısı ve tabletlerin kapasitesi ana bariyerler olarak belirlenmiştir. Geleneksel bir çalışma yöntemini tam anlamıyla dijitale dönüştürmek için resmi bir plan veya iş akışı oluşturulması gerektiği belirlenmiştir. İnşaat aşamasında dijital olarak toplanılan bilginin işletme aşamasında kullanımının çok önemli olacağı saptanmıştır.

Röportajlarda alınan cevaplara göre inşaat projelerinde karşılaşılan ortak problemlerin yenilik kullanımını motive ettiği belirlenmiştir. Katılımcılar projedeki yeniliğin adaptasyon sürecini ve izlenen stratejileri anlatmıştır. Sahadaki başlıca BIM fonksiyonları gerekliliklere göre şekillenmiş ve projedeki sorunları azaltmak adına kullanılmıştır. Saha çalışanlarının kültürel dönüşümü büyük bir zorluk olarak

görülmüştür. Saha çalışanları da yeni bir uygulama öğrenmek için çaba sarfetmenin onları zorladığından söz etmişlerdir.

Yapılan röportajlar yeniliğe ihtiyaç duyulmasını projenin boyutu, karmaşıklığı, ofis ve saha arasındaki mesafe, inşai süreçle ilgili doğru bilgiye kolay ulaşımı ve projenin kısıtlı süresi olarak belirlenmiştir. Saha personelinin BIM sistemine adaptasyonu için sahada günlük aktivitelere dahil olarak yakından takip edecek bir BIM ekibi kurulmuştur. Saha BIM ekibi projenin farklı katlar ve lokasyonlarında görevlendirilmiştir. Saha ekibinin değişime olan direnci BIM sisteminin faydalarını tecrübe etmeleri ve üst yönetimden gerçekleşen baskılar sayesinde aşılmıştır. Altyüklenicilerin de BIM süreçlerine uyması aylık hakedişlerinde koordineli BIM modellerine uygun pafta çıkarma ve imalat yapma, tablet üzerinden onlara adres edilmiş konuların çözümlenmesi, dijital denetleme formlarını kullanmaları gibi koşullar sunarak sağlanmıştır. BIM saha mühendisleri tarafından yaşanan en başlıca sorun olarak saha personelinin kültür değişimi olarak belirtilmiştir. Bunun yanısıra sahada BIM modeli kadar hassas uygulama yapılamamasının zaman zaman onları zorladığından bahsedilmiştir. Sistemin başlıca avantajı en güncel ve koordineli proje bilgisine sürekli erişim olması olarak belirlenmiştir. Koordineli BIM modeline göre imalat yapılması sök-tak ihtimalini engellemiştir. Zaman gerektiren resmi süreçler dijital platform herkesin dahil edilmesi sayesinde engellenmiştir. Saha personeli için yeni bir teknoloji öğrenilmesi ve buna kısa bir süre içinde alışılması bir dezavantaj olarak belirlenmiştir. Bunun yanısıra onların departmanında olmayan BIM saha mühendislerine hesap verme zorunluluğu onları zorlamıştır. Saha BIM mühendisleri ise başta onların çok istenmediği ortamlara girerek insanları yeni bir sisteme adapte etmeleri zorlamıştır.

Projedeki sahadaki BIM adaptasyonun başarıya ulaşması sahadaki BIM ekibinin kurulması ve onların günlük takipleri olmuştur. Saha mühendislerinin doğru iletişimleriyle birlikte üst yönetimin de desteğinin bu adaptasyona çok büyük etkisi olmuştur.

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1. INTRODUCTION

This chapter introduces the research work presented in the thesis. It describes the background, aim, objectives, methodology of the research and organization of the thesis.

1.1 Background

Adequate collection of onsite construction data and timely communication of this data is an essential concern to all parties involved in the construction industry (Cox et al, 2002). The ability for professionals to have access to relevant and appropriate information in a timely manner is key to successful project delivery (Maghiar et al., 2015).

A successful project delivery can only be achieved when the practitioners have access to relevant and appropriate project information on time. Even though the accelerated innovations in technology, construction sector is remarkably far away from adopting these recent developments compared to other industries. Most of the construction companies, for instance, rely on manual processes and traditional communication tools (Nourbakhsh et al, 2012). Construction industry does not take advantage of what technological developments can offer. According to an analysis conducted by McKinsey Global Institute, the new digital technologies has not been yet embraced by construction industry, even if the long-term benefits are significant as shown in Figure 1.1 (Agarwal et al., 2016).

Most of the construction companies, for instance, rely on manual processes and traditional communication tools (Wang et al., 2012). Project participants still do not take advantage of what these developments can offer.

The use of Building Information Modelling (BIM) has potential to improve information sharing and communication in between the parties on construction projects although there are still many areas where information fails to flow in the current implementation of BIM in real project practices. (Maghiar et al., 2015). According to McGraw-Hill

Construction Market report, 88% of the BIM projects use BIM as a representation tool (McGraw Hill Construction 2012).

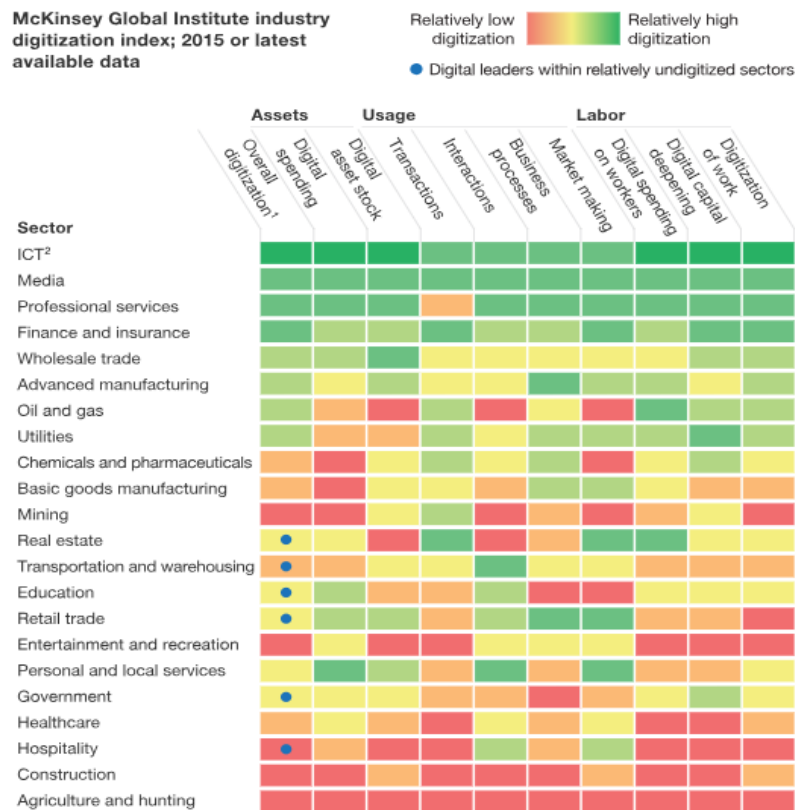


Figure 1.1 : McKinsey global digitization index (Agarwal et al, 2016).

The companies trying to adopt BIM are predominantly focused on how BIM can enhance the communication and collaboration among the stakeholders (e.g., 3D representation and modelling, engineering simulation, 4D CAD, evaluation and documentation, etc.) along the project life cycle, which is typically constrained in office environments as well as in the form of conventional desktop computers (Wang et al., 2012). Information collected and designed in BIM should be eventually applied in the construction site in order to fulfil its maximum potentials and promises. In order to achieve maximum potential of BIM, efforts made in the offices should be applied in the construction site. Research on BIM is mainly focused on theoretical BIM implementation in design (Santos, 2017). The ones mentioning BIM execution in construction are restricted with prototypes created for single projects and focused on a specific task on site (Santos, 2017). There has been far less effort to describe integration of BIM during construction in order to create a new way of managing projects. This thesis is part of a research that seeks to contribute to that effort. Our research explores

a real-world project to analyze barriers/ challenges, advantages/ disadvantages observed from implementation of mobile BIM during construction stage of a complex infrastructure project while managing the utilization of right technologies and people transformation.

1.2 The Aim and Objectives of the Research

The aim of this research is to illustrate BIM adoption at site and to identify barriers/challenges, advantages and disadvantages of implementing BIM at the construction site in a complex infrastructure project. In order to accomplish this aim the objectives of the research are as follow:

1. To illustrate BIM adoption at site including project-specific strategies and implementation details for a complex infrastructure project.
2. To identify cultural& technical barriers/challenges, advantages and disadvantages of implementing BIM at the construction site.
3. To capture lessons-learnt and innovative solutions that were developed.

1.3 Research Methodology

1.3.1 Case study

A case study can be defined as an intensive study about a person, a group of people or a unit, which is aimed to generalize over several units. In a case study the focus is based on a specially unit (Jacobsen, 2002). A similar definition is that a case study is an analysis of systems that are studied with a comprehensive view by either one or several methods (Thomas, 2011).

“The case study method “explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information... and reports a case description and case themes” (Creswell, 2013, p. 97)

Since case studies do not develop testable generalizations, they are often criticized in not to be enough scientific according to Encyclopedia Britannica, II (1979). Yin (2009) writes that during the design of the case study, the structure should be identified. Tables and figures make the case more reliable because of the rich presentation of evidence.

If the case study also contains appendixes with extra information or/and theoretical sampling of the case or cases the case study become more dependable according to Eisenhardt & Graebner (2007).

Benefits with a single case study are that they are not as expensive and time consuming as multiple case studies (Gustafsson, 2017). Single case studies are better when the writer wants to create a high-quality theory because this type produces extra and better theory. A single case study also makes the writer to have a deeper understanding of the exploring subject. Other benefits are that single case studies richly can describe the existence of phenomenon and it is better to make a single case study than a multiple case study when the writer wants to study, for example, a person or a group of people. When a single case study is used the writer also can question old theoretical relationships and explore new ones.

1.3.2 Survey research

Blaxter et al. (2001) defined survey research as the method of collecting information by asking a number of predefined questions in sequence in a structured questionnaire to a sample of respondents selected to be representative of a specific population. The aim of surveys are to collect information from sampling frames, which include a number of respondents, to identify more specific characteristics among groups. Surveys are based on probabilistic or non-probabilistic sampling and vary from the use of structured questionnaires to unstructured interviews.

The questionnaire survey is the most commonly used research method and can be used to gather information on any topic from large or small numbers of people. The main advantages of questionnaires are the ease of completion and analysis, access to dispersed respondents and accuracy (Kumar, 1999). In questionnaires, questions have to be clear and easy to understand because there is no one to explain the meanings of questions.

1.3.3 Interview research

Blaxter et al (2001) described the interview research as exploratory personal investigation which involves original field interviews on a limited scale with interested parties and individuals with a view to secure greater insight into the practical aspects of the problem Using interview which allows open-ended responses would lead to the in-depth study of individual cases. The interview method involves questioning or

discussing issues with people. It can be a very useful technique for collecting data which would likely not be accessible using techniques such as observation or questionnaires. Interviews may take place face-to-face, or at a distance, e.g. over the telephone or by email.

1.3.4 Adopted methodology and justification

The appropriate methodology in any research adoption varies according to the type of research question in operation (Yin, 1996) which involves the type of the expected outcome, degree of control needed, the focal point of study in terms of time (present or past), the aim and objectives. As stated by Flyvbjerg the approach followed in this study is to derive lessons from specific cases (Flyvbjerg, 2004). Even though case studies have been evaluated as unscientific since they cannot be generalized and open to bias, Flyvbjerg defends them, by explaining the force of the real-world practices which includes complexity and randomness according to theoretical research.

A case study that utilized participatory research approach was adopted in the research to present the planning and implementation of mobile BIM implementation on site in an ongoing complex construction project. The essential elements of participatory are interviews, observations and examination to gain understanding of the respondents' perspective (Fellows and Liu, 2003). The strengths of participatory research methodology come from creating new ideas and in the data used in this research derived from project documents, observations, formal meetings and data stored in the cloud system collected by researchers who involved to organizations' in daily activities.

Considering the fact that evaluation of BIM implementation on site in a single case is the main objective of this research, the approach of this study has considered the survey and interview approaches as they seem fit to answering the research questions and criteria. The survey approach can be used in suggesting possible motives behind relationships in variables from a collected data; it also facilitates the collection of data from a substantial population in an economical way by the use of questionnaires. This tends to be used in comparing variables in an explorative and descriptive research, making possible to answer research questions of what, where, who, how many, how much and so on (Saunders et al, 2009).

A personally administered survey has been performed for collecting data to establish perspective of mobile BIM implementation on site and to gather improvement of

respondents in terms of future improvement suggestions. This has been chosen in order to collect data immediately and to have high response rate.

When the questions were prepared, the questionnaire has been tested on a small number of respondents in order to check survey efficiency and validity of questions. It was significant in order to identify unclear questions and provide information about the reliability of the collected data. Necessary revisions were made to the questionnaire at this stage and the revised questionnaire has been conducted with the respondents.

Close ended and Likert-scale response questions were used in the questionnaire to facilitate analysis, secure a higher response and minimize missing data. Five-choice questions has been selected. A copy of the questionnaire appear as Appendix B.

Interviews were used to get an insight in how BIM is used in the construction project on site and to get answers on the research questions. The data was collected through twelve semi-structured interviews with the personnel aiming to gain an understanding of the case who were actively involved. Key actors who are knowledgeable about BIM implementation have been selected and interviewed. The interviews are conducted in June 2018, when the construction works were almost complete and test & commissioning process was ongoing

The data that is used consists of semi-structured and open-ended interviews to get a good representation of different actors and their different views on the subject. The persons being interviewed were chosen because of their interest and knowledge of the subject.

The interviews followed a schedule motive to innovate, innovation process, main BIM functions, barriers/ challenges, advantages/ disadvantages, grounds for successful adoption, future developments and lessons learned; but participants were allowed freedom to discuss their experiences and thoughts about BIM in their own terms.

In order to achieve the aim and objectives mentioned in Section 1.1, the followings actions were taken in the research process:

- 1) In order to illustrate BIM adoption project documentations are explained and analyzed through a participatory research. By a comprehensive literature research, state-of-art for site BIM processes are identified and the case study are evaluated accordingly in order to discover limitation, weakness and strengths of the project.

- 2) Identification of cultural & technical barriers/ challenges, advantages and disadvantages are accomplished by survey to be conducted with site engineers. To gather more specific information on the issue, interviews are also conducted with the key personnel.
- 3) Lessons-learned and innovative solutions will be finally determined through integration of the observations made by the researcher, survey and interview results.

1.4 Research Approach

Research approaches are commonly classified as: qualitative, quantitative and mixed (triangulation) approaches (Cresswell, 2003). In this thesis, mixed approach has been followed by with utilization of both qualitative and quantitative approaches.

1.4.1.1 Qualitative approach

The qualitative approach is based on constructivist perspectives (i.e. multiple meanings of individual experiences) or advocacy/participatory perspective (i.e. political, issue-oriented, collaborative or change oriented) (Creswell, 2003). Qualitative research is a type of research where the data are not in the form of numbers (Blaxter et al., 2001). Chadwick et al defined qualitative research as: “several different modes of data collection, including field research, participant observation, in-depth interviews, ethnomethodology and ethnographic research.” In qualitative research, the exploration of the research subject is undertaken without past formulations and the aim is to collect information data for future emerging theories. Therefore, qualitative research is a precursor to quantitative research and the data gathered may be unstructured (Fellows and Liu, 2003). The limitations of the quantitative approach is a starting point to use qualitative research since the main ideas surrounding qualitative research are different from those in quantitative research (Flick, 2006).

1.4.1.2 Quantitative approach

The quantitative approach basically uses post-positivist claims for developing knowledge (i.e. cause and effect thinking, reduction to specific variables and hypotheses, use of measurement and observation and testing of theories), select strategies of inquiry such as experiments and surveys and access numerical data

(Cresswell, 2003). Quantitative research is a type of research where the data is in the form of numbers (Blaxter et al, 2001).

1.4.1.3 Mixed approach (triangulation)

The mixed approach (triangulation) uses the strategy of collecting data either simultaneously or sequentially to best understand research questions. Triangulation means combining qualitative and quantitative methods (Flick, 2006). This approach uses both numeric (e.g. instruments, surveys) and textual data collection techniques. Triangulation is very helpful for gaining results and to assist in making inferences and drawing conclusions (Fellows and Liu, 2003).

1.5 Organization of the Thesis

The thesis is organized into seven chapters and appendices. Brief summaries of the various chapters are provided below.

Chapter one is an introduction to research, it provides a statement of problem, the aim and objectives of the research, and discussion of research methods available and justifies by describing the methodologies used in the research.

Chapter two reviews the state of the art of site-BIM implementations. These include market reports to illustrate the need for research, and use cases for site-BIM applications in the literature studies.

Chapter three presents the case study of IGA, with elaboration of the case through participatory observations and documentation analysis.

Chapter four presents the design and results of the survey study conducted.

Chapter five presents the design and results of the interview study conducted.

Chapter six presents the summary and discussion based on case, survey and interview studies performed.

Chapter seven presents the conclusions from the work and discuss the future research needs to be addressed for site-BIM implementation issue.

Appendices consist of additional information relevant to this research work. These compromise literature study, survey questions and survey results.

2. LITERATURE REVIEW

Literature research was undertaken to investigate the issue of site BIM implementation issue in terms of market reports and proposed academic studies to reveal in which aspects that this study will contribute to the literature the most. Various BIM applications used for on site management purposes have been summarized into 5 use cases with references from 40 literature studies. These use cases are named as Design Management, Information Management, Quality Control and Assurance, Resource Management and Performance Management. This literature analysis is aimed to reveal state-of-art for site BIM processes by introducing possible mobile BIM operations on site and relevant outcomes proposed by the literature. After detailed explanation of the case studied, the case has been evaluated according to the literature findings in order to reveal potentials and limitations for a real-world BIM implementation on site for a complex project.

2.1 Analysis of Market Reports on Site BIM Implementation Issue

According to McGraw Hill Construction Smart Market Report of The Business Value of BIM for Construction in Major Global Markets, Contractors have been mostly focused on improving their internal processes by investing in BIM training and software for the upcoming years. McGraw Hill Construction has evaluated the companies in terms of level of BIM engagement based on their skill, experience and percentage of BIM projects they are involved in. According to evaluation 61% of the highest level of BIM engagement contractors concentrates on tablets and mobile devices, which will allow pave the way for them to transfer the value of BIM to the staff in the field (McGraw Hill Construction, 2014). In the same report it has been noted that BIM users at a high level of implementation grew from 20% in 2015 to 52% in 2017. By 2019, 61% forecast that they will be at that high level of implementation.

According to The Business Value of BIM for Infrastructure Report the most common use of BIM models are determined as interdisciplinary project collaboration, aid production of 3D deliverables to owner, deliver design intent to construction,

visualizations, communication with clients and stakeholders and aid production of 2D deliverables. But the degree of value experienced from BIM is still not at its full potential as shown in Figure 2.1.

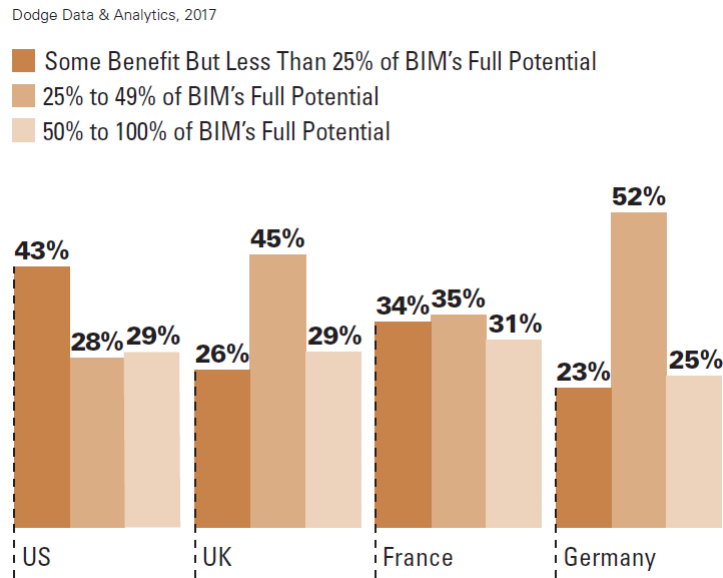


Figure 2.1 : Degree of Value of BIM, (Smart Market Report, 2017).

In the same report, degree of value experienced from BIM has been also analyzed across four countries. By far, the largest percentage of respondents consider BIM to provide the greatest value during design development. BIM is still considered to have greatest contribution to predesign and during design development as shown in Table 2.1 (McKinsey, 2017). This is caused by the fact that BIM is still not fully implemented during construction phase in the projects. It is needed to extent BIM to construction site in order to receive its full potential.

Orlando International Airport Terminal C has implemented BIM in the project. They have focused on how design team works collaboratively in cloud via 3D models. BIM Manager of Orlando Airport Borzich says:

‘The contractors build their models in parallel to ours. Ours is a point of reference for them to refer and note changes and use it to gauge what’s going on. Our model is for reference only’

This above approach limits BIM only with office and does not reveal what can be succeeded with the implementation through all phases during project. Information

collected and designed in BIM should be eventually applied in the construction site in order to fulfil its maximum potentials and promises.

Table 2.1 : Project stage at which BIM provides the greatest value, (Smart Market Report, 2017).

Project Stage at Which BIM Provides the Greatest Value (According to Engineers and Contractor

	US	UK	France	Germany
Before Design Begins				
Preplanning (US)/Brief (UK, France, Germany)	7%	0%	4%	2%
Predesign (US)/Concept (UK, France, Germany)	15%	22%	10%	19%
During Design				
Design Development (US)/Developed Design (UK, France, Germany)	36%	49%	49%	44%
Construction Documentation (US Only)	11%			
Bidding/Construction/Installation				
Bid Letting (US)	1%			
Production (UK, France, Germany)		13%	20%	22%
Construction (US)/Installation (UK, France, Germany)	28%	7%	3%	13%
Post-Construction				
Project Closeout (US)/As Constructed (UK, France, Germany)	0%	7%	12%	0%
Maintenance (US)/Use (UK, France, Germany)	0%	2%	1%	0%

2.2 BIM Integrated with Mobile Computing to Support On-Site Activities

“Construction is a diverse industry handling both production on-site and also services such as engineering, design, management in order to achieve a unique project with variety of teams brought together” (Blayse and Manley, 2004). Management of several number of different on-site and off-site tasks, large amounts of information in many forms, continuous communication in between the parties needs to be achieved for a successful project delivery. BIM has allowed designers and contractors to optimize, coordinate design by providing collaboration. Construction will be benefitted from having a system collaborates and improves all of these functions/assets so called BIM.

Even though there are many research conducted to improve efficiency and productivity in construction projects by improved communication and collaboration enabled by BIM, BIM is often constrained in the office environments in the real projects. Site management activities and daily activity level of work are still dominated with manual processes and paperwork. While there are still such traditional methods are followed on site where the final product is delivered, benefits of BIM implementation in construction cannot be realized at its maximum potential (Sacks et al, 2010b). There are still deficiencies while transferring the digital BIM data from office to site. Mobile

computing has begun to serve for this purpose. Cox et al developed an application to be used in a pocket PC in order to automate collection of inspection information from site. This application has provided cost saving by minimizing errors, reduction of paperwork, and automatic generation of reports and faster distribution of electronic data (Cox et al, 2002). Elvin has examined the use of tablet and wearable computers in terms of improvement of communication between field staff with off-site participants in design and construction (Elvin, 2002). He found that usage of these may lead to more efficient design-construction process by improving quality of communication in between office and site. Chen and Kamara has explored the potential benefits of mobile computing by evaluating user perspective and preferences. Final outcome was that mobile computing is still its infancy for the users (Chen and Kamara, 2008). Kimoto et al described a software to be used on PDA for construction managers to perform inspections, position checks and progress monitoring. Development of such system enables more information in construction site, increases productivity of construction managers, and creates a link in between site and office information for progress monitoring (Kimoto et al, 2005). Chen and Kamara developed a model for process of selecting mobile computer technology in construction (Chen and Kamara, 2007). This model is also evaluated in a case study for validation later on (Chen and Kamara, 2011). Nourbaksh has developed a prototype to enhance communication and manage on-site info and this prototype is tested against postgraduate students (Nourbaksh et al, 2012). Kim et al introduced a system to improve performance of on-site construction management via mobile computing. After testing this proposed system on a case study, it has been found that quality improvement, reduction of construction time and construction cost by removing travel time to office to gather project documentation, by minimizing possibility of rework by effective information management and clear work orders, reducing incidents of defects with work task information (Kim et al, 2013). The common points of these developments in mobile computing to improve project performance in terms of time, cost and quality is that lack of practical implementation. Khanzode et al investigated the lessons learned by adopting BIM/VDC technologies (3D/4D modelling) for coordination of MEP systems on a complex medical office building. They have observed benefits of using such tool as prefabrication, zero conflicts in the field, savings in cost and schedule (Khanzode et al, 2008). Mathews conducted a case study by extending detailed design of RC structure to construction by

using a commercial cloud based tool on tablets (Mathews, 2010). They have intended to evaluate the effectiveness of the proposed system enabled by BIM based improved management processes and practices on-site. Davies and Harty developed a tool called SiteBIM used on tablets to support site operations during construction phase for accessing design information, recording quality and progress on site (Davies and Harty, 2013). This implementation is judged to be successful since the technology was approved, delivered and adopted by the users with informal processes. But the system did not create a transformation in the current site management practices, it only eased the existing processes by partly automating them. This research is a case study of a real-world project to implement BIM-related tools and tablets for mobile computing use on-site and its assessment in terms of advantages/ disadvantages, challenges/barriers and lessons learned.

2.3 Literature Analysis for BIM Integrated On-Site Activities

In order to identify use cases on construction site proposed to be improved by BIM, a comprehensive literature research has been performed. Various on-site BIM applications have been summarized into 5 main categories with references from 40 literature studies as shown in Appendix A. This literature research has been aimed to reveal state-of-art for site BIM processes by introducing possible mobile BIM operations on site and relevant outcomes proposed by the literature.

The sub-interest area of the categorized site BIM processes in the literature studies are explained below:

2.3.1 Design management enabled through BIM

This section introduces the studies on design management enabled through BIM. Use of BIM models on site via mobile devices through model viewers and augmented reality have been described.

Wang et al developed a conceptual framework to investigate how BIM can be extended to the site via AR. They have used Augmented Reality (AR) to provide the real-time communication and integration of BIM to the site and task conditions, and the interaction of BIM with the field crew. [32] (Wang et al, 2012). Brathen and Moum analyzed the use of BIM by site workers through BIM-kiosks which allowed workers to access BIM models on-site. The study found that the site workers are benefitted from

BIM through the kiosks and it helped them to handle complex elements during construction. It is also noted that the use of kiosks provided greater level of face-to-face collaboration between workers on-site while they meet randomly in front of kiosks to visual the models. (Brathen and Moum, 2016). Meza et al analyzed the potential of AR and presented how the component based software engineering method can be used to efficiently implement a BIM-based AR system for construction. An architecture of the software system is proposed and verified by a prototype which was tested in a real construction project. They have found out that the use of AR can provide the connection missing in between the digital model and the real world. But currently there are challenges for large models caused by technical and capacity issues expected to be solved by the IT industry in the years to come (Meza et al, 2014). Parfitt and Whyte details the development of a complementary mobile visualization environment to be used on site. Their light-weight mobile solution enables a group of users to navigate a 3D model at a 1:1 scale and to work collaboratively with structured asset information. However it offers greater flexibility as two users can assemble and start using it at a new location within an hour. The solution has been developed and tested in a laboratory and planned to be piloted in engineering design review and stakeholder engagement applications on a major construction project. (Parfitt and Whyte, 2014). Wang et al has investigated the need for the onsite information system for construction site activities, and then formulated the methods of configuring BIM + AR prototypes on site. They have are identified four functions as BIM+ AR based walkthrough, context-aware mobile system, on-site assembly, wayfinding and then tested them. They have demonstrated that BIM extended to the site via AR helps to address more real problems, such as low productivity in retrieving information, tendency of committing error in assembly, and low efficiency of communication and problem solving (Wang et al, 2014). Yang and Kang has developed an interactive interface for site workers to retrieve information from BIM models instead of using limited data comes with 2D drawings. They created an interface provides hand-based gesture control that allows BIM models to be navigated with ease (Yang and Kang, 2014). Akula et al developed a conceptual solution for processing and incorporating point cloud data obtained from 3D imaging technologies into the drilling process. BIM was used to provide real-time feedback to the drill operator about whether it is safe to continue drilling based on the position and orientation of the drill. It has been found that this proposed system improved safety, productivity and quality of engineering

processes by helping avoid the time and cost of rework (Akula et al, 2013). Davies and Hart developed a BIM-enabled tool to allow site workers using mobile tablet personal computers to access design information and to capture work quality and progress data on-site. Technical IT skills were adopted into the construction project through personal relationships and arrangements rather than formal processes. (Davies and Hart, 2013). Shen and Jiang created a BIM model of an institutional building for 3D mobile game application on tablet in order to allow users to visualize and interact with the HVAC BIM components. They have reported the preliminary findings in developing a BIM-based tablet 3D game application for CCL activities in architecture, engineering, and construction and also technical barriers of using BIM models to create mobile 3D collaboration, communication and learning (CCL) applications.(Shen and Jiang, 2012).

2.3.2 Information management enabled through BIM

This section introduces the studies on information management enabled through BIM. Use of 2D drawings and other project documentation on mobile devices; digital communication on site spontaneously have been described.

Matthews et al examined the effectiveness of cloud-based BIM for real-time delivery of information to support progress monitoring and management of the construction of a reinforced concrete (RC) structure using action based research. They have re-engineered existing paper-based processes to accommodate the use of cloud-based BIM during construction. The design and implementation of a real-time object oriented bi-directional system, allowed information to be captured on-site and synchronized with a federated BIM. (Matthews et al, 2015). Sattineni and Schmidt interviewed several end users to discover how they are using mobile devices on construction sites. The study revealed that these devices are increasingly effective in enabling site personnel in many ways for information management. (Sattineni and Schmidt, 2015). Chong et al reviewed total of forty-two cloud computing applications consisting of general cloud applications, Building Information Modelling (BIM), and project management cloud applications. Based on this study they have developed a decision-making model to assist parties in selecting a suitable application. (Chong et al, 2014). Yeh et al has developed a wearable device that can project the construction drawings and related information on the basis of the needs of the users. This device is envisaged to help engineers avoid carrying the construction drawings to the site, and to reduce the

effort required in looking for the correct drawings to obtain the information they need. The device includes four modules: the information-integration module, the display module, the positioning module, and the manipulation module. A hardware device called iHelmet has been developed to implement the four modules. (Yeh et al, 2012). Elvin explains the opportunities for saving time and money on integrated projects, and issues in implementing innovative technology. Results indicate that tablet and wearable computers may significantly reduce rework, while productivity decreased slightly when tablet and wearable computers were used. (Elvin, 2003).

2.3.3 Quality control and assurance records enabled through BIM

This section introduces the studies on quality control and assurance records enabled through BIM. Site inspections via mobile devices and defect reporting have been described.

Xu and Wang has analyzed the construction characteristics and construction quality control difficulties of the project based on a urban complex project. Then combining BIM technology and AR technology in the concrete application of the construction stage, they have enhanced the project construction quality through prior control and process control and post control (Xu and Wang, 2017). Zhou et al investigated the feasibility of using Augmented Reality (AR) to rapidly inspect segment displacement during tunneling construction. They have conducted a case study to evaluate the benefits of the inspection using a prototype AR system over a conventional method. According to the results of their study inspections and analyses can be conducted on-site, in real-time, and at a very low cost (Zhou et al, 2017). Having identified inspection as one of the promising AR application areas in industrial construction in a previous study on the suitability of AR technologies, Shin and Dunston detailed the development of their AR prototype system for steel column inspection, the ARCam. The detailed technical methods for the operation of the ARCam are discussed, as are developments required for field application that were revealed through the development of the ARCam (Shin and Dunston, 2010). Park et al investigated the issues and needs of current defect management practices in the construction industry. They have derived a conceptual system framework for construction defect management that integrates ontology and AR with BIM (Park et al, 2013). Tsai et al presented an approach for inspection of construction enabled via BIM. The approach provides that the inspector's

tasks at the construction site are well defined and free of possible interference from site engineers (Tsai et al 2014). Kwon et al addresses issues by utilizing BIM, image-matching, and augmented reality (AR) to develop defect management systems. Experimental results demonstrate the defect management system's effectiveness in automatic omission and error detection at real job sites. (Kwon et al, 2014).

2.3.4 Resource management enabled through BIM

This section introduces the studies on resource management enabled through BIM. Materials delivery, jobsite planning and logistics, crew tracking, safety monitoring have been described.

Lin et al discussed the use of a user-centered design approach to develop and evaluate a tablet application that aims to address drawbacks and improve the day-to-day practices and management of safety inspections. Their Evaluation results indicate the usefulness and practicality of the application. Furthermore, the developed tool allows consistent data collection that can eventually be used to aid the development of advanced safety and health data analysis techniques (Lin et al, 2014). Lin et al then proposed a motion planning and coordination method to evaluate construction machinery management. The results of their test indicate that the method can provide a collision-free path for two sets of machinery in different complex environments within one minute. This method can help engineers evaluate the site plan from a logistics approach, and thus determine the possible site layout. (Lin et al, 2015). Dimitrov and Goparvar proposed a new vision-based method for material classification from single images taken under unknown viewpoint and site illumination conditions. The results of their study show the promise of the applicability of the proposed method and expose the limitations of the state-of-the-art classification algorithms under real world conditions (Dimitrov and Goparvar, 2014).

2.3.5 Performance management enabled through BIM

This section introduces the studies on performance management enabled through BIM. Construction field activity records, on-site progress monitoring, automatic report generation, schedule tracking have been described.

Bae et al presents a scalable markerless and infrastructure independent mobile augmented reality system for commodity smartphones and tablets, with client-server

architecture and cloud computing basis, to facilitate both accessing to project information and conducting field reporting in three dimensions. The client-server architecture of the proposed system allows an onsite access to most updated project information and field reports as they are being documented on the server. The overall system is also validated on several indoor/outdoor work areas of three real-world construction projects. The experimental results show the potential of the proposed method in prompt field reporting in three dimensions, minimizing the time field personnel spent on accessing project information, and communicating with others to resolve an issue/conflict on the jobsite spontaneously (Bae et al, 2015). Bosche et al proposed a scan-versus-BIM object recognition framework includes laser scanning and project 3D/4D BIM model joint in order to detailed assessment of as-built status of construction projects. This issue has already been demonstrated for tracking structural works, but Bosche et al assess MEP works of the construction of a utility corridor in a university engineering building. The system improved by them could provide superior performance over existing systems, enabling automated and robust quality control and delivery of true as-built BIM models to operations. (Bosche et al, 2014).

2.4 BIM Implementation for Building and Infrastructure Industries

Compare with the building, the infrastructure is complex physical and organizational structures for society and mainly owned and managed by governments. Airport, bridge and main road all belong to the transport infrastructures, which have their own construction methods and characteristics. The experiences and investigation data in building are not fit for infrastructure. According to a literature study Shou et al. the initial development of BIM in infrastructure can be referred to the existing BIM experience from the building industry; and the comparative analysis of BIM in infrastructure and building cases highlights the support of new BIM use, enhanced of traditional project management and transformation of project delivery method (Shou et al, 2015).

2.5 Comparison of BIM Implementation in Different Procurement Types

Mostafa has conducted a study to investigate the advantages/ disadvantages of BIM use on procurement types for Design-Bid-Build, Design-Build, Build-Operate-Transfer (BOT) and Construction Management (CM) (Mostafa, 2016). The results of this study

have been summarized in the table 2.2. The most effective current procurement method used with BIM adoption is Build-Operate-Transfer because only one organization is responsible for the design, construction, operations and the integrated relationship among the participants that enhances the cooperation and increases the level of coordination. However, it requires changes in the agreements to force sub-contractors to adopt BIM with predefined standards.

Table 2.2 : Comparison of BIM implementation in different procurement methods

	Design-Bid-Build	Design-Build	BOT	CM
Advantages	- The requirements and procedures are well known. - More accurate and reliable bids and risk of later claims are reduced. - Minimised conflicts and inscrutability among tender documents. - Bidders can use BIM models to extract information for price evaluation. - Conformity between the BIM model and 2D drawing is achieved.	- Early involvement of contractor team in a project. - Integration is enhanced that will contribute to management and accountability. - Client can assess among the proposals with ease and accuracy and check the compliance between proposal and the stated requirements. - Enhanced accuracy of bids in terms of price and construction capability. - Bidders can avoid errors and conflict on their proposal before the final submission. - Selected contractor saves time of preparation since error-free shop drawing is already ready. - Facility management is improved due to level of detail in the BIM model.	- Increased dispute potential in international contacts can be minimized with the use of BIM. - Cost estimation through BIM can indicate accurate and more reliable costs to financiers. - Cost benefits of the consortium can be enhanced through minimised cost overruns and claims through BIM. - Data collected through BIM can help to reduce the risks expected during operations. - Technical risks can be overcome with the use of technology enabled by BIM. - Integration of design, construction and operations team is achieved.	- Quantitative information held by BIM model can be used in preparing cost estimation and coordination between project team. - BIM limits the request for clarification and provides prompt answers. - Project participants share equal responsibility of the project.
Disadvantages	- Integration among participants very limited which will affect the integration, communication and collaboration. - Contractor engages after 100% completion of design phase. - There is no opportunity for contractors to learn BIM process.	- Unclear requirements from client's design team. - Since preparation of the BIM model is costly and time consuming, the period of the tender will be also longer. - Clients do not have sufficient knowledge about meeting BIM requirements and controlling BIM process.	- Government do not have sufficient knowledge about meeting BIM requirements and controlling BIM process. - Since preparation of the BIM model is costly and time consuming, the period of the tender will be also longer.	- Construction manager has to be a BIM expert who can manage, control and coordinate the information flow among participants.

2.6 Summary of Literature Analysis

40 studies about site BIM applications researched during the literature analysis consists of 25% design management (DM), 24% information management, 19% quality control and assurance, 17% performance management, %15 resource management cases. (Figure 2.2)

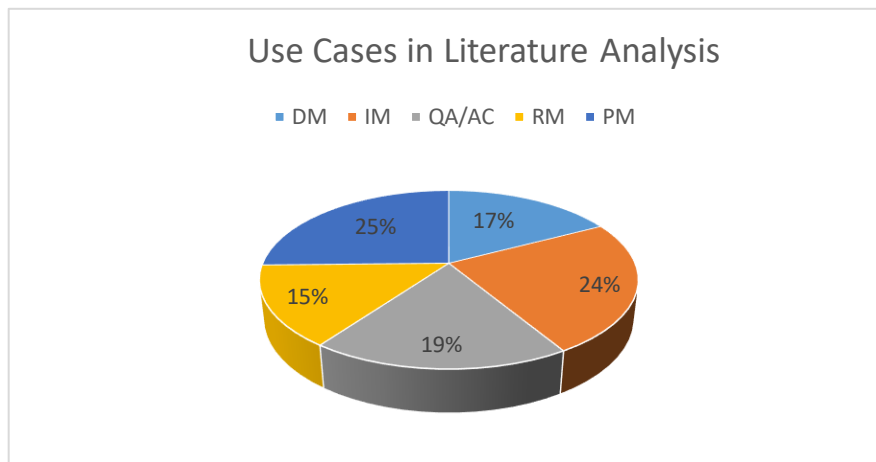


Figure 2.2 : Distribution of use cases researched in literature analysis.

With 65% prototypes are the most used tools for site BIM studies mentioned in this study. The rest consists of 20% reports and 15% commercial tools. (Figure 2.3)

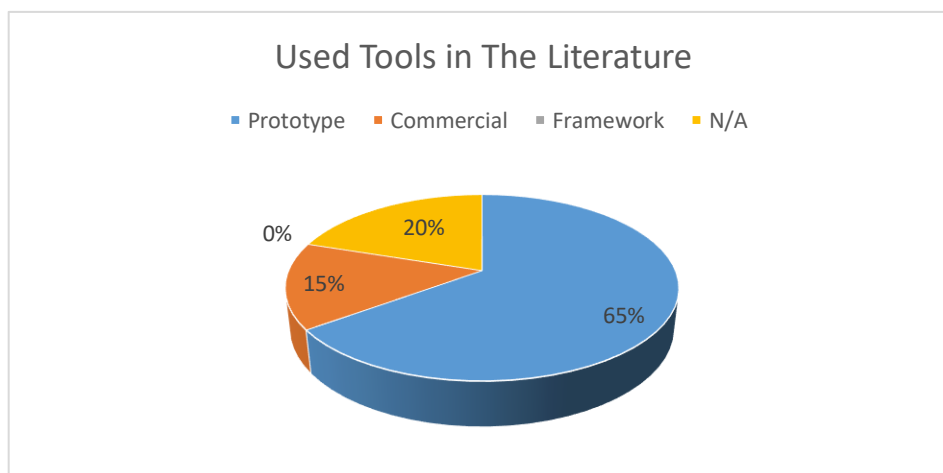


Figure 2.3 : Distribution of used tools researched in literature analysis.

The studies published in site-BIM issue as real-project implementation mentions the use cases respectively according to percentages are: performance management, design management, information management, quality control and assurance, resource management. (Figure 2.4)

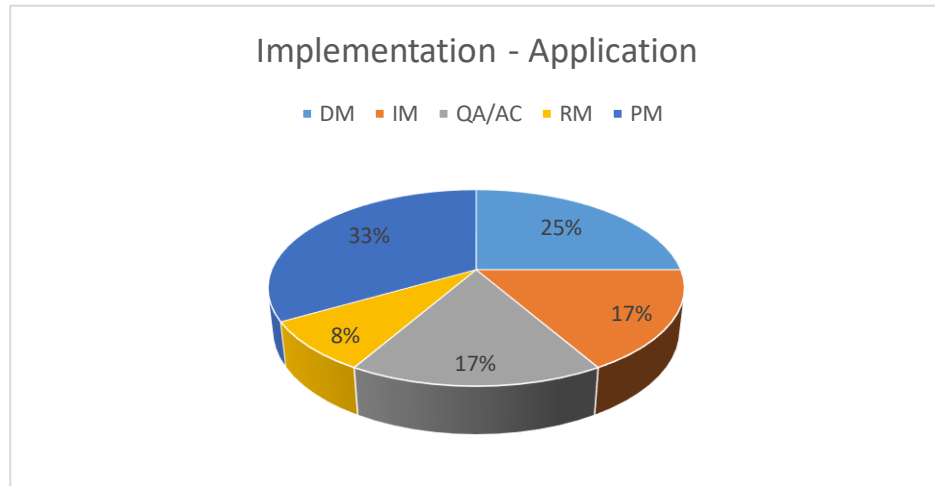


Figure 2.4 : Distribution of used applications in terms of use cases.

The studies published in site-BIM issue as real-project implementation used 60% commercial software and 40% prototypes. (Figure 2.5)

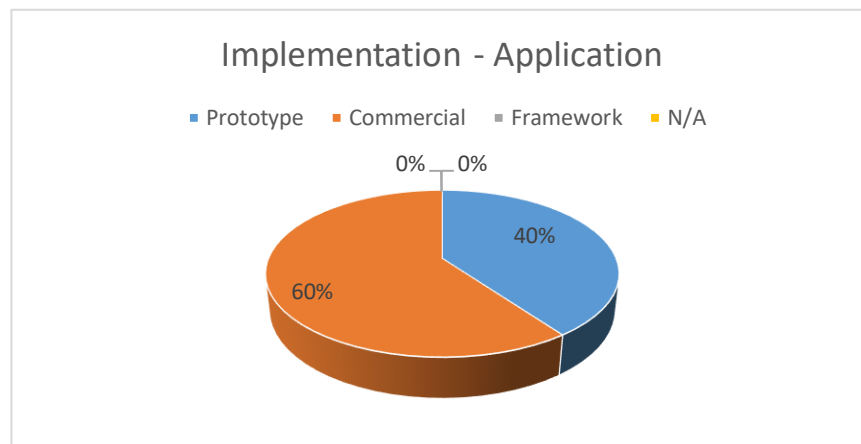


Figure 2.5 : Distribution of used applications in the implementation type studies.

Even though there are some studies performed for site-BIM issue, real-world cases to investigate the issue are very limited. Besides, these studies performed site-BIM analysis only for a limited construction activities and did not aim to transform the overall process of the organizations. There has been a very limited effort to describe and evaluate adoption of site-BIM in a real-world complex project by implementing all of the use cases described.



3. CASE STUDY AND EVALUATION

3.1 Introduction

In order to capture mobile BIM implementation in a real-world project, a case study that utilized participatory action research approach was adopted in the research to present the planning and implementation of mobile BIM implementation on site in an ongoing complex construction project. This research is conducted by a researcher who has also taken responsibility in the company's BIM Department as BIM Engineer for 2 years to examine and elaborate on the BIM implementation in IGA project. The data used in this research derived from literature analysis, project documents, observations, survey and interview results collected by a researcher who is involved to organization in daily activities. This chapter present the case study of IGA, with elaboration of the case through participatory observations and documentation analysis.

3.2 Project Description

At the time of research was conducted, Istanbul New Airport project's design was complete and construction well progressed with phases of the work being handed over for commissioning for the first phase of the project. The airport is planned to be constructed with 4 phases. The first phase includes the construction of 3 runways, terminal including 5 piers with an area of 1.3 million m², a car park with an area of 700,000 m² and other site facilities. In the project scope, the critical assets of the main terminal building, runways and related emergency runway/taxiway systems will be constructed. The period of completing the official construction of the first phase that would serve for 90 million passengers is predicted to be finished in 2018. With the completion of first phase by late 2018, operation of the airport will be directly initiated. In the next three phases of the project, it is aimed to build remote terminal together with additional runways and buildings by 2028. At the end of the completion of all phases, the project will come to life providing 76 million m² of airport area with 6 runways, supporting 3,500 take-offs and landings per day, 200 million passengers a year and access to 350 worldwide destinations.

IGA as a joint venture was founded in 2013 with the purpose of constructing and operating the new airport for Istanbul. The project is performed through a public-private partnership deal and contracted on a Build-Operate-Transfer model with a joint venture contractor formed by five Turkish companies. The contractor also has responsibility for the facilities management of the project for twenty-five years after handover.

Airport design and construction is highly complicated and incorporates a varying mix of infrastructure-including buildings, terminals, runways, passenger gates, car parks, railways, and roads. Collaboration and coordination amongst the different international and local companies involved in the project require a structured and holistic approach. This needs a platform integrating all these related parties for on-time and on-budget completion of the project. Thus, BIM perspective is the only feasible construction methodology to achieve on-time and on-budget targets. In this study, IGA has been researched under two main subjects; Design & Engineering and Project Management. IGA project makes a compelling context for mobile BIM study.

This research is conducted by a researcher who also has taken responsibility in the company's BIM Department as Senior BIM Engineer to examine and elaborate on the BIM implementation in the IGA project for 2 years. Organization schema of IGA-BIM department is shown in Figure 3.1.

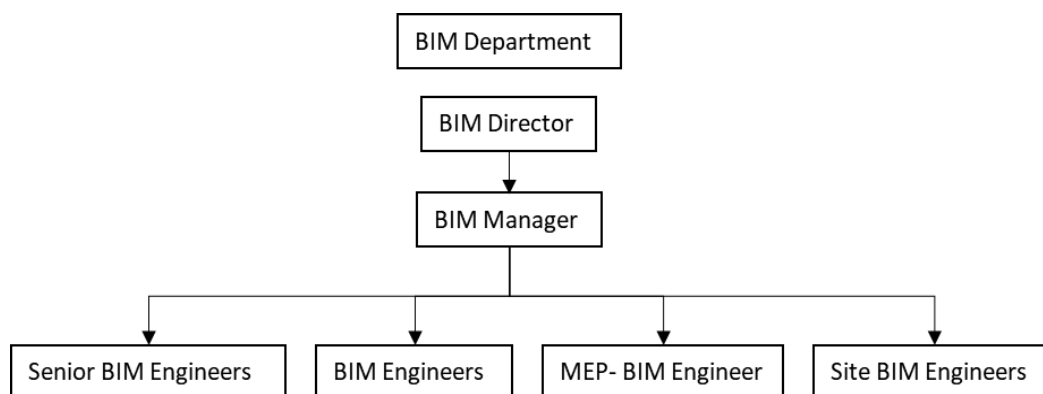


Figure 3.1 : Organization schema of IGA BIM department.

The researcher was attending both daily and weekly meetings and had access to relevant documents as shown in Figure 3.2. These meeting concepts will be elaborated in section 3.3.1.1.

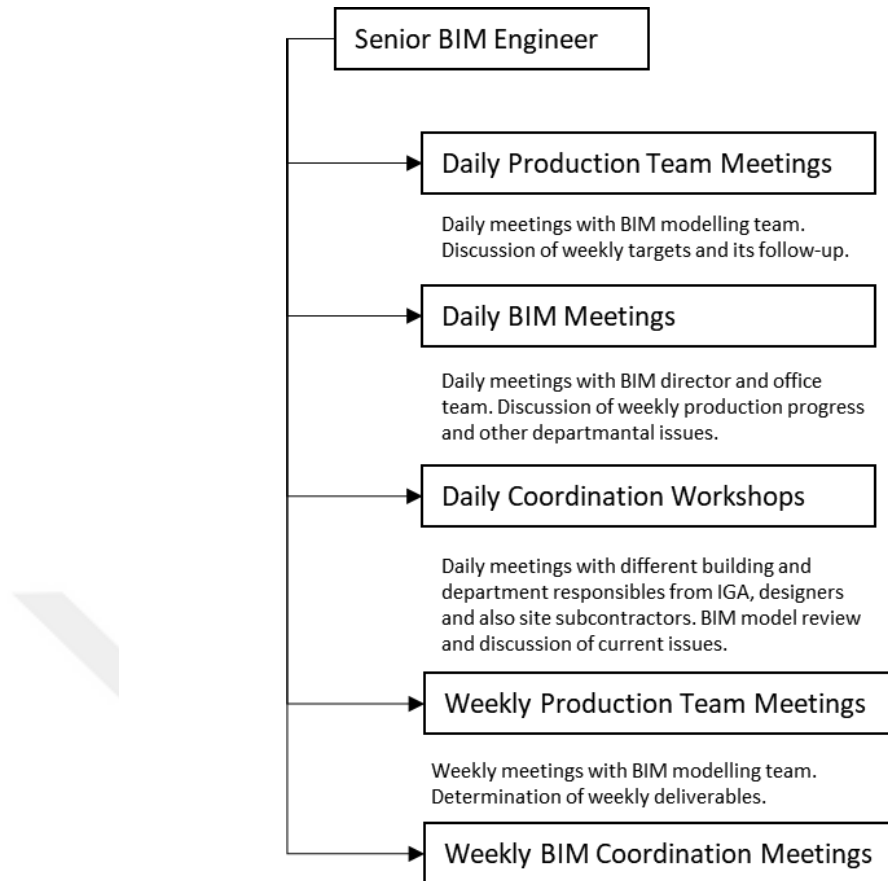


Figure 3.2 : Meetings that researcher/ senior BIM engineer attended.

3.3 BIM Implementation Strategies and Transformation Process

There are many parties involved in BIM processes in IGA project as shown in Figure 3.3. Starting with design parties delivering their documents to BIM department, BIM model has been created. Together with drawings, general specifications are also considered while creating the BIM model. After the creation of BIM model, construction baseline is integrated to model to create 4D model. After the BIM model is coordination is finalized by using clash reports then bill of quantities are generated from the model. This coordinated model then have been circulated to construction parties for them to produce their 2D/3D production documents. QA/QC inspections and then test and commissioning has been done while the mobile use of BIM to make ready for hand-over to the owner.

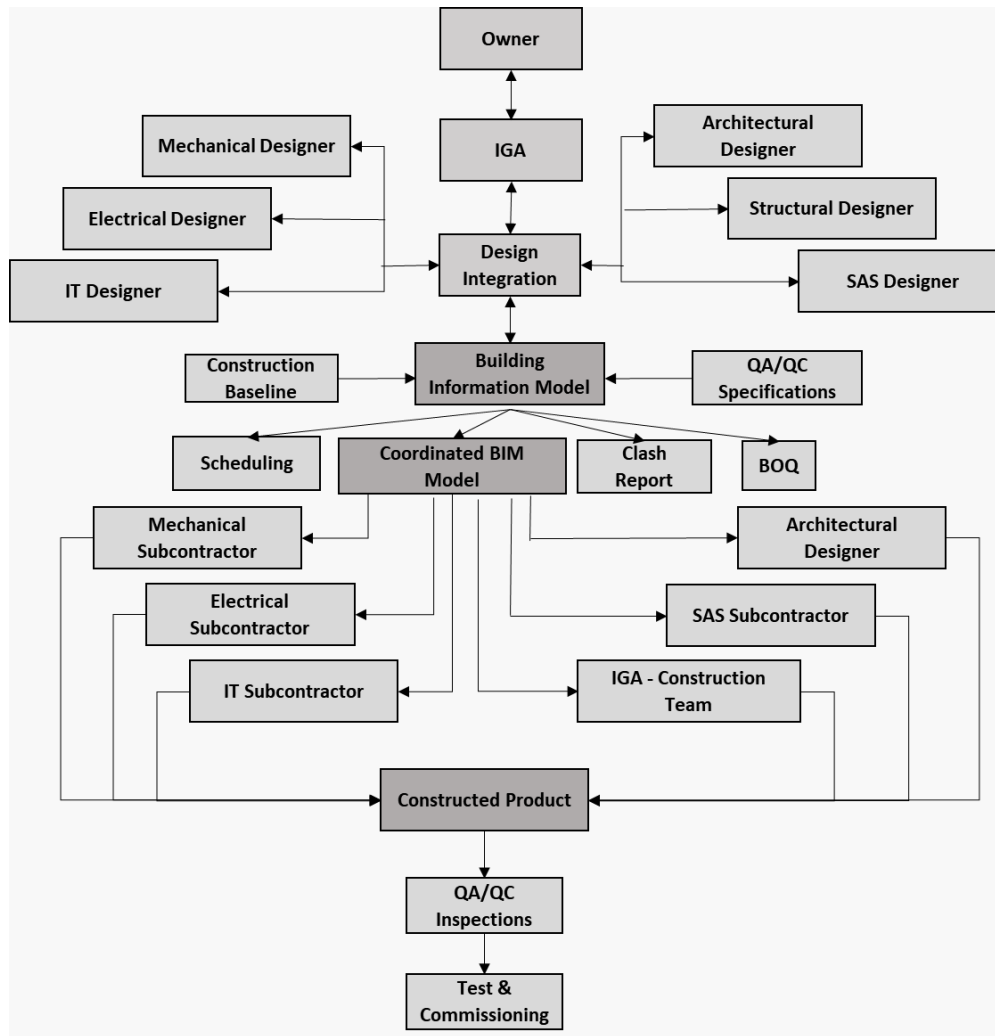


Figure 3.3 : Flowchart of final product with BIM enabled model.

3.3.1 Design and engineering

In this section, BIM execution for communication and collaboration, information management for data sharing, BIM model creation and coordination, clash reporting format, 2D drawing production procedures and finally 4D/5D applications used in the project is explained.

3.3.1.1 BIM execution for communication and collaboration

BIM implementation at IGA first took a role to sustain integration of all disciplines and related parties in a single virtual environment. Asset-wise meetings and workshops are scheduled in order to support BIM coordination among all project stakeholders starting from the design phase. (Figure 3.4) The workshops are held at the BIM Room can be seen in the Figure 3.5 which is equipped with a wide screen video wall and powerful

workstations in order to establish an effective decision making environment by enabling collaboration and communication by using BIM model. It is crucial to note that bring people together in a common environment plays an essential role in BIM success as well as technological improvements provided. The project individuals have had started to get familiarized with both BIM products and new way of collaboration enabled by BIM with the initialization of the workshops under a common environment provided.

IGA- BIM WORKSHOP SCHEDULE					
Time	Monday	Tuesday	Wednesday	Thursday	Friday
08:30	Weekly BIM Production Meeting Attendees: BIM Management, BIM Production	BIM Production Meeting Attendees: BIM Management, BIM Production	BIM Production Meeting Attendees: BIM Management, BIM Production	BIM Production Meeting Attendees: BIM Management, BIM Production	BIM Production Meeting Attendees: BIM Management, BIM Production
09:00				General BIM Coordination Meeting Attendees: BIM Management, Design Managers, Design Consultants	
09:30					
10:00					
10:30					Airside-Sitewide BIM Coord. Workshop Attendees: BIM Management, Design Managers, Design Consultants
11:00					
11:30					
12:00					
12:30					
13:00					
13:30	Terminal BIM Workshop Attendees: BIM Management, Design Managers, Design Consultants	Carpark BIM Workshop Attendees: BIM Management, Design Managers, Design Consultants	Piers BIM Workshop Attendees: BIM Management, Design Managers, Design Consultants	Terminal BIM Workshop Attendees: BIM Management, Design Managers, Design Consultants	Piers BIM Workshop Attendees: BIM Management, Design Managers, Design Consultants
14:00		BHS BIM Workshop Attendees: BIM Management, IGA SAS (BHS), BHS Subcon., Terminal Architect, IGA Architecture, IGA Structure, Structural Engineer			
14:30					
15:00					
15:30					

Figure 3.4 : IGA-BIM workshop schedule.



Figure 3.5 : IGA-BIM meeting room.

Since the airport itself contains several facilities such as terminal, piers, multi-storey car park, apron and landside infrastructure; these facilities have been treated as different assets and workshops are shaped accordingly. Each workshop is held with the attendance of design managers for relevant asset/discipline from contractor and design consultants for relevant asset/discipline and also BIM management team. The workshops start with all of the design consultants reporting current state of design and latest revision agenda. Afterwards, up-to-date BIM Model is reviewed together by going over the discussed revisions, issues that designers raise in order for clarification, and the issues such as RFIs and clash resolutions addressed by BIM Management team regarding mismatches and incomplete items. If a zone in the reviewed asset has already become critical for site production according to design-construction schedule explained in section 3.2.1.3, then coordination and constructability issues are also discussed and decisions are made in order to make the mentioned zone ready for installation with zero conflicts on site.

BIM implementation workflow as shown in figure 3.6 has been developed and put on action by IGA to define how the information will be gathered, processed and delivered as final for design and engineering processes of BIM.

IGA BIM Workflow consists of BIM Integration, BIM Production and BIM Management. BIM Integration includes IGA officials and subcontractors from all design disciplines and QA/QC. The first step is to gather the design information

(models, documents, drawings, revisions,..) from the parties working on different disciplines generating overall airport services/systems via Vault data management tool which is explained in detail in section 3.3.1.2. The information and design deliverables (2D and/or 3D) from all disciplines is submitted to Vault in 2-week intervals. BIM Management Team filters this design information received according to its consistency, relativeness and also to construction schedule then delivers the necessary information to BIM Production Team for modelling. Document submissions are logged by Project Coordination Team and reported to BIM Management and submitting discipline officials after each submission.

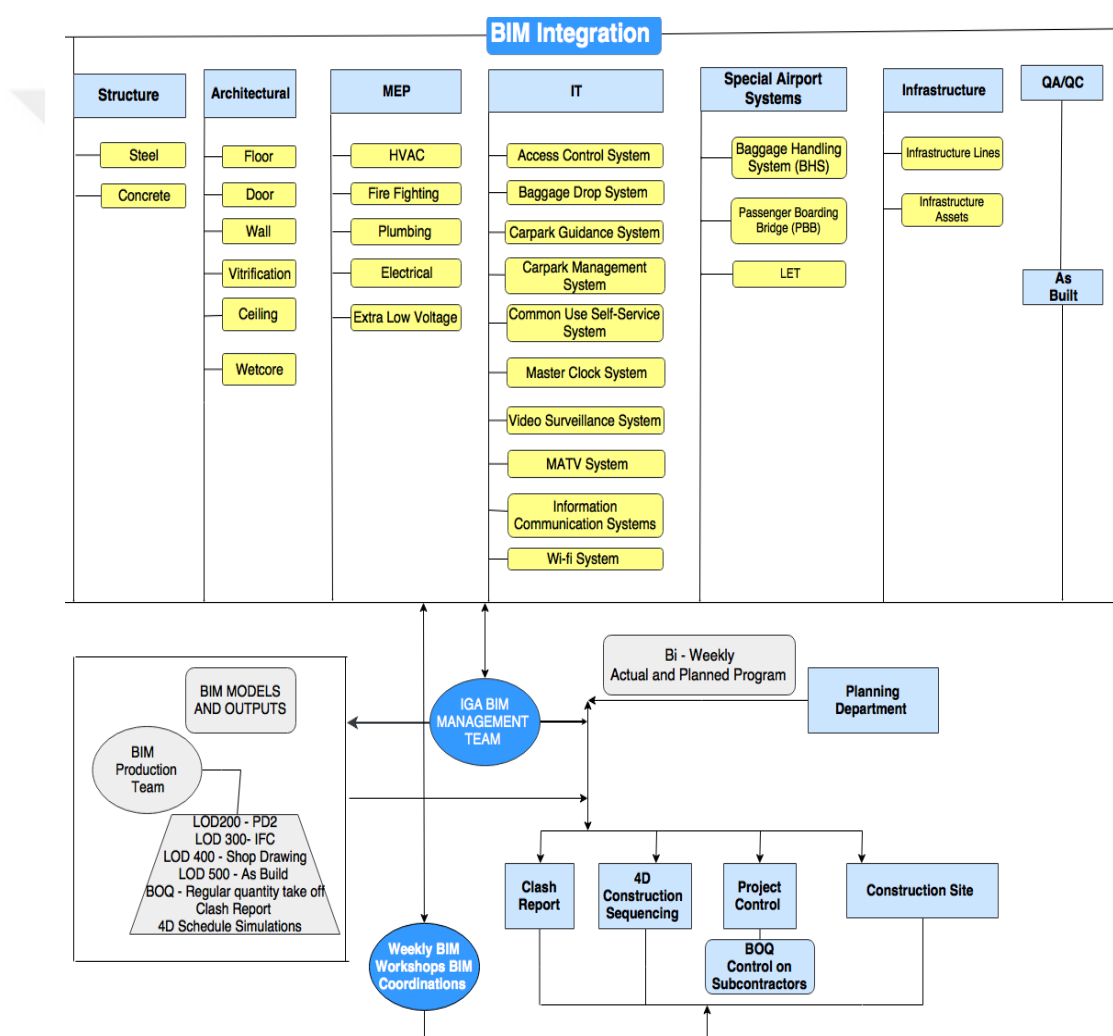


Figure 3.6 : IGA-BIM integration workflow.

Design Integration, QA/QC check and analysis, 2D design drawing inconsistencies and omitted information is gathered through raised RFIs from BIM Production team to the relevant disciplines. Major design issues are subject to RFIs thus RFI is the precursor

before clash detection. All RFIs and discipline responses are logged as open/closed by BIM management. Open RFIs are agenda item in BIM Coordination Workshops. RFIs are critical for developing PD designs to IFC level. BIM Production is where all design information (which includes but not limited to 2D layouts, sections, elevations, schedule, design specifications etc.) is incorporated into 3D BIM model. BIM Production Team works under administration of BIM Management Team and responsible for revising the models in line with the information provided and submits the asset and zone-wise models both in Navisworks and Revit file format in agreed LOD depending on the design& engineering phase. BoQ extraction from BIM model, clash detection and reporting, 4D schedule simulation is performed regularly. Submitted models are reviewed both for clashes and general coordination issues with designers.

The IGA BIM management team develops and executes BIM execution plan, which prescribes a roadmap for BIM implementation process of the IGA project. The BIM department gathers project information from all disciplines through Vault and Buzzsaw environments. Project coordination is achieved by weekly BIM coordination meetings, where major RFI's (Request for information) and other project issues are resolved. Leading the designers and subcontractors to familiarize and follow the BIM workflow as given in the BIM execution plan is highly critical for the success in project coordination. BIM management is responsible for BIM-based project coordination, BIM model management and integration of design, schedule, quantity and as-built information. Project coordination is achieved by weekly BIM coordination meetings and Workshops where major RFIs and other project issues are solved.

3.3.1.2 Information management for data sharing

Reaching the necessary information and resolving of future operational problems related to airport systems during pre-commissioning, commissioning and maintenance stages will be possible with usage of BIM model efficiently. The participant parties working on different design tools submitted their design information to BIM management team as agreed in the beginning of the project with a formal workflow, so different formats of data is gathered all together. Cloud based data management tools are being use to publish models, coordination documents and other related information via Buzzsaw and Vault applications. The data is gathered through the use of cloud

based information management tools. In these tools, defined individuals from each party has been assigned and related permissions have been set by BIM team. Terminal architects are working on Revit, pier architecture; all MEP-IT and all concrete works are in AutoCad, airside surface and drainage model are in Civil 3D, baggage handling system is in AutoCad 3D. After gathering all of the data from different sources and from different parties, overall Master Model in Navisworks file format shown in Figure 3.7 has been exported from Revit which includes all the latest project data to be used, reviewed and analyzed during workshops. It kept updated by receiving all of the necessary updates which have been discussed in weekly workshops.

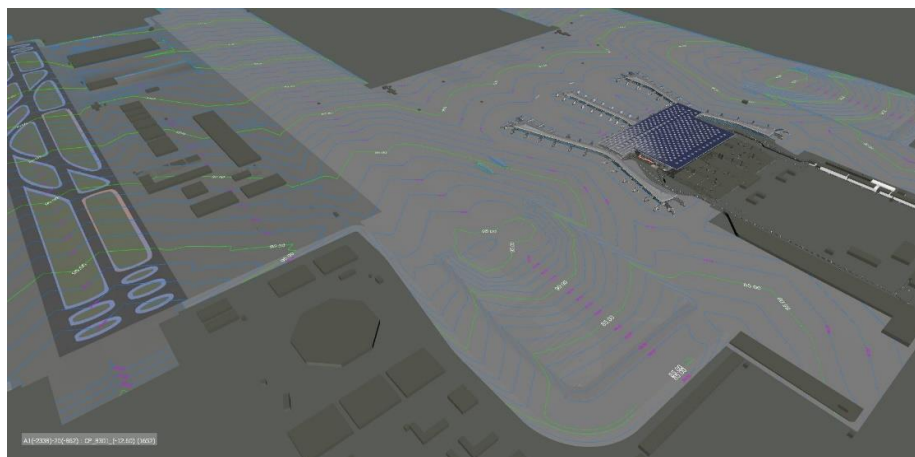


Figure 3.7 : IGA-BIM master model image.

IGA has chosen Vault as the information exchange platform for designers and consultants in construction site. All exchange of files & information between separate teams based in construction site is through Vault only. IGA has chosen Buzzsaw as the information exchange platform for remote designers and consultants. All exchange of files & information between separate teams will be through Buzzsaw only. All the design data, drawings, models, reports are circulated through Vault and Buzzsaw in the consultant/discipline specific folders. Same folder structure is used in Vault and Buzzsaw to enable synchronization. BIM folder in Vault is synchronized to Buzzsaw continuously to ensure all parties benefit up-to date information. All the information in Buzzsaw then synchronized to a local server as a back-up procedure. In these tools, defined individuals from each party has been assigned and related permissions have been set by BIM team. At this point, BIM implementation in the project gives many opportunities in means of providing easy access to all project data including BIM models.

3.3.1.3 BIM model creation & coordination

IGA project has been split into building zones in order to ease the management of planning, design, construction which could have not been possible only with levels. For the zones which are foreseen as critical according to construction schedule are reviewed with subcontractors in BIM room at weekly workshops and necessary engineering decisions considering all the disciplines and up-to-date design information have been made. As explained in the section 3.3.1.2 BIM models are generated and revised periodically by gathering the latest design information from the project participants by following the formal workflow and weekly workshops. These incorporated to BIM Model and reported clashes have been resolved and make ready to share with site for installation. Delivery of these models to construction site will be explained in detail in section 3.3.2.

Every two weeks a clash report is generated by BIM production team. Discipline model elements tested against other discipline model elements according to clash disciplines matrix. These issues have been discussed in the weekly coordination workshops and models are coordinated with the decisions taken in these meetings.

BIM model creation and its collaborative review has provided a common visual environment for the systems forming the airport facility, therefore cross disciplinary coordination and engineering decisions have been accomplished under the supervision and guidance of BIM department. This led a quick passage from design to construction. BIM coordination process is based upon the construction schedule in order to lead production on site with accurate construction models. A design-construction schedule has been developed to prioritize the zones that site installation start date is close according to the schedule. Since project is divided into high level zones and assets, an Excel sheet is created to follow upcoming construction zones which signals that coordination should be initialized in order to give an accurate construction model to site for constructability purposes. This schedule is organized by combining design drawing submission dates, BIM modelling timeframe, shop drawing production time frame, coordinated shop drawing date and start date of construction according to project baseline. Design drawing submission dates are prepared asset-zone and level wise by design managers for each service related to their disciplines. Start dates of construction is taken by project baseline which is also working in asset-level and zone-wise. 1 week buffer is given from the start date of construction than the date that coordinated shop

drawing needs be ready is found. If there is less than 30 days left till shop drawing production it timeframe until shop drawing is highlighted as red, if 40 days has left it is yellow and if there are 60 days it is highlighted as green. 60-30-40 periods are determined according to observed mock-up zone coordination duration.

TERMINAL BUILDING MECHANICAL DESIGN-CONSTRUCTION SCHEDULE											
SYSTEM	BLOK	FOR CONSTRUCTION DESIGN SUBMISSIONS		BIM MODELING TIMEFRAME (DAYS)		TIMEFRAME UNTIL SHOP DRAWING		COORDINATED SHOP DWG		MECH. CONS. SCHEDULE (Start)	
		LEVEL B (-11.00/-13.00) & LEVEL C (-7.00) (SOG+CEILING)	LEVEL D (0.00) & LEVEL Y (+2.70) (SOG+CEILING)	LEVEL B (-11.00/-13.00) & LEVEL C (-7.00) (SOG+CEILING)	LEVEL D (0.00) & LEVEL Y (+2.70) (SOG+CEILING)	LEVEL B (-11.00/-13.00) & LEVEL C (-7.00) (SOG+CEILING)	LEVEL D (0.00) & LEVEL Y (+2.70) (SOG+CEILING)	LEVEL B (-11.00/-13.00) & LEVEL C (-7.00) (SOG+CEILING)	LEVEL D (0.00) & LEVEL Y (+2.70) (SOG+CEILING)	LEVEL B -C (SOG+CEILING)	LEVEL D (0.00) & LEVEL Y (+2.70) (SOG+CEILING)
DOMESTIC WATER SYSTEMS											
TB1											
TB1-3		17.03.2016	17.03.2016	32	80	27	75	18.04.2016	5.06.2016	25.04.2016	12.06.2016
TB1-4		17.03.2016	17.03.2016	7	39	2	34	24.03.2016	25.04.2016	31.03.2016	2.05.2016
TB1-5		17.03.2016	17.03.2016	7	50	2	45	24.03.2016	6.05.2016	31.03.2016	13.05.2016
TB1-6		17.03.2016	17.03.2016	16	58	11	53	2.04.2016	14.05.2016	9.04.2016	21.05.2016
TB1-7		17.03.2016	17.03.2016	40	86	35	81	26.04.2016	11.06.2016	3.05.2016	18.06.2016

Figure 3.8 : Sample of design-construction schedule.

Navisworks is used in this project in all stages for co-ordination, clash detection & resolution and review purposes. The Navisworks file is used in workshops for coordination purposes. Model elements are managed through selection sets based on Discipline Key/Critical Areas and based on Asset, Discipline, Level and Zone. BIM management team is responsible for distribution of 3D Navisworks BIM Model to relevant parties. Navisworks models have managed selection sets and viewpoints to enable easier Navigation for all users who have different 3D skill levels. Model elements can be selected according to discipline, zone or key areas. Viewpoints are arranged to enable accurately view by zones or by key areas. Clashes and issues are highlighted/clouded and saved as viewpoints. The Navisworks file will be circulated to everyone in NWD format on Friday. The BIM managers/leads will merge all individual file in master NWD file for development purpose and also the individual file for every building for review and analysis. The viewpoints related to RFIs will only be added date wise and once the RFI's are resolved the same will be archived inside the Navisworks file.

After major coordination issues solved utilizing RFI procedure, the model is in basic coordination stage. At this stage remaining issues are found using clash detection. Clash detection is cross-check of discipline models against hard (real) and soft (clearance) clashes. Each discipline model is checked against other discipline models according to discipline clash check matrix. The clash results are reported to

stakeholders in IGA clash reporting format. The idea is to remove all clashes and establish a clash free coordinated model inclusive of the data required for quantification and operations compliances at later stages.

Figure 3.9 is the workflow created and adopted by IGA for BIM MEP-IT coordination. This coordination process requires close follow-up with the parties and quick resolutions, weekly BIM workshops held in order to provide and maintain interdisciplinary coordination throughout all of the building/ infrastructure assets in the airport construction. Clash reports are produced to identify the issues in case of the latest design information collected in BIM. With this collaborative work, parties were able to visualize the latest status of design issues and also aware of the effects of any possible revisions to the other parties. In this way, design process has been optimized by the parties and any rework resulting from poor coordination and communication has been eliminated.

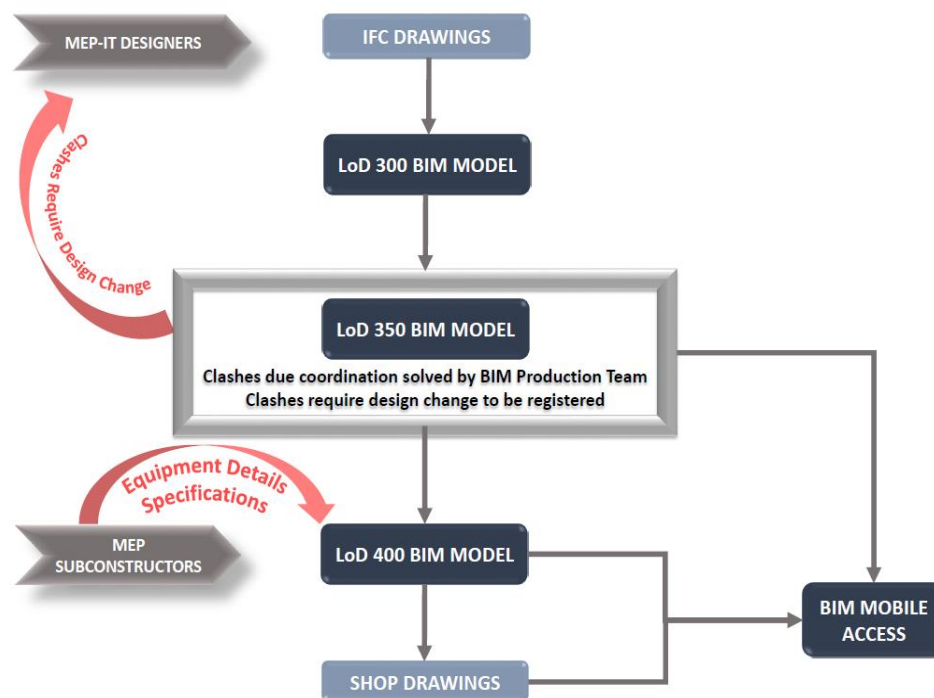


Figure 3.9 : IGA-BIM MEP-IT coordination workflow.

3.3.1.4 Clash reporting format

Every two weeks a clash report generated by BIM production team. Discipline model elements tested against other discipline model elements in order to reveal the problems regarding design.

3 levels of criticality for clashes have been adopted in the project and clashes are treated in different ways.

- 1. Critical severity:** Design Change is required.
- 2. Moderate severity:** Coordination is needed.
- 3. Low severity:** BIM production team will resolve.

In general most of the moderate severity clashes will be solved by BIM production team upon approval of discipline teams. Moderate severity clashes are to be resolved in BIM Coordination Workshops. Critical severity coded clashes are the major clashes needs design change. Major clashes are saved as viewpoints in Master Navisworks file submitted by BIM production team. These viewpoints are used in BIM Coordination Workshops and by disciplines individually to manage and solve issues.

All of the engineering processes including MEP-IT and BHS (baggage handling system) disciplines and design coordination between MEP-IT-BHS-Architectural and Structural disciplines and also with each other individually have been realized in BIM environment.

In terms of preliminary engineering, BIM has provided visualized environment for MEP-IT-BHS (Baggage Handling System) systems separately, enabled the design teams to take their decisions under the supervision and guidance of BIM department which is the core coordination party for IGA for design to construction delivery processes. BIM in IGA has been the integrative platform between all the related parties in case of design and coordination.

3.3.1.5 2D drawings production procedure

The BIM Model was part of project deliverables, where relevant subcontractors is required to produce appropriate design products compatible with the BIM Model specified also in the contractual level as shown in Figure 3.10. This workflow is created and put on use by IGA to regulate 2D drawing production procedure of subcontractors. MEP-IT subcontractors responsible for producing Shop Drawings for site installation were required to derive their 2D Shop Drawings from BIM model, where the process is monitored by BIM department and relevant contractor designers and the drawing approval process was based on this manner. Incompatible drawings with BIM model coordination were not being accepted in a strict control process.

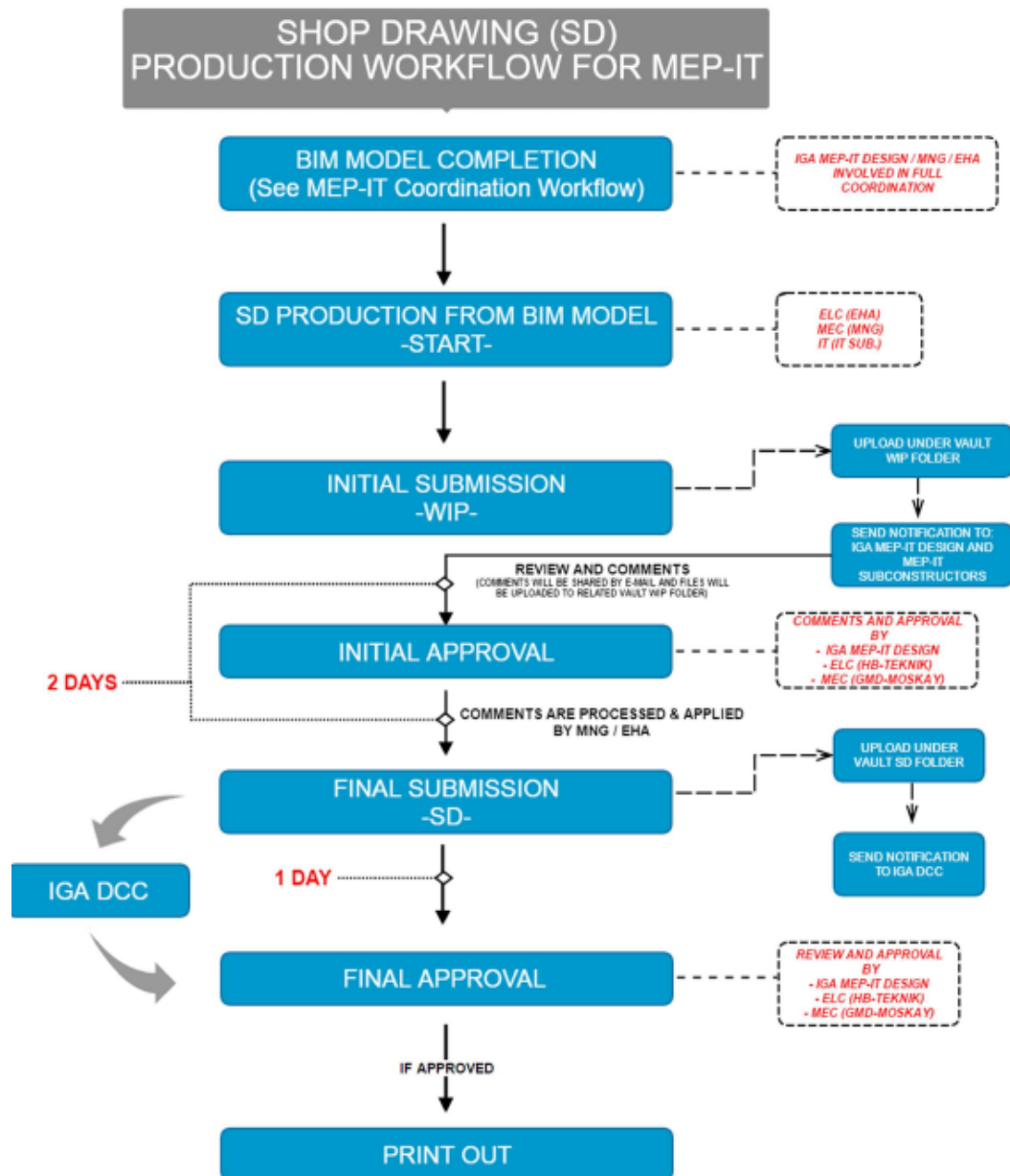


Figure 3.10 : SD production workflow for MEP-IT.

3.3.1.6 4D/5D

The use of BIM gives opportunity to design and construct a digital version of a project in a virtual environment before the physical construction and the integration of the programs of the construction project stage into the 3D can be produced and called 4D and these allows the users to see the sequence of construction activities which could highlight the logistical problems such as the movement of trucks and swing the crane areas and also, using 4D phasing visualizations can be able to quantify time saving of up to 19% of duration during a project (Suermann, 2009).

BIM integration in IGA is not limited to design coordination but also aimed to improve project management with 4D Construction sequencing, 5D Quantity estimating and also construction site supervision processes. For 4D construction sequencing, baseline schedule of the project has been combined with the BIM model and discussed in BIM Room with the construction teams in terms of both actual progress and possible site installation clashes for critical activities. This 4D model is developed and integrated more than 30,000 activities into the model to know and monitor the IGA construction progress on daily and monthly basis to have dynamic control over the progress in the IGA project. Especially for the executive decisions making and 4D model snapshots of the key assets and zones are shared weekly with directors and the responsible bodies. The 4D BIM model is used for coordination and communication with the related stakeholders, who are also attending to the BIM meeting room. In IGA BIM workflow the 4D BIM model is an analysis tool for decision makers to help take preventive and corrective actions to avoid delays. Other than showing construction activities status, 4D schedule utilized to manage design development and coordination as well. BIM based quantity take-off has been performed periodically and shared with purchasing and contractor technical offices which are controlling subcontractor installation quantity and progress payments according to these installations.

With the up-to-date design information collected in BIM model, quantities for each discipline has been extracted in the format agreed with the technical office and used by them to control the subcontractors. These efforts done in the office are also controlled by site BIM engineers in the construction site in order to ensure the decisions made are also applied during construction.

The main advantage of using BIM for quantities management is to derive actual quantities of items used in the project to remove out any excess amount and to verify the estimated amount. Bill of Quantities (BoQ) from the BIM model are generated and issued to the technical offices of each discipline. Figure 3.11 is the workflow of 4D/5D integration with site progress reporting. This workflow is created and put on use by IGA to show the BIM based progress monitoring followed in the project.

The workflow shown in Figure 3.11 explains how BIM based project progress monitoring applied in IGA. Since planning, quantities and QA/QC are directly carried with BIM and the progress payments are done accordingly, subcontractors have to comply with BIM both for their work on site and also reporting to IGA.

This means subcontractors should follow the milestones given in the baseline, install on site by conforming QA/QC standards together with BIM model and report the quantities in line with the BoQs extracted from BIM model.

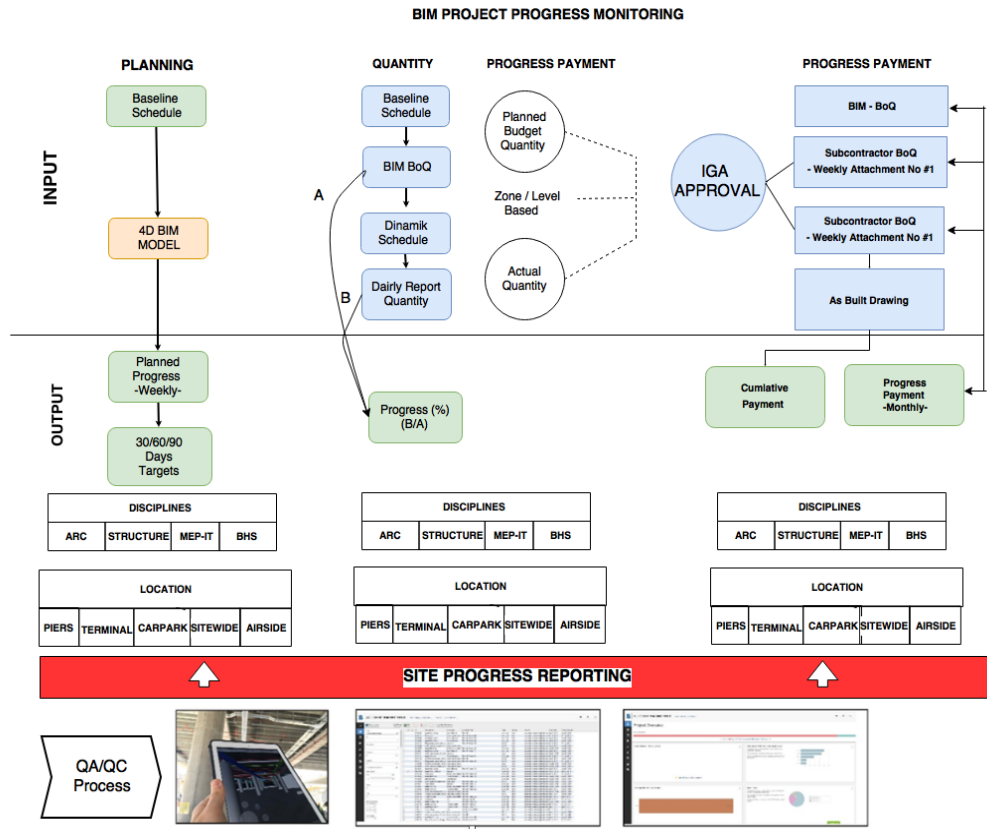


Figure 3.11 : BIM enabled project progress monitoring workflow.

3.3.2 Project management

During design and engineering phase in IGA Project BIM has provided interdisciplinary coordination via BIM model clash detection and daily workshops held in the BIM Room. Since all of the relevant parties including subcontractors was involved in the process, 2D shop drawings produced for site installation purpose was also compatible with coordinated BIM model. Apart from design coordination, construction schedule was integrated with the BIM model to monitor progress and take necessary decisions to avoid any possible delays. BIM based quantity take-off has been performed periodically and shared with purchasing and contractor technical offices which are controlling subcontractor installation quantity and progress payments according to these installations. Whilst design team was progressing with BIM implementation process and adoption, it was needed to extend all these efforts

performed in the office to the construction site to maximize BIM benefits. With improved formal workflows enabled by technology and cumulative BIM efforts, increase in engineering quality, reducing unnecessary rework, savings in cost and project schedule have been aimed. BIM activities performed on site in the project are categorized according to the literature analysis table Appendix A. have been addressed on site which forms the mobile BIM in this case study. These categories have been expanded to subcategories which are realized in IGA project as shown in the Figure 3.12. Survey questions are also structured in parallel to this Figure 3.12.



Figure 3.12 : Use cases enabled by mobile BIM implementation.

Cloud based collaboration tools Autodesk BIM 360 Field and BIM 360 Glue have been selected to transfer digital BIM data from office to site, and lead all the processes given in Figure 3.12 because of the tool's compatibility with the common tools used in design phase and their user-friendly features. The aim was to keep the site updated about the latest and the most accurate design/construction data in forms of BIM Models, Shop

drawings, MS (Method Statement), MAF (Material Approval Forms) whilst monitoring automatically and improving quality management workflows.

To run these applications on site, organization schemes of all the departments within the company has been studied while determining the total number of tablets to be purchased. Selected tablet users has been discussed with the head of departments and the final number has been settled as 150 for 6 departments: MEP, IT, BHS, SAS, Superstructure, Infrastructure and QA/QC.

Site engineers have been equipped with iPads as shown in figure 3.13 that only selected and approved tools by BIM department are installed. Access to internet browsers or any other applications selected by BIM have been restricted by company's IT department via Mobile Device Management system. These arrangements ensured that the site personnel are focused on only work related activities while using tablets and also privacy of project data by restraining data sharing with any other device.

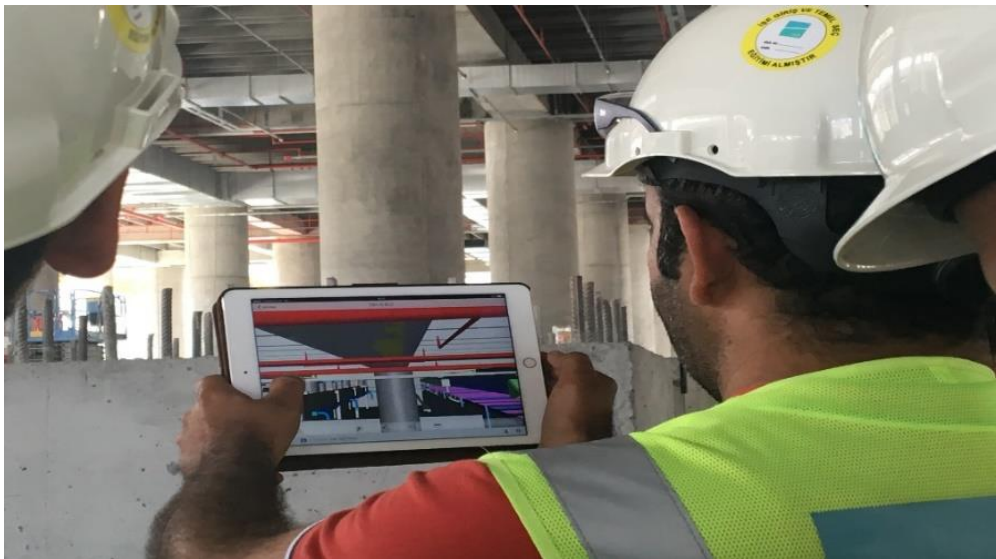


Figure 3.13 : Site engineers are using tablets on site.

Site engineers and QA/QC personnel have been started to get familiarized with the new tools, workflows and communication ways with the trainings given by BIM engineers who have formed the structure of the tools for effective use according to project characteristics by optimizing processes. Because of the size of the project, managing issues on daily/weekly base was foreseen as challenge. For this purpose weekly sessions are set with all the users to upskill them when using the system. These sessions were not considered as on-off processes, they are still continuing periodically for all of

the departments to educate new comers and also keep current users updated with the features and workflows regarding the tools in use.

Mobile BIM Guide has been prepared and distributed by BIM department in order to create an easily accessible document for anyone involved in the project as shown in figure 3.13. By this way, also a standard has been put on use for common processes to be followed by every personnel.



Figure 3.14 : IGA-BIM mobile access guide.

The aim was to steer site installation progress while making it cost effective and high quality with minimized rework with BIM Mobile Access in this project. Glue and Field tools are functional on site with the following context; coordinated BIM Models, approved 2D shop drawings, QA-QC documentation including Material Acceptance Forms and Method Statements, QA-QC processes; inspection forms, inspection checklists and site observations, performance tracking, crew and jobsite planning.

3.3.2.1 Mobile tool set-up

In the cloud project, selected tablet users, as explained in the previous section, are identified in the Glue project by assigning them to both relevant departments and

company in order to give them accurate permissions. Selected subcontractor staff had also given access with the edit-restricted permission. While contractor staff is able to see all the issues assigned to each subcontractor, subcontractors are able to see only the issues/documents related to their company.

3.3.2.2 Model integration process

Native file format that are used to create and update BIM models is Revit. In order to publish this models to iPads workflow shown in Figure 3.15 has been followed.

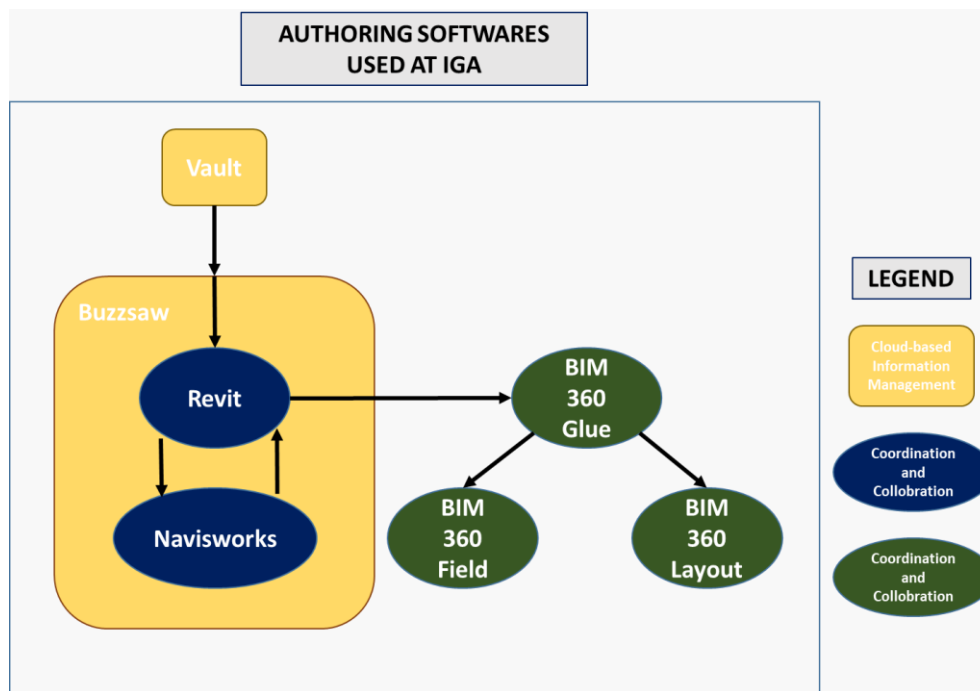


Figure 3.15 : Model integration workflow from office to site.

On-site designers submits design information through Vault. Off-site designers submits design information to Buzzsaw. This design information has been transferred to BIM production team through Buzzsaw and they submit Navsworks models with clash reports. Through workshops clashes are resolved and coordinated models in Revit are shared with Glue application directly via Glue add-in. Because of size and multiple assets in the project, it has been decided to share the BIM models in asset / level / zone wise logic. In order to do that, each zone is saved as view in Revit models then shared with Glue in the relevant folder created according to model hierarchy. Discipline and zone wise Revit models in Glue is checked by BIM production team and by appending all the disciplines in one zone merged models are shared with Field application for site use.

3.3.2.3 Mobile BIM practices performed on site

Design management enabled through mobile BIM

After finalizing the cross-disciplinary coordination in BIM environment in the offices BIM models are shared with BIM 360 Field application by following the workflow in Figure 3.15. Any design change or installation information with integrated disciplines delivered to site within minutes as shown in figure 3.16. This led to a faster and correct application of the coordinated design without any delay and with less problems on site.

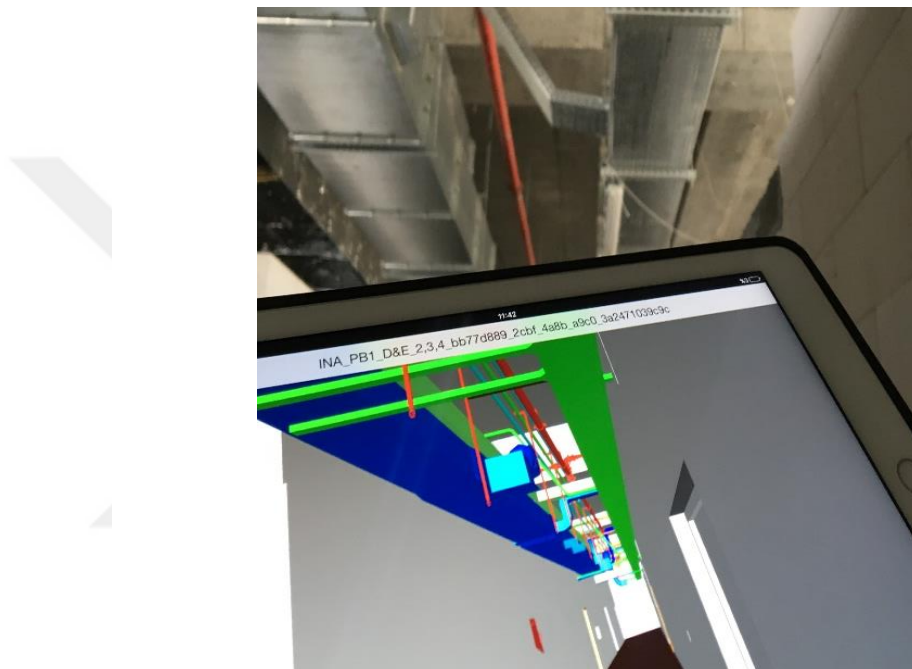


Figure 3.16 : Multidisciplinary merged BIM model view on tablets.

The models are split into zones which are already created in the system in the beginning of mobile utilization. There were 2 types of updates identified and carried out to keep site team informed about up-to date BIM model:

Bi-weekly architectural-structural updates:

All of the structural and architectural updates have been gathered from the related departments in weekly manner to keep BIM model up-to-date. These updates are reflected to BIM models and shared with the site team in bi-weekly periods.

Immediate coordination:

Once cross-disciplinary coordination progress is finalized, clash-free engineering models are shared with the site team to steer installation.

The merged model, shown in figure 3.16, shared with site for one zone included followings:

1. **Structural model:** includes all of the concrete and steel elements
2. **Architectural model:** includes all of the architectural elements including wall, floor, façade, lifts, elevators, escalators.
3. **MEP-IT model:** includes all of the coordinated mechanical, electrical and IT services.
4. **BHS model:** includes all of the elements of baggage handling system which is the main system in an airport facility.

The resulting clash-free BIM Model, with necessary engineering decisions considering all disciplines has been made, shared to the site directly via mobile applications for site engineers to carry out production on-site.

Observed advantages of design management enabled by mobile BIM applied on site have been listed below:

- Any late delivery of design change has been prevented which will eventually cause rework and delay on-site.
- Construction team had opportunity to foresee their disciplines further interactions with the rest of the services and process accordingly.
- Production on-site followed clash-free coordinated BIM models which lead effective and zero-defect production.
- Site team has followed the latest design information with the periodic updates. In this way, physical distance in between office and site has been eliminated.
- Any design and engineering considerations taken into account while finalizing BIM models has been transferred to site. This lead the correct application of considerations which will prevent any further problems foreseen.

Information management enabled through mobile BIM

Together with BIM model also 2D drawings compatible with BIM coordination are also installed on tablets after an approval process includes cross-check with the latest BIM model. This control process ensured that everybody is working on the latest and approved design and engineering information. Site engineers do not periodically update the hard-copy 2D drawing that they supervise the installation on site with. It is very easy for them to use the old revision of a hard-copy drawing since there is no sign that

a drawing is expired. On the other hand, this possibility is minimized with BIM enabled improved information management on site. Users both receive immediate notifications after each upload to project library in Field application and they can also search through a specific drawing to follow latest revision. These documents can be both viewed and also notes can be taken with mark-up tool.

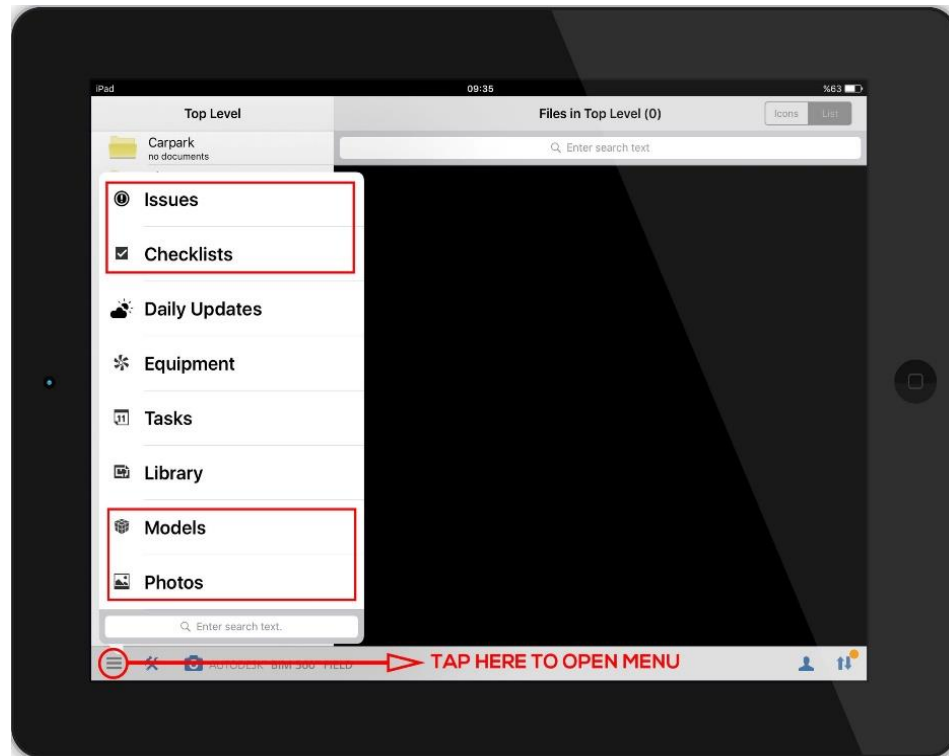


Figure 3.17 : Project documents are accessible on tablets.

Apart from 2D drawings, other project documents such as MAF and MS are also stored in cloud which is accessible with Field application on-site. Without needing any print-outs all the necessary information needed on site can easily be found in the tablets and production is lead in the most accurate way. Site engineers can reach the current project documentation on a cloud platform which makes a significant contribution to improved engineering quality.

Observed advantages of information management enabled by mobile BIM on site have been listed below.

- Any information to be used to manage site works were made available with the mobile devices can be carried to anywhere.

- Production on site has followed these most updated and accurate approved project documentation which ensured that desired quality has been applied on-site.
- Project information did not stay on the papers with old revisions.

Quality control and assurance records enabled through mobile BIM

The mobile BIM workflow as shown in figure 3.18 ensures that all of the parties are coordinated during their design phase with clash detection process therefore generated construction documents (shop drawings, BIM model, etc.) are already improved in terms of any issues on site to avoid any possible rework on site. These documents does not only stay in the office, also transferred to site seamlessly with cloud-based mobile applications to site personnel's tablets for BIM complied installation management in the construction field.

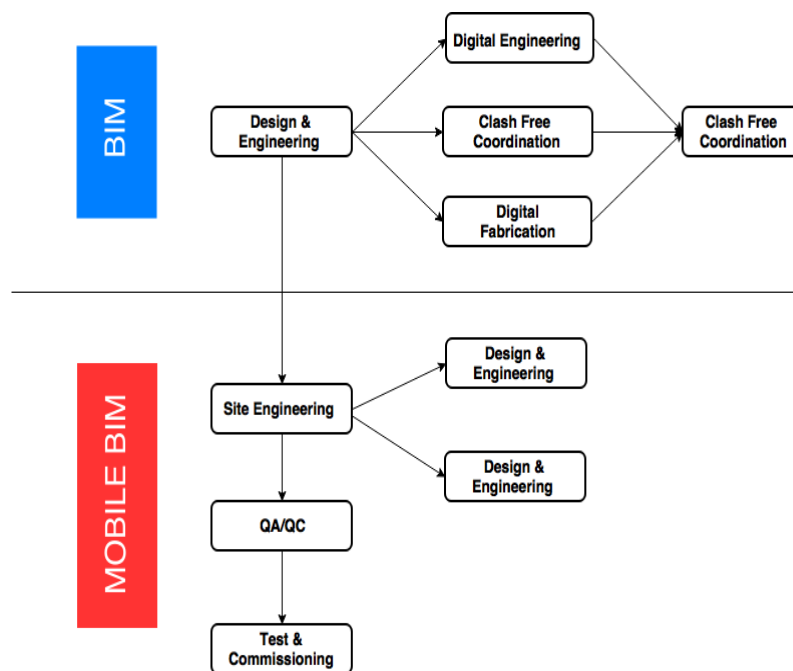


Figure 3.18 : Mobile BIM workflow.

While storing QA/QC records digitally, any high-level reporting, which can be generated periodically or spontaneously in various forms to show progress, completeness, trend or details of the defects, is utilized and distributed to the related departments. This draw a clear picture for spotting errors and made possible to take preventative actions to facilitate zero-error production. Since everyday site installation

practices are handled and improved with BIM practices, error reduction is made possible.

While setting up the mobile quality system, traditional workflows and checklist documentations have been examined and optimized to form an effective process by IGA BIM team. Improved site inspection workflow enabled by mobile BIM is shown in figure 3.19 that is put on use by IGA to define NFI process.

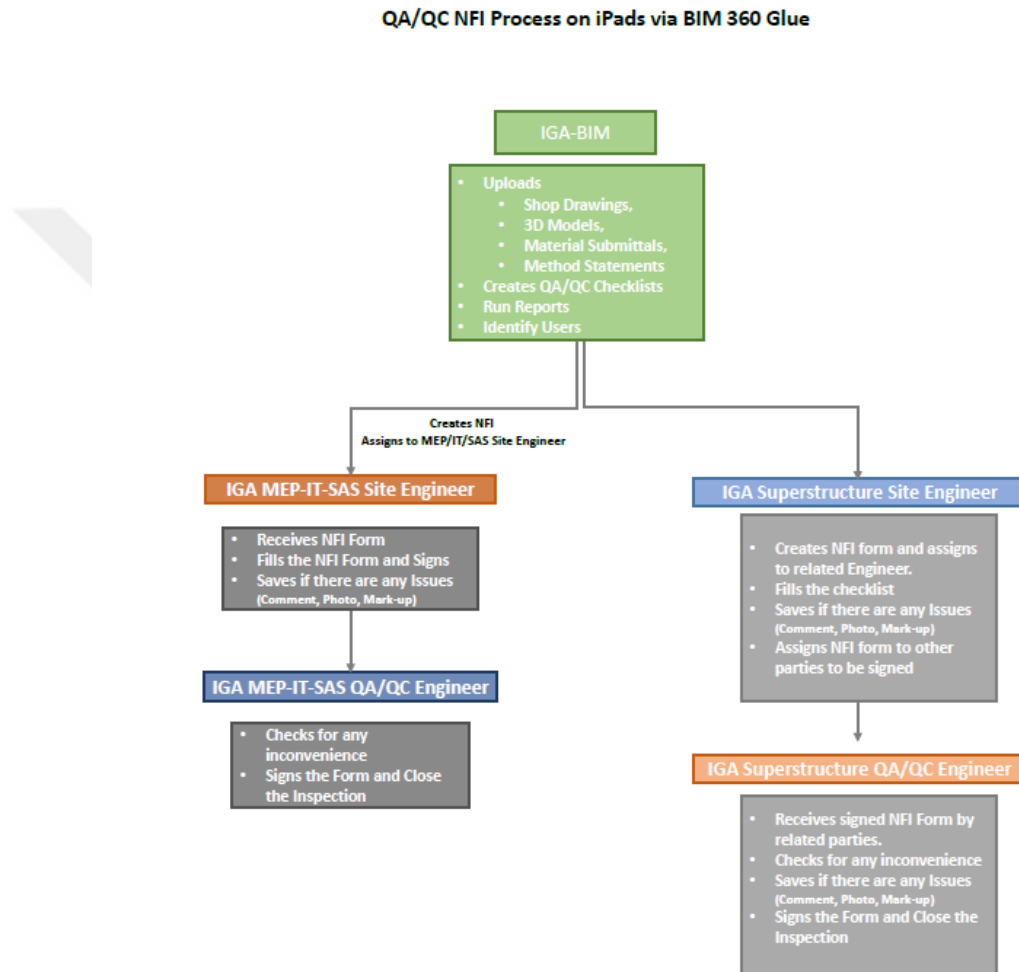


Figure 3.19 : Improved QA/QC workflow enabled by mobile BIM.

According to improved workflow, first step is to identify all of the QA/QC checklists to be used during inspections in the BIM 360 Field application either manually or using Excel spread sheets. After creation of the checklists on the system, a template is also saved for future assignments for each task type for easy reference of tablet users.

Steps of the inspection workflow is standardized in detailed and users are trained in the same manner to avoid variations during the practical implementation. This standard procedure created and put on use is explained in detailed below:

- Subcontractor notifies the contractor in daily basis when the site installation completed for each zone.
- Contractor QA/QC Team schedules inspection program according to subcontractor notification and sends the information (zone, discipline, date& time) to BIM Management team.
- BIM Management team create tasks daily according to the schedule provided by QA/QC team, attach related shop drawing, fill the checklist form with subcontractor, assignee and finally assigns the tasks to relevant site engineer and notifies everybody with email.
- Site engineer receives the email with Outlook app, synchronizes his tablet to receive his tasks and fills the inspection form offline on site.
- If there are any nonconformities in some of the items, the system creates “issue” and assigns to the relevant subcontractor and attaches the photo if site engineers takes any, or attaches a document which are already uploaded to Field application or mark the model.
- Site engineer assigns the completed task to QA/QC engineer.
- QA/QC engineer checks the inspection form and gives an overall rate and either closes or leaves it open.

After completing this inspection workflow, since everything is recorded in the cloud system spontaneously; corrective actions are taken immediately. Corrective action procedure is also standardized as follows:

- Open items identified by site engineers are shown in subcontractor’s web-based dashboard with the related attachment. After subcontractor complete the rejected work, they change the item status as “work completed”.
- Site engineer who created the issue is automatically informed, he confirms the work is completed correctly and changes the item status as approved.
- QA/QC engineer is automatically informed, he confirms and closes the checklist.

Advantages observed with implementation of Quality Control and Assurance Management enabled by mobile BIM has been listed below:

- Collaboration of both people and parties has been achieved in digital platforms. This has eased the communication and provided quick and effective resolutions on site.
- With the improved workflow of inspections, time spend on this process has been highly minimized.
- This system implementation made possible to transfer all of the data stored during construction to the next processes.
- No time has been spent on paperwork which has no effect on project delivery.
- Any non-conformance trends have been detected and necessary actions are taken to address these issues all together before creating any major impacts in terms of delay, rework and quality.

Resource management enabled through mobile BIM

While bringing BIM to construction site to maximize its efficiency, there was also a need aroused to supervise all these tasks performed on site. BIM site team is formed to track the project progress and resources. By using mobile BIM applications on tablet, the engineers are able to record any resource problems which may be concluded with delays with respect to construction schedule. These include resources like crew, material and site logistic issues. If the engineers detect a resource issue, they create an automatic issue from their tablets by attaching a photo, the main cause, relevant party, related project zone information and the description of the problem. This could be lack of crew, wrong material delivery or any issues related with site logistics. The issues saved by the site engineers are reported to technical offices in weekly basis to take necessary decisions before any major delay occurs. Subcontractors are also identified in the mobile BIM applications as both company and user, therefore they can also access to the resource issues assigned to them and manage their works on site accordingly.

Users of the system could access to the specialized dashboard which is automatically updated with the each update done in the system. This provided transparency through the project with easy access and clear picture of the ongoing issues regarding resources.

Observed advantages of resource management enabled by mobile BIM have been listed below.

- Detailed reporting of resource problems directly from site has been achieved.
- Continuous access to the latest resource issues from all of the relevant parties is enabled. This made technical office to determine the problems regarding resources quickly and address to the relevant party for resolution.
- Efforts performed to gather various forms of data from different departments to detect the problems are eliminated.

Performance management enabled through mobile BIM

BIM site engineers do not assigned to only track the resources on site, but also monitor the performance of the project. Similar to resource management workflow, site engineers recorded progress issues by attaching the relevant information from their tablets with BIM 360 Field application. There are both detailed reports to be discussed in the weekly meetings and summary reports to be presented in executive level are generated to monitor progress and related issues. The most important outcome of this monitor reporting is observed as having access to real-time information automatically updated information from construction site directly. Subcontractors are allowed to see their progress in terms of completed inspections, observations and also progress issues.

BIM site team is able to record any as-built information digitally when there is any variation from the BIM model. Since these records stored with asset, zone, site photo, related company information, they are accessible to anyone in the project and ready to report with required filters.

In order to control critical site installations precisely, BIM360 layout application which is compatible with the robotic total stations and BIM models is used by BIM site team as shown in Figure 3.20. Site control points which BIM Management team require measurement are created in Revit models and shared with Glue application to be measured via Layout application in terms of deviation.

Advantages observed with the performance management implementation on site have been listed below:

- Executive level has been informed with the reports generated through BIM system which eliminates them to wander with unstructured, detailed and out-

of-date reports. Management decisions has been taken by analyzing BIM based reports.

- Spontaneous reporting was possible by including any required information.
- There was no effort performed to gather various forms of data different departments are holding to create reports to monitor the project.
- Contractor had immediate access to subcontractor`s performance reports which gives a way to effectively manage them to deliver the project in timely manner.
- Subcontractors are able to their progress in terms of completed tasks, not-approved works and approved shop drawings. In this way, they take corrective actions directly based on this system.
- Various subcontractors performing the work on-site had access to the latest project information to be followed.



Figure 3.20 : Controlling site installation with BIM360 Layout application.

3.4 Project Participants

Project participants integrated with BIM include design firms, construction subcontractors and BIM production team. Whilst most of these firms are Turkey-based local companies there are also companies from India, United Kingdom and Holland have been integrated with BIM in this project.

Data flow starting with design information and concluding with coordinated BIM models and compatible subcontractor drawings has been shown in figure 3.22. Design teams submit 2D/3D design information to BIM management team. BIM management team transfers it to production team for modelling and integration, production team submits 3D models. After coordination process as explained in section 3.3, coordinated BIM models are circulated to subcontractors and design teams. Subcontractors produce the construction drawings according to the coordinated models and submit to both BIM management and IGA design management team for related discipline. BIM management team checks the conformity of the drawings according to BIM model. If the drawings are approved by both teams they are shared with site via tablets as well as coordinated models. If the drawings are rejected they are sent back to subcontractor for relevant corrections.

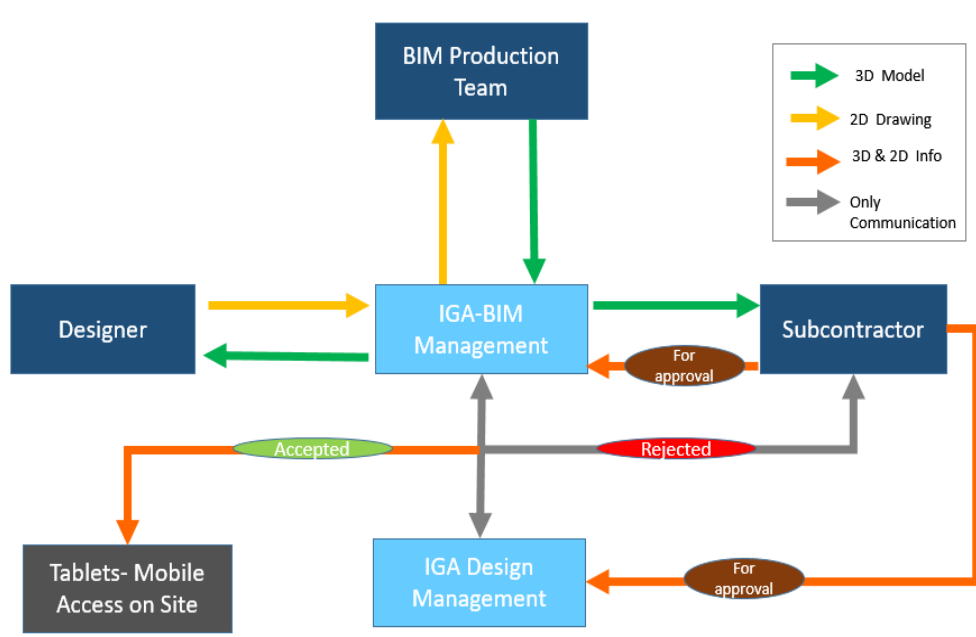


Figure 3.21 : Data flow in between project participants

3.4.1 BIM Production Team

As shown in figure 3.6, IGA BIM management team transferred the design data in forms of 2D/3D to outsourced BIM production team in India for 3D modelling and integration. There have been follow-up meetings held in between BIM management team and BIM production team daily to track the progress and deliverables. This outsourced team has been selected due to their previous airport and infrastructure related BIM modelling experience. They have never worked at such scale as Istanbul

New Airport project, but they have achieved similar type of projects in the past. IGA BIM production team obliged production team to follow BIM execution plan where each deliverables standard have been specified. Compliance of the initial submittals according to BIM execution plan have been examined by management team in detail. Any problems identified has been reported to the team in India for as a general correction notice throughout the project.

There has been some issues occurred regarding the deliverables requested by BIM management team in terms of wrong or late delivery through the project process. BIM management team has experienced these issues when the work requested was not clearly and in detailed explained to the production team. Since the staff of the production team is mostly focused on absolute modelling and does not have same concerns as the management team, the work given to them should be described very clearly as well as the final in all its assets. Because of continuous communications with the production team these type of misunderstandings have been largely avoided during the project.

Since the production team is very open to technological improvements their adoption or use of new tools integrated for mobile access was not a challenging process. For each tool they have been given a basic training on how to use and then started the process straightforward.

3.4.2 Designers

Designer teams were responsible to submit the design information in forms of 2D/3D to BIM management team. For architectural design there were there local companies and each of them worked for different assets of the project: Terminal building, piers and car park. Terminal architect was doing the design in Autodesk Revit and submitting to BIM management team their design as 3D. Pier and car park architects were working on 2D. For structural design there were local companies working on steel and concrete structures of the project. Steel designers were doing their design in Tekla and submitting their design information in .ifc format to be integrated into Revit model. Concrete designers were working on 2D design tools. For mechanical, electrical and IT design again there were local firms working on 2D design tools. Baggage handling system designer was Holland based firm working on their 3D in-house design tool and submitting in AutoCAD 3D format to management team to incorporate into Revit

model. For runway and drainage design UK based designer team was working on Civil 3D and submitting their design as AutoCAD.

The main perception difference in between local and foreign designers was to motivation to innovation accompanied with BIM integration. Whilst foreign BHS and runway designers were already using 3D tools and familiar with the concept of BIM, many of the local firms did not work in BIM workflow before and they tried to stand back from BIM adoption for a while. This perception of them have been changed during the weekly workshops by presenting the problems in their design can be only detected in 3D environment. They had opportunity to monitor the status of their design as integrated with adjacent services. Experiencing these opportunities with BIM gave these local companies confidence to adopt to BIM in time.

3.4.3 Construction Subcontractors

Construction subcontractors were all local firms and none of them used BIM for their previous projects apart from BHS subcontractor. BHS designer was also installing BHS services on site. They have used their 3D model to manufacture BHS components to be installed on site. They have submitted their model to BIM management team for interdisciplinary coordination in this way their final model was coordinated and ready to install on site. Because of this integrated workflow, they were the most successful subcontractor in terms of timely completion even though the complexity of their design.

Rest of the subcontractors received the coordinated Revit models from BIM management team in order to complete their construction drawings. Even though they have directly export 2D sheets from the model, because of their lack of experience working in Revit they could only use Revit models as reference and complete their drawings manually. Even though the companies are interested in working with BIM, there are not many trained people in Turkey in the area of modelling. That is why the major modelling job was outsourced to India be

Once the subcontractors completed their drawings they submitted them to IGA for approval. Their drawings have been checked according to coordinated models and approval is given accordingly. In the beginning there were many inconsistencies found in the subcontractor drawings. Because they have been rejected very strictly and it affected their progress payments, subcontractors had to follow BIM models. In order

to use Revit models they have employed personnel who has understanding and ability to use 3D models.





4. SURVEY STUDY OF IGA

4.1 Introduction

This section presents the results of a survey conducted within IGA site engineers. The survey focuses on 5 use cases of the mobile BIM implementation and also key issues needs to be developed. It is carried out to review the perspective of mobile BIM implementation in the project and to gather information about weak and strong functions together with barriers and challenges. The result of this study illustrates how respondents approach mobile BIM implementation on site. The results identified key issues needs to be developed for BIM implementation on-site. In this survey the sampling frame was composed of professionals having different positions and roles within the company. Respondents were selected from site engineers who are actively involved in the mobile BIM system. Responses have been received from 51 engineers from 4 different departments.

4.2 Survey Design

In order to evaluate the perspective of site engineers on BIM use cases, a Likert-scale survey study has been conducted.

The aim of this questionnaire is to identify cultural and technical barriers, challenges, advantages and disadvantages as well as of implementing BIM at construction site.

Section 1 included information about the participant's occupation, professional role, department, age, overall and BIM experience.

Section 2 included 40 questions about various aspects of the mobile BIM implementation and these were grouped into the following subheadings:

- Design Management
- Information Management
- QA/QC
- Resource Management
- Performance Management

- Feedback on BIM Functions
- Further Improvement Suggestions

For each question, participants were asked to tick the box presents their assessment on scale 1 (strongly disagree) to 5 (strongly agree).

A copy of the questionnaire is included in Appendix B. Each respondent has taken active role on the themes asked in the survey, therefore they have replied all of the questions. The results of the evaluation, comments and recommendations from the evaluators are presented in the following section.

4.3 Survey Respondent Profile

In the first section of the survey participant's occupation, professional role, department, age, overall and BIM experience has been asked. According to overall population of 51; percentages in terms of age, experience and departments have been presented in the figures below. (Figure 4.1, 4.2, 4.3) Engineers from several occupations and roles have been participated to the survey. Civil, geomatics, electrical, mechanical, electric-electronic engineers and architects have been joined to the survey. Respondents included site engineers, site chiefs and also site managers from several departments and working at IGA- main contractor. Average age of the respondents have been calculated as 30 years with 1.5 years of BIM experience out of overall 7 years of experience. It has been found out that IGA project is the first BIM experience for everyone who joined to the survey, so that BIM experience has reached to maximum 3 years which is the duration of the project so far. (Table 4.1) Respondents were selected from 4 departments within IGA company; MEP-IT, QA-QC, Superstructure and BIM.

Table 4.1 : Participant's age, experience and BIM experience information.

	Minimum	Maximum	Average
Age	22 years	48 years	30 years
Experience	9 months	31 years	7 years
BIM Experience	9 months	3 years	1.5 years

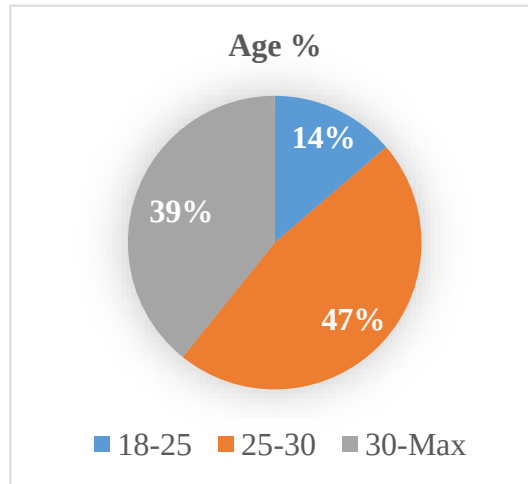


Figure 4.1 : Age distribution of respondents.

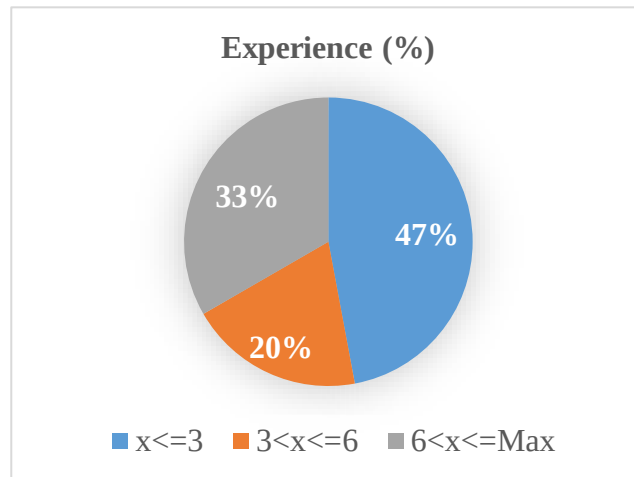


Figure 4.2 : Experience distribution of respondents.

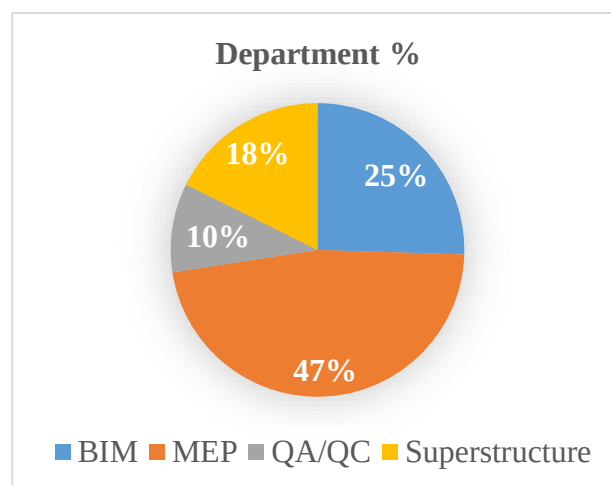


Figure 4.3 : Department distribution of respondents.

4.4 Results

A detailed analysis of the various sections of the questionnaire is presented below. It should be noted that the statements of the questions were designed as positive in terms of BIM achievements, therefore during the evaluation of the result 4 (agree) and 5 (strongly agree) ratings will be considered as positive responses. The responses can be found in Appendix C.

4.4.1 Design management

82% of the respondents strongly agree/agree on the design management questions. (Table 4.2). 10% of the respondents neither agree nor disagree and 8% of the respondents strongly disagree/disagree on the design management questions.

Table 4.2 : Responses on design management questions.

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
A	Design Management (Average %)	1	7	10	37	45
A.1	Access to interdisciplinary BIM model eased the production.	0	1	2	18	30
A.2	It is easy to navigate the BIM model in the tablet.	0	2	6	16	27
A.3	Revisions on the design can be followed from BIM model in the tablet.	2	7	7	23	12

Respondents agree the most first statement of design management “Access to interdisciplinary BIM model on site eased the production.” with 94% positive response. 18% of the respondents does not agree on the third statement implies design revisions can be followed from BIM model (Figure 4.4).

General summary of the responses to DM section of the questionnaire is listed below:

- There is a general agreement that mobile access to interdisciplinary BIM model contributes to production on site.
- Respondents considers navigating the 3D BIM model on tablet is easy.
- Respondents agree that design revisions can be followed from BIM model in the tablet. But 18% of the participants does not agree together with %14 neither agree nor disagree on that statement, this should not be ignored.

- There has been a connection discovered in between the responses on DM and the respondent's age. Older respondents tend to agree on DM statements less than others. (Figure 4.5)

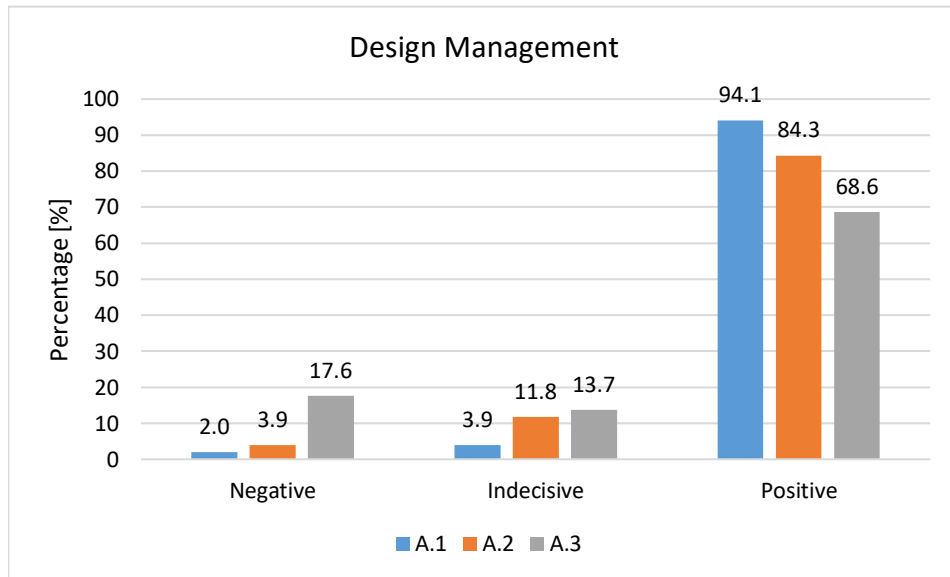


Figure 4.4 : DM question responses of overall population.

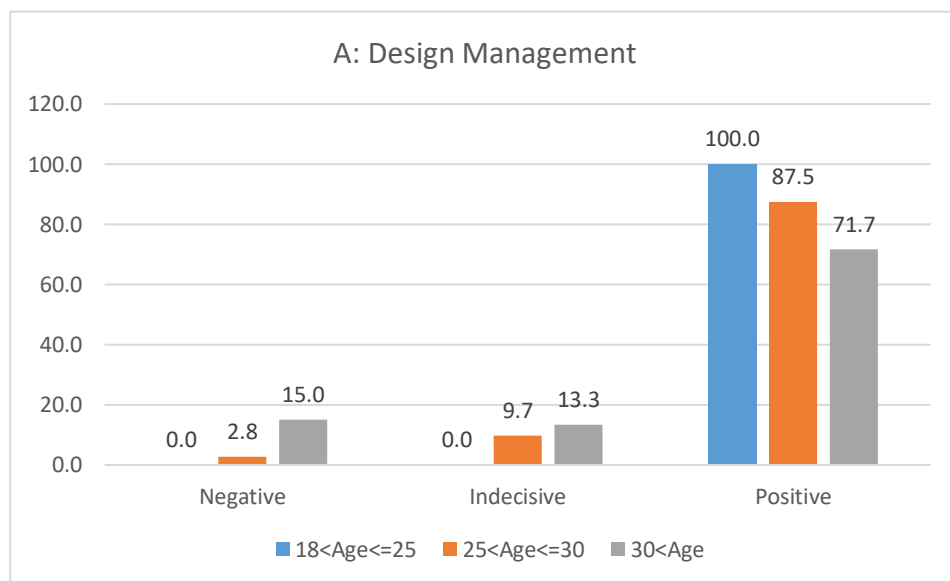


Figure 4.5 : DM question responses according to age categories.

- 25% of respondents who work in MEP department does not agree that design revisions can be followed from 3D model. This could be the cause of the fact that MEP design includes various different services together and it is more complex than other disciplines to view in the model from tablet. (Figure 4.6)

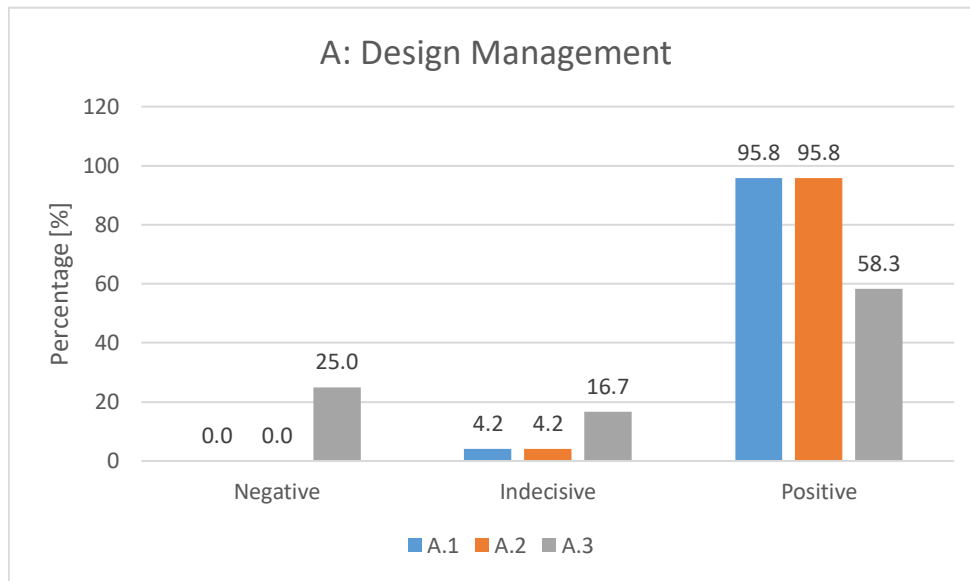


Figure 4.6 : DM questions responses of MEP department.

- QA/QC department diverges from the other departments in terms of their responses to DM statements. Even though 47% of QA/QC department stuff agree, there is 27% does not agree and also same percentage of not sure about the statements on DM. The reason for this situation could be interpreted, as QA/QC department engineers does not take a role during design realization on site. (Figure 4.7)

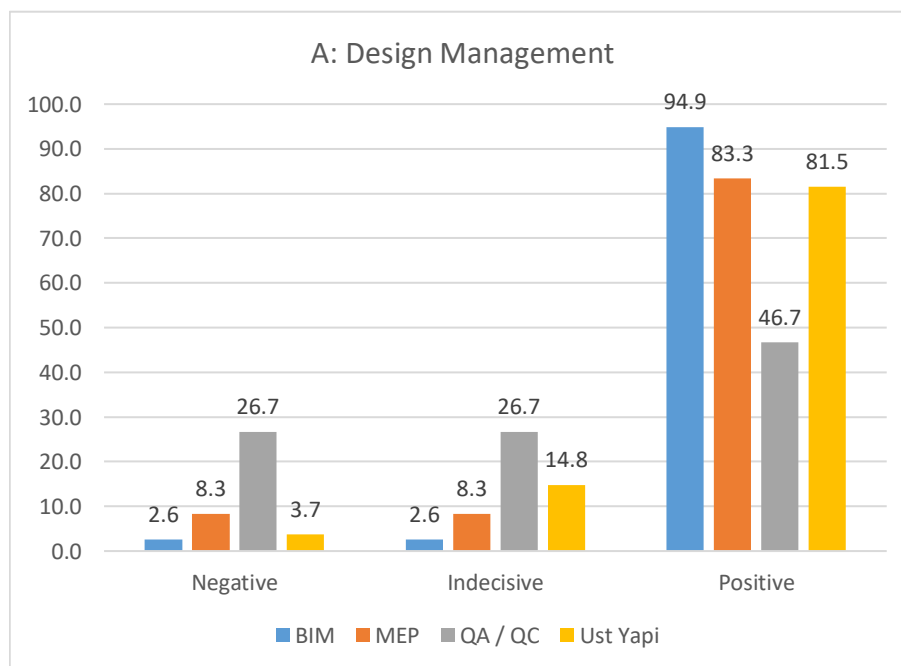


Figure 4.7 : DM question responses according to departments.

4.4.2 Information management

84% of the respondents strongly agree/agree on information management questions. (Table 4.2). 14% of the respondents neither agree nor disagree and 2% of the respondents strongly disagree/disagree on the design management questions. (Table 4.3)

24% of the respondents does not agree on the third statement implies design revisions can be followed from BIM model (Table 4.3).

Table 4.3 : Responses on information management questions.

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
B	Information Management (Average %)	1	1	14	44	39
B.4	I would prefer to use 2D shop drawings on the tablet to print-outs.	0	3	2	18	28
B.5	It was easy to follow the revisions from 2D drawings periodically updated in the tablets.	0	2	2	24	23
B.6	Being able to access to MAF documents from the tablets eased the document control process during inspections.	0	2	5	19	25
B.7	Being able to access to MAF documents from the tablets eased the material tracking process on site.	0	0	5	25	21
B.8	Being able to access to Method Statement documents from the tablet was beneficial for production follow-up.	1	0	12	24	14

General summary of the responses to IM section of the questionnaire is listed below:

- Accessing to 2D drawings from tablets are preferred to traditional way of print-outs.
- Participants agrees that design revisions can be followed from 2D drawings from the tablets.
- Accessing to MAF documents from tablets eased the document control process for inspections and material tracking.
- Accessing to MS documents from tablets found beneficial for production follow up from the majority. But 24% of the participants are indecisive about this statement. (Figure 4.8)

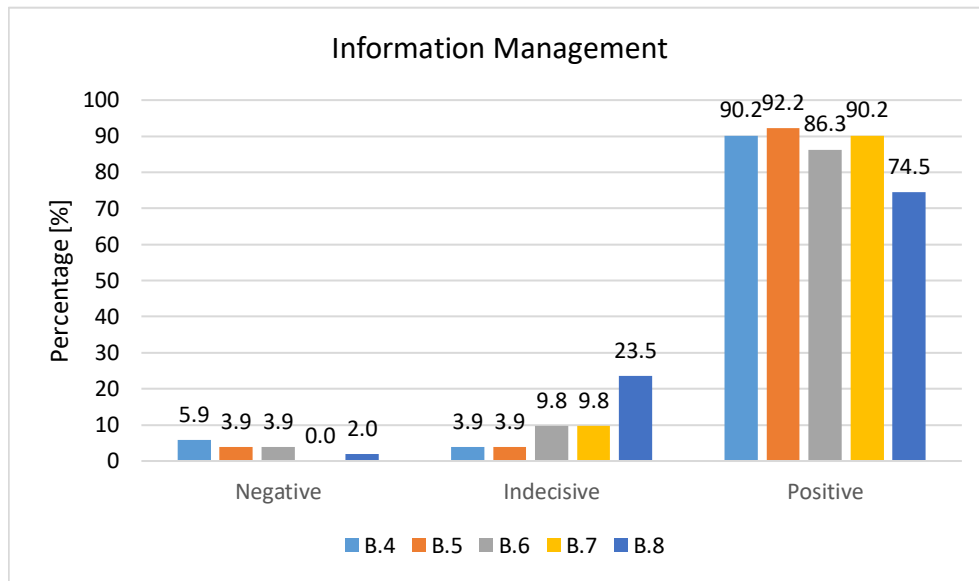


Figure 4.8 : IM question responses of overall population.

- QA/QC department agrees the most among the other departments to IM statements. MAF and MS documents are prepared and checked by them on-site. They are benefitted from digital access to these documents on-site. (Figure 4.9-10)

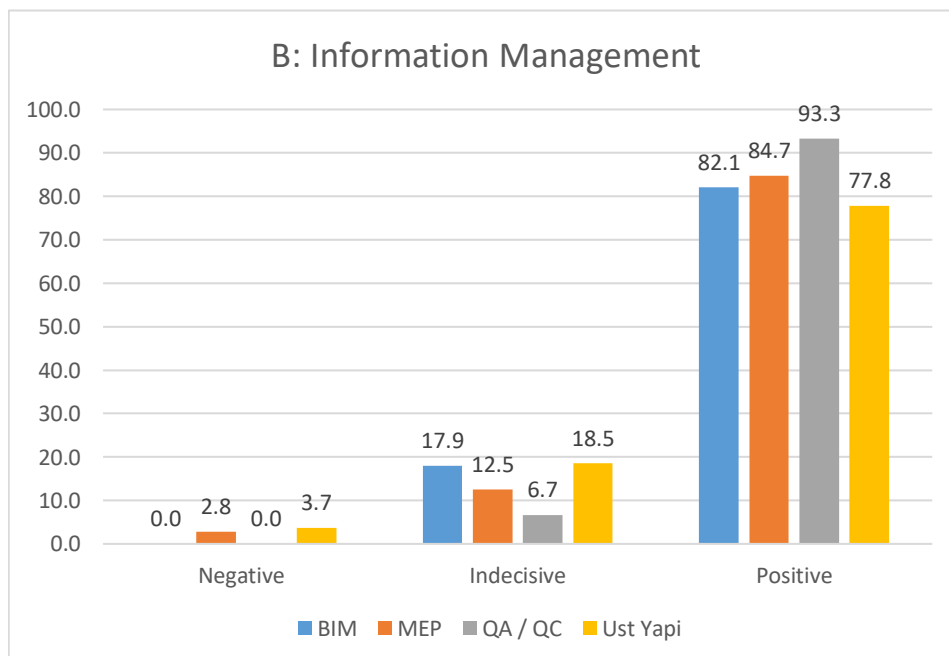


Figure 4.9 : IM question responses of according to departments.

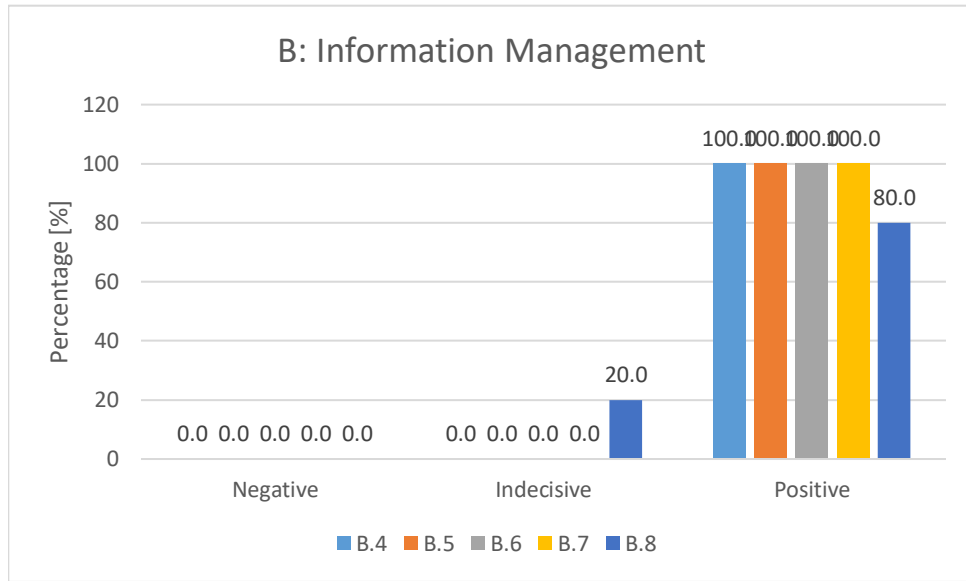


Figure 4.10 : IM question responses of QA/QC department.

4.4.3 Quality control and assurance

88% of the respondents strongly agree/agree on QA/QC questions. (Table 4.4). 12% of the respondents neither agree nor disagree and none of the participants strongly disagree/disagree on the design management questions. (Table 4.4)

Table 4.4 : Responses on QA/QC questions.

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
C	Quality Control and Assurance (Average %)	0	0	12	44	43
C.9	Filling the inspections forms on tablet provided time-saving according to paperwork.	0	0	7	18	26
C.10	Missing information during the inspections are avoided since the forms are filled through tablets.	0	0	8	25	18
C.11	Filling the inspections forms on tablet regulated the follow-up procedure of the issues saved during inspection.	0	0	4	22	25
C.12	Saving of the issues as observations, regarding the problems about production, ensured that the responsible subcontractor to fix the issue faster.	0	0	7	21	23

General summary of responses to QA/QC section of the questionnaire is listed below:

- Participants consider that during inspections using digital forms instead of paperwork is time-saving. (Figure 4.11)

- Filling forms digitally prevents any missing information during inspections.
- Follow-up of issues detected during inspections are regulated with the use of mobile BIM.
- Subcontractors are solving the issues reported as observations directly from the site.

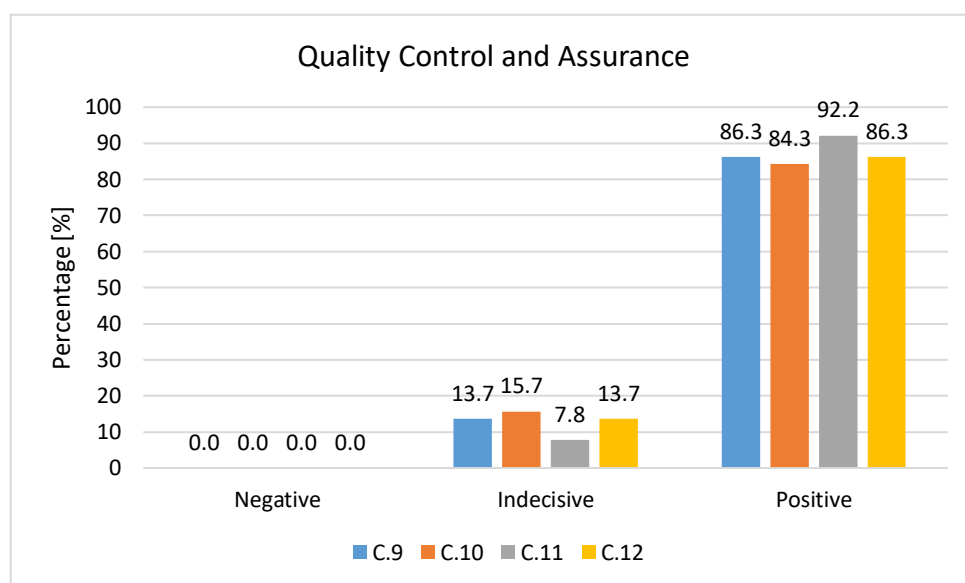


Figure 4.11 : QA/QC question responses of overall population.

4.4.4 Resource management

69% of the respondents strongly agree/agree on Resource Management questions. (Table 4.5). 22% of the respondents neither agree nor disagree and 8% strongly disagree/disagree on the design management questions. (Table 4.5)

Table 4.5 : Responses on QA/QC questions.

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
D	Resource Management (Average %)	5	4	22	37	32
D.13	Reporting any issues regarding crew resource with tablets in order to avoid any delays provided completion on-time.	3	2	18	16	12
D.14	Reporting the issues regarding material and logistics that are preventing production with tablets provided fast solutions by raising the issues.	4	4	10	18	15

General summary of the responses to RM section of the questionnaire is listed below:

- Generation reports for crew tracking from the tablets are mainly considered as contributing to completion on-time. But slightly many respondents (35%) are indecisive and some of them (10%) even does not agree with it.
- Generation reports for material and logistics from the tablets are considered as resolving the related faster. But there are also 20% of the respondents are indecisive and 16% of them does not agree with it.
- There is a connection in between respondent's age and perspective on the resource management. Young respondents think more positively than older respondents. (Figure 4.12)

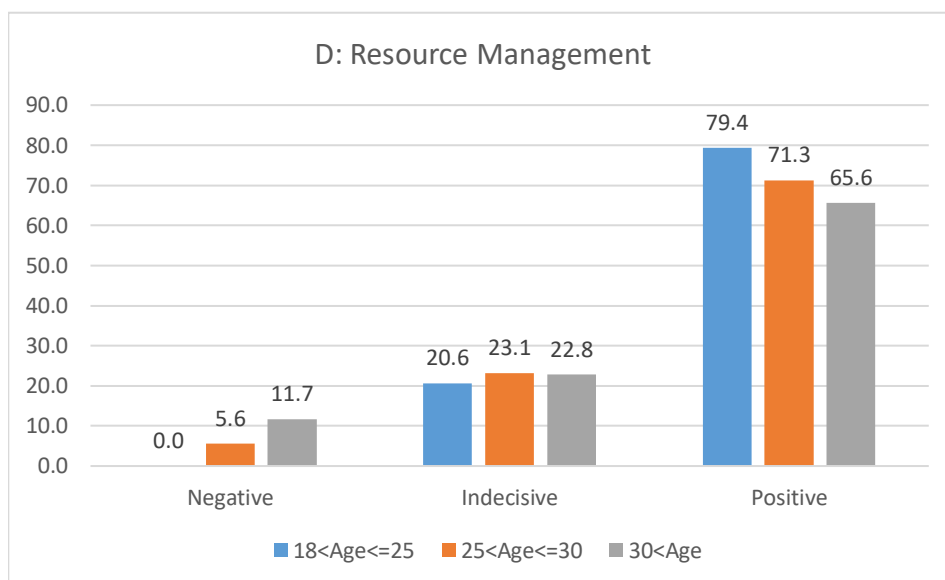


Figure 4.12 : RM question responses according to age.

- Superstructure department agrees the most among the other departments to RM statements.
- QA/QC department is very indecisive for the RM statements for both of the questions.

4.4.5 Performance management

78% of the respondents strongly agree/agree on performance management questions. (Table 4.6). 15% of the respondents neither agree nor disagree and 7% strongly disagree/disagree on the design management questions. (Table 4.6)

Table 4.6 : PM question responses of overall population.

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
E	Performance Management (Average %)	4	3	15	41	37
E.15	Performance tracking of subcontractors got easier with reports exported from BIM360 system.	0	3	4	20	24
E.16	Production follow-up got easier with construction schedule tracking on-site and reporting of any problems spontaneously.	4	0	7	24	16

General summary of the responses to PM section of the questionnaire is listed below:

- Use of BIM system eased the performance tracking of subcontractors.
- Use of BIM system helped to follow construction schedule and reporting of any problems about any delays.
- There is a connection in between respondent's age and perspective on performance management. Young respondents think more positively than older respondents. (Figure 4.13)

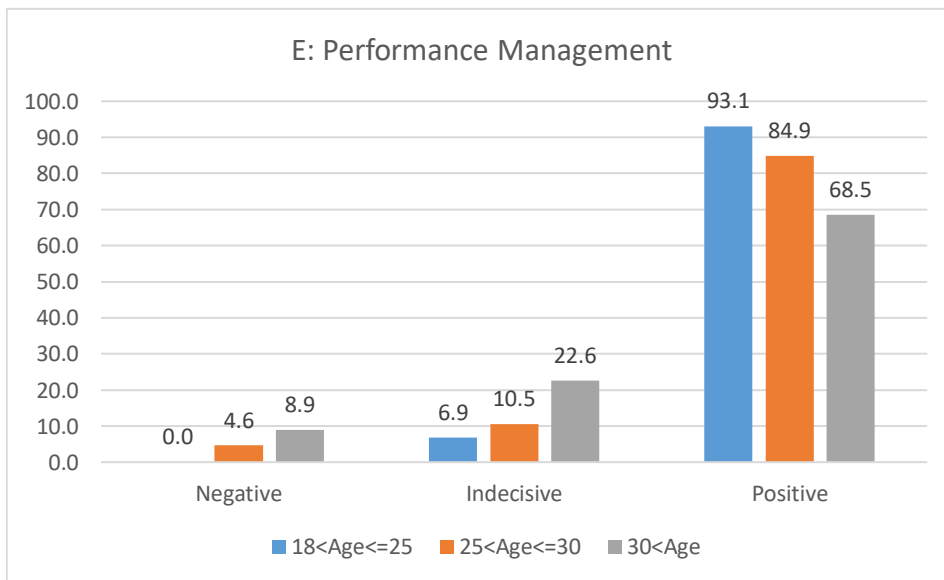


Figure 4.13 : PM question responses according to age.

- BIM department agrees the most among the other departments to PM statements. They were directly responsible of reporting performance issues from tablets. (Figure 4.13)

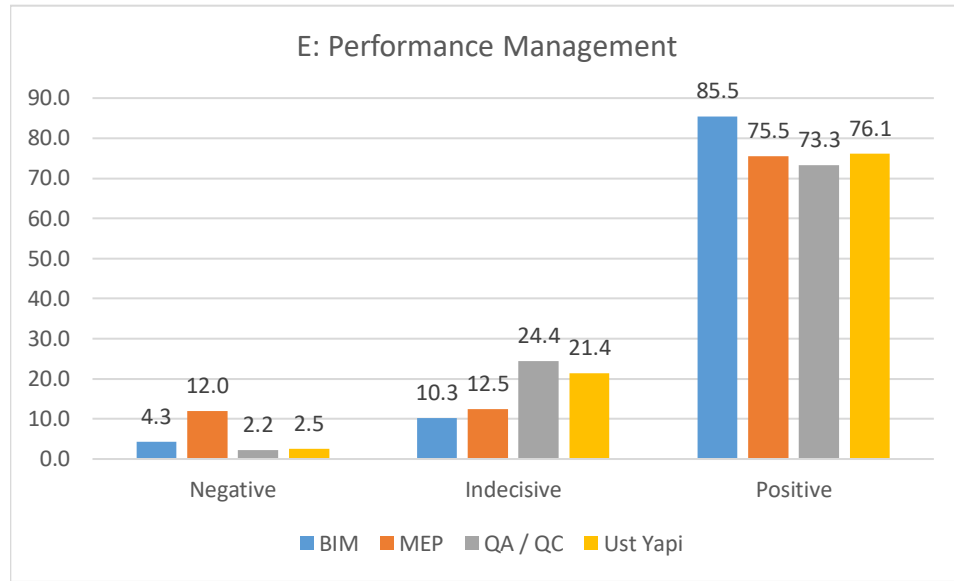


Figure 4.14 : PM question responses according to department.

4.4.6 General questions on BIM use

Responses on the general questions on BIM use are shown in the table 4.7.

The least agreed statements (more than 15% disagreement) on this section are:

- Design revision update frequency on the tablets was necessary. (24% of disagreement)
- It did not create any problem that the BIM model did not include all of the elements which are in place on site such as hangers, formwork, etc. (24% of disagreement)
- Wi-Fi provided on site did not affect the works requires tablet use. (16% of disagreement)

The most agreed statements (more than 90% agreement) on this section are:

- I would like to use BIM in the next project. (96% of agreement)
- Implementation of BIM in the project improved the QA/QC processes. (94% of agreement)
- Implementation of BIM in the project and collected data throughout the project will be significant for project's operations phase. (92% of agreement)
- Implementation of BIM in the project increased the constructability of the design. (92% of agreement)

- Using tablets instead of drawings or forms as printed papers was advantageous in bad weather conditions. (92% of agreement)
- Implementation of BIM in the project decreased rework. (90% of agreement)
- Implementation of BIM in the project increased the efficiency. (90% of agreement)

Table 4.7 : General question responses on BIM functions

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
F	Feedback on BIM functions (Average %)	0	1	10	35	54
F.17	The size of the tablet screen is enough to work on site.	1	3	5	25	17
F.18	Wi-Fi provided on site did not affect the works requires tablet use negatively.	2	6	8	25	10
F.19	It is easy to understand and navigate 3D model.	1	1	6	21	22
F.20	It is easy to explain work to be performed from 3D model to foremen and workers.	0	0	6	20	25
F.21	It is easy to find the location within the model.	1	2	3	24	21
F.22	It did not create any problem that the BIM model did not include all of the elements which are in place on site such as hangers, formwork, etc.	6	6	10	19	10
F.23	The period of getting revisions made in the design on the tablets was necessary.	5	5	13	17	11
F.24	The trainings given for the use of mobile BIM was adequate.	0	1	12	20	18
F.25	Utilization of BIM increased the efficiency of the work on site.	0	1	6	24	20
F.26	Utilization of BIM shortened the work completion duration by compressing the project schedule.	0	0	9	17	25
F.27	Using tablets instead of drawings or forms as printed papers was advantageous in bad weather conditions.	0	0	4	16	31
F.28	Implementation of BIM in the project mitigated the risks.	1	3	8	12	27
F.29	Implementation of BIM in the project increased the constructability of the design.	0	0	4	18	29
F.30	Implementation of BIM in the project increased the quality of shop drawings.	1	1	5	18	26
F.31	Implementation of BIM in the project improved the QA/QC processes.	1	1	1	17	31

Table 4.7 (continued): General question responses on BIM functions

F.32	Implementation of BIM in the project decreased number of RFIs.	0	1	17	14	19
F.33	Implementation of BIM in the project decreased number of change orders.	1	0	11	27	12
F.34	Implementation of BIM in the project increased the efficiency.	0	1	4	25	21
F.35	Implementation of BIM in the project decreased the unplanned changes.	0	1	6	25	19
F.36	Implementation of BIM in the project decreased the number of activities which do not proceed according to the project baseline.	1	1	9	22	18
F.37	Implementation of BIM in the project decreased rework.	0	1	4	25	21
F.38	Implementation of BIM in the project decreased the cost overruns.	0	1	10	19	21
F.39	Implementation of BIM in the project and collected data throughout the project will be significant for project's operations phase.	0	1	3	23	24
F.40	I would like to use BIM in the next project.	0	0	2	11	38

4.4.7 Further improvement suggestions

In this section respondents has been asked if they agree with the statement “I would like to use BIM in the next project”, what they would like to be improved from the options given. The options included the statements about BIM software, material tracking, planning, trainings, design revisions update on tablets, as-built information and work safety.

The least agreed statements (more than 20% disagreement) on this section are:

- Software programs used in the project should not be changed. (22% disagreement)
- Structure of the trainings should not be changed. (29% disagreement)
- The most agreed statements (more than 80% agreement) on this section are:
- As-built information on-site should be updated in BIM model. (88% agreement)
- Project baseline should be tracked from the tablets. (80% agreement)



5. INTERVIEW STUDY OF IGA

5.1 Introduction

This section presents the results of an interview conducted within IGA project from IGA's site and managerial staff and also subcontractor. The interviews were used to get an insight in how BIM is used in the construction project on site and to get answers on the research questions. The result of this study illustrates how individual respondents approach mobile BIM implementation on site. The results identified the key strategies that are developed for BIM implementation on-site.

The data was collected through twelve semi-structured interviews with the personnel aiming to gain an understanding of the case who were actively involved. Key actors who are knowledgeable about BIM implementation have been selected and interviewed. The interviews are conducted in June 2018, when the construction works were almost complete and test & commissioning process was ongoing.

In this section findings of a series of interviews conducted with key players in the project is presented in order to illustrate how they approached the innovative process of BIM implementation.

5.2 Interview Design

The data that is used consists of semi-structured and open-ended interviews to get a good representation of different actors and their different views on the subject. The persons being interviewed were chosen because of their interest and knowledge of the subject.

The interviews followed a schedule motive to innovate, innovation process, main BIM functions, barriers/ challenges, advantages/ disadvantages, grounds for successful adoption, future developments and lessons learned; but participants were allowed freedom to discuss their experiences and thoughts about BIM in their own terms.

In order to analyze outcomes of construction innovation process performed in this project, following questions were addressed during the interviews:

1. Why it was needed to innovate in this project?
2. What are the BIM systems used in the project?
3. Which roads have been followed to adopt the staff will be using BIM at site?
4. How the innovation process was managed, what are the processes?
5. What has been changed for traditional procedures with the new system?
6. Which strategies are applied for effective usage of BIM functions?
7. What are the main functions of BIM application used on site?
8. What is the process of subcontractor involvement to the system?
9. What are the main cultural and technical barriers/challenges raised during implementation?
10. What are the main disadvantages and advantages of the applied system?
11. What are the main reasons that the BIM system was adopted in this project although it is not widely adopted by the other projects?
12. What is the effect of position of BIM department in the project and organization of company to BIM system implementation at site?
13. What are the strategic or technical improvements you suggest by considering experiences and problems faced in this project?
14. What are the main lessons learned while considering the implementation in this project?

Managerial questions regarding innovation adoption (questions 3, 4, 6, 8) were only asked to site BIM engineers and BIM coordinator because only they were responsible for the implementation process within interviewees.

5.3 Respondent Profile

In this survey the sampling frame was composed of professionals having different positions and roles within the project. Respondents were selected from site engineers who are actively involved in the mobile BIM system. Semi-structured interviews have been conducted with 12 engineers their occupation, position and company can be followed from Table 5.1.

Table 5.1 : Interviewee profile.

No.	Occupation	Position	Company
1	Civil Engineer	BIM Director	Main Contractor- IGA
2	Civil Engineer	Site BIM Engineer	Main Contractor- IGA
3	Civil Engineer	Site BIM Engineer	Main Contractor- IGA
4	Civil Engineer	Site BIM Engineer	Main Contractor- IGA
5	Civil Engineer	Site BIM Engineer	Main Contractor- IGA
6	Geomatics Engineer	Site BIM Engineer	Main Contractor- IGA
7	Geomatics Engineer	Site BIM Engineer	Main Contractor- IGA
8	Electrical Engineer	MEP Site Engineer	Main Contractor- IGA
9	Electrical Engineer	MEP Site Engineer	Main Contractor- IGA
10	Mechanical Engineer	MEP Site Engineer	Main Contractor- IGA
11	Civil Engineer	Superstructure Engineer	Main Contractor- IGA
12	Electrical Engineer	Electrical Engineer	Electrical Subcontractor

5.4 Results

The results are explained under the categories constituted according the questions as motive to innovate, innovation process, adoption strategies, changes in processes, main functions of the system, main barriers and challenges, main advantage and disadvantages, grounds for successful adoption, improvement suggestions and lessons learned.

5.4.1 Motive to innovate

All of the interviewees state the challenge of completing the project in a very limited time. Since the project time is very limited, the common idea is that the activities should be done at once without needing any rework. Processes do not bring any value to the project should be minimized by using technological tools and devices. These processes include paperwork for registering any type of data, approval efforts and such.

Some of the interviewees mentioned about the challenge of working in such size of a construction and also long distance in between site and offices. Collecting the project documents such as construction drawings or QA/QC documentation in daily basis is found ineffective. It would also create delays or mistakes while reaching the most updated and accurate documentation through the project because design and

construction is progressing in parallel. Easy, fast and effective way to access to the documents was highly needed.

Because of the complexity of the project, it was predicted by interviewees that there will be many congested areas where different services built by various departments interact with each other. Good and effective communication between the project participant companies and departments can be achieved with a common environment that BIM provides. According to BIM workflow there are

5.4.2 Innovation process

Questions regarding innovation process was only asked to BIM Site Engineers and BIM Director because they were responsible of managing or conducting the innovation.

First of all along with the BIM engineers in the office, site BIM engineer team was set up in order to carry out the digital transformation from office to site. In the beginning five engineers were hired and assigned to the different locations of the construction area. They were responsible of implementing BIM functions on site which also includes adoption of site engineers to the new system.

The most important thing in the process stated as the daily follow-up of the activities on site by BIM site personnel. They made personal communication with site engineers and provided effective communication with them. During the interviews they have pointed out that, in the beginning only some of the site personnel was eager to use BIM on site. That is why BIM site engineers had to identify the key contacts in their area who has more interest and contacted with them first. The common initial idea of the site personnel was that they will continue to perform daily construction activities in the traditional way and use BIM as a control mechanism in case of a problem. It was the first BIM experience for the site engineers and therefore they were not aware of the capabilities of BIM. BIM site engineers had to change this perspective and make sure tablets are used actively during installation.

The innovation was not fully accepted in the first month of implementation and site teams did not actively used tablets for installation or for digital NFI registration. BIM site team had put pressure on the subcontractors and also on IGA site team as explained in the following sections. Site BIM engineers tracked the works on site in daily basis and gave notice to any personnel who is not using his mobile device. One of the

interviewees from BIM site team has directly stated that BIM implementation would not be successful if there was no pressure.

5.4.2.1 Adoption strategies for IGA site personnel

During the adoption phase of IGA site engineers to BIM system, their main argument was that they know how to do their job in the best way and site BIM engineers does not have enough experience to change the way how they do the job. They had emotional reaction when someone not from their department (site BIM engineers) intervene with their construction works.

While site BIM engineers were giving notice on the work performed on site as not being consistent with BIM coordination according to the model accessible at site via mobile devices, many heated debates occurred in between BIM team and IGA site teams. But when the coordinators of the relevant department were informed about the debates, the sub-staff has been informed to follow BIM very strictly. The significance of BIM was even secured and has been expressed by CEO of IGA to top managers of the departments many times.

When there were two or more services physically interacted on site, problems occurred in between parties which they failed to resolve very quickly. There are only verbal arguments and some inconsistent construction documentation could be used with if the traditional way was used. Therefore, they had to refer to BIM coordination model for accurate and quick solutions. Because BIM model constituted the most updated revision and the coordinated services, it was very straightforward for parties to identify what caused the problem on site and which action should be taken by whom in order to correct it. Once they have experienced this opportunity, they started to figure out the advantages of using BIM during construction.

Interviewees from site BIM team stated that whilst, at first only white collar personnel used BIM for almost six months, now not only white collar but also blue collar are aware of the benefits of the system. Eventually, the first thing to do was to agree on what is in the BIM model before starting the construction because they have experienced rework when they ignored BIM coordination model. Site personnel of IGA states that thanks to BIM they only perform construction once and they are sure how the end product will come out.

Both with the personal pressure from BIM site engineers to the site staff who is performing physical work on site and also managerial pressure from BIM coordinator to other department coordinators played an important role on the adoption process. The site personnel experienced the benefits of using BIM by themselves and this led a passage to transformation from traditional method to innovative way.

5.4.2.2 Adoption strategies for subcontractors

Enforcement on subcontractor has been managed with two ways. The first one was that in order to claim the monthly payment from IGA, subcontractors had to document digital inspections forms as approved. If the inspection forms were done on paper and not digitally through mobile devices at site, the payment has not been approved by IGA. This obliged subcontractors to perform inspections digitally in order to receive the payments entirely.

The second way was the control of constructed area by subcontractor according to coordinated BIM models. Site BIM engineers created observations from their tablets if there is any incompliance in the constructed area. When the subcontractor requested these type of area to be inspected, inspection form was not even registered because of the ongoing observation issue. Subcontractor had to resolve the observation issue first and then request for the inspection later. Since their monthly payments are based on approved inspections they had to follow BIM coordination and resolve any incompliances.

Despite of these two strict procedures, some of the subcontractors were failed to follow them in some areas. Once they face with the fact that they have to comply with BIM in order to receive the payments, they had to do some rework which cost them money and time. With these experiences they had to accept the BIM system and do their work accordingly.

5.4.3 Main functions of BIM on site

Main functions of BIM has been stated by the interviewees that as (1) instruction of construction with BIM model, (2) registration of inspection forms, (3) creating observation, (4) supervision reports for the problems on site, (5) progress monitoring, (6) registering punch lists, and (7) registration of test and commissioning reports.

In order construction to follow the coordinated BIM model, BIM site team has instructed the construction teams according to the BIM model and most updated construction drawings. Through BIM model all of the services in an intended construction area were coordinated in order to support staff who are physically performing construction on site.

If site BIM engineers discover any problem for construction work on-going on-site they create a supervision issue from their tablets in order to address the problem before the work is completed. It provided the problem to be resolved without causing any rework. It is one step before the observation. If the problem cannot be resolved before completing the work, it converts to observation type of issue.

Observation issue is registered when site BIM engineers find out a problem in a constructed area. Before moving on with inspection, observation issues had to be resolved by the responsible company. This enabled that minor inconsistencies to be addressed before causing major problems in time.

When the construction is completed with no supervision or observation issues, inspection forms have been registered with tablets by IGA site engineers. Any issues determined during inspection in terms of QA/QC have been recorded digitally and assigned directly to the related party to be resolved.

Issues regarding progress of the construction according to baseline have been detected and registered by site BIM engineers as progress monitoring. Since they have the completed view of the construction through BIM model, they were able to determine the work sequence and find out the problems.

Test and commissioning checklists are registered with tablets by IGA site engineers. Any issues determined during inspection in terms of QA/QC have been recorded digitally and assigned directly to the related party to be resolved. Completion percentage commissioning is directly updated in the BIM system and to be followed anytime from there.

Installation and completion of technical rooms are tracked with punch lists registered through tablets. Punch list for each room have been recorded by IGA QA/QC engineers. The deficiencies is being tracked by site BIM engineers. Completion percentage of the technical rooms is directly updated in the BIM system and to be followed anytime from there.

Supervisions, observations, inspections, progress monitoring, test& commissioning, punch lists are reported in weekly basis to IGA department coordinators. Department coordinators are informed about the problems and they distributed the work to their team to be resolved. Since these reports show the performance of any department transparently it creates a natural pressure on the departments for fast solution.

5.4.4 Main barriers and challenges

Main barrier for implementation has been indicated as cultural change by site BIM engineers. Even though it has been managed in this project it was not a straightforward process to be overcome.

According to most of the interviewees it is a challenge that BIM model and construction did not have the same level of detail. BIM models did not include some elements as hangers or some second fix electrical armatures in this project. Even though it did not create problem for coordination, there have some problems occurred on site in terms of constructability because of the site conditions and physical limitations. It was experienced as not enough space to worker to do installation or obstacles to do the connections or use some installation equipment. Even though the level of detail cannot be fully same for BIM model and construction, construction method or its further use in operations in terms of accessibility or maintenance could have been taken account during modelling.

During construction there had to be some important design changes applied caused by fast-track delivery strategy followed. Some of these design changes were related to the changes with the stakeholder agreements and their service area accordingly. In addition to this, since the construction has started before the design was fully completed. It was a challenge for both site engineers and BIM-site engineers to follow all of these changes and supervise the construction accordingly.

5.4.5 Main advantage and disadvantages

Project team had access to most updated and coordinated project information. With 2D construction drawings it would be very challenging to construct such a complex project. Many times construction drawings were too complicated to understand the installation. On the other hand, performing construction was quite straightforward with coordinated BIM models. The main advantage of using BIM models over drawings was listed as

being able to (1) take measurement from any reference point, (2) see the adjacent systems coordinated, (3) access to latest revision and (4) determine method of construction. These functions enabled to make a progress with construction without reworks.

Since consolidated BIM model is available before starting to construction in an area, the best method and sequence to carry out the construction has been decided by site team and workers are instructed accordingly.

The system provided a common digital environment to the parties to address and resolve the issues in a very transparent way. Fast access to project documentation when needed was provided with the use of BIM system.

Time consuming formal procedures to be followed for construction has been eliminated through supervision of BIM.

Subcontractor interviewee pointed out that the digital documentation can be reached any time eased their track on the project in terms of their performance. They did not spend time on repetitive paperwork.

Disadvantage for the site engineers was necessity to learn a new technology and get used to it. In addition to that site BIM engineers were dominantly intervened in site engineers' work. They had to compensate from their own traditional ways. In the end these efforts brought a lot of value to the end product. Without BIM system it would not be possible and they would face with very serious issues.

A disadvantage from the perspective of the site BIM engineers was that they had to spend very long time for training and they had to work on adopting site staff to the new system. They had to break the unwelcoming environment to their existence because of site personnel's resistance to change.

5.4.6 Grounds for successful adoption

According to interviewees, the most important reason for successful adoption was to have on-site BIM team works in separate areas in the project. This team was involved in the daily construction activities and follow the work on their area very close to address any issues before occurring. The successful communication of the on-site BIM team has affected the adoption in a very positive way. They were able to be part of the site team with their efforts and their contributions.

Leadership commitment on BIM had a big impact on the project teams to adopt the new system. The system was well supported by the CEO of the main contractor.

Numbers of tablets were large enough to be used on site effectively by all of the departments in different construction zones.

5.4.7 Development suggestions and lessons learned

As technical aspects, interviewees suggested that the application used in the tablet should also include sectioning function in the 3D model viewing. In the congested areas BIM model could be very complicated to understand without taking any sections. Some of the interviewees has been suggested that progress tracking function should be added to the mobile applications. They have mentioned that showing the progress status in the model in tablets will ease their job. Apart from these tablet capacity and also WI-FI speed have been mentioned for technical developments. But the WI-FI was only needed for synchronization of the tablet and data synchronized was be able to be used offline on-site.

It has been suggested that the significance of BIM should be determined by organization schema of the company to direct other departments from the beginning of the project. Authority to enforce other departments should be given to BIM department by the organization schema.

Early integration of design team with BIM tools was also suggested. If the design has been performed with BIM tools there would not be many design changes during construction and it would not affect the job on site.

BIM site team interviewees states that project staff has entirely understood the importance of using BIM after experiencing it. But they suggest with more examples of successful implementation, adoption process will not be necessary since everybody in the industry will be familiar with the system in time.

6. DISCUSSIONS

6.1 Case Study of IGA

During design and engineering phase in IGA Project BIM has provided interdisciplinary coordination via BIM model clash detection and daily workshops held in the BIM Room. With clash reporting clash free coordinated model has been established. Design process has been optimized and any rework resulting from poor coordination and communication has been eliminated. Since all of the relevant parties including subcontractors was involved in the process, 2D shop drawings produced for site installation purpose was also compatible with coordinated BIM model. Apart from design coordination, construction schedule was integrated with the BIM model to monitor progress and take necessary decisions to avoid any possible delays. BIM based quantity take-off has been performed periodically and shared with purchasing and contractor technical offices which are controlling subcontractor installation quantity and progress payments according to these installations. These efforts performed during design phase led a quick passage from design to construction.

In order to maximize BIM benefits, the efforts performed in the office extended to the construction site. With improved formal workflows enabled by technology and cumulative BIM efforts, increase in engineering quality, reducing unnecessary rework, savings in cost and project schedule have been aimed. There has been a BIM Mobile Access Guide has been created to put a standard on use for common processes to be followed by every personnel while using tablets on site. The aim was to steer site installation progress while making it cost effective and high quality with minimized rework with BIM Mobile Access in this project. BIM tools used from tablets were functional on site with the following context; cross-coordinated BIM Models, approved 2D shop drawings, QA-QC documentation including Material Acceptance Forms and Method Statements, QA-QC processes; inspection forms, inspection checklists and site observations, performance tracking, crew and jobsite planning. Subcontractors were also involved to the system.

Design management functions of the BIM system applied on site enabled to access BIM models and also follow the design revisions via models. Any design change or installation information with integrated disciplines made in the office was delivered to site via tablets from the office. Design management has provided the followings:

- Possible rework and delays were prevented.
- Access to visualize overall interactions between the various services has been provided.
- Production efficiency has been improved.
- Physical distance in between office and site has been eliminated.

Information management functions of the BIM system applied on site enabled to access 2D production drawings, MAFs and MS. Since these documents uploaded to tablets after approval and kept updated, site personnel used the most updated and accurate documents during construction. By this was there has been a significant contribution made to improved engineering quality. Information management has provided the followings:

- Project documentation is made mobile to be carried out anywhere on site.
- Production on site has followed the most updated and accurate approved project documentation.
- Project information did not stay on the papers with old revisions.

QA/QC functions of the BIM system applied on site enabled to make site inspections and observation through tablets. QA/QC has provided the followings:

- Collaboration of both people and parties has been achieved in digital platforms.
- Time spend on this QA/QC process has been minimized.
- A digital copy of the data captured during construction to the next processes has been directly stored.
- Paperwork has been eliminated.
- Detected trends for non-conformances provided to take necessary actions as whole.
- Issues are addressed before creation of any major impacts in terms of delay, rework and quality.

Resource management functions of the BIM system applied on site for make crew tracking and logistics planning purposes. This provided transparency throughout the project with easy access and clear picture of the ongoing issues regarding resources. Resource management has provided the followings:

- Reporting of resource problems directly from site has been achieved.
- Access to the latest resource issue is enabled.
- Problems regarding resources are determined and addressed quickly.
- Time-consuming efforts performed to gather data from several departments are eliminated.

Performance management functions of the BIM system applied on site for make crew tracking and logistics planning purposes. The most important outcome of this monitor reporting is observed as having access to real-time information automatically updated information from construction site directly. Performance management has provided the followings:

- Executive level is reported directly from BIM system.
- Management decisions has been taken by analyzing BIM based reports.
- Spontaneous reporting was possible by including any required information.
- Time-consuming efforts performed to gather data from several departments are eliminated.
- Contractor had immediate access to subcontractor`s performance reports.
- Subcontractors monitored their progress and has taken corrective actions.
- Subcontractors performing the work on-site had access to the latest project information to be followed.

6.2 Survey Study of IGA

In order to identify cultural and technical barriers, challenges, advantages and disadvantages of mobile BIM at construction site a survey study has been performed.

From the results of the design management section of the survey study it can be stated that respondents agree that the mobile access to interdisciplinary BIM model contributes to production on site. They have found the navigation of the 3D BIM model on tablet easy. There has been some disagreement on the following on design-revisions

from BIM models especially for MEP department. This could be the cause of the fact that MEP design includes various different services together and it is more complex than other disciplines to view in the model from tablet. There has been a connection derived for respondent's age and the view on design management issue. Younger respondents evaluated design management functions more positively than older respondents. Respondents from QA/QC departments tend to agree less to design management statements. The reason for this situation could be interpreted as QA/QC department engineers does not take a role during design realization on site.

From the information management section of the survey study it can be stated as site engineers prefers to access to 2D drawings, MAF& MS documents from tablets to print-outs. It has been found that participants agree on mobile access to documents has eased the document control processes on site. Even though some of the respondents found design revision to follow from BIM models, they have stated that it can be followed from 2D drawings from the tablets. QA/QC department agreed the most among the other departments to IM statements. Since MAF and MS documents are prepared and checked by them on-site they have found this functions more beneficial than other departments.

In the QA/QC section of the survey study participants consider that during using digital forms on site as time-saving, and less possibility with end-up missing information. According to participants, the mobile BIM system has also followed a regulated follow-up of issues detected during inspections. They also agree that the system has enforced subcontractors to resolve the issues addresses to them through the system faster.

In the resource management section of the survey study participants mainly consider crew and material tracking and logistics planning from the tablets contributed on-time completion. On the other hand there was some disagreement and also indecisive responses captured. Daily activities of resource management has not been completely done through BIM system unlike QA/QC. Some of the functions came with BIM tools are adopted to follow resources but this system was not the formal way of following the resources. The results show that if there is no formal workflow for transforming an activity to digital than traditional, benefits of BIM functions might not be fully discovered.

In the performance management section of the survey study participants agree that use of BIM system eased the performance tracking of subcontractors and also the system helped to follow the construction schedule by reporting of any problems about any delays. BIM department agreed the most among the other departments to PM statements. They were directly responsible of reporting performance issues from tablets and also monitoring these issues.

In the general questions on BIM use it has been found that some of the respondents found the design revision updates on the tablet not frequent enough. They have also stated to not to see some elements (Hangers, formworks, etc.) in the model created problems for them. Wi-Fi provided on site has had created for some of the respondents.

Participants agree on that BIM use has increased the constructability, efficiency; decreased the rework and improved the QA/QC processes. They have found to use tablets advantageous for weather conditions on-site. They have agreed that the data collected through BIM during design and construction will be significant for operations phase.

96% percent of the participants stated that they would like to use BIM in their next project. Even though they have stated some disagreements with the advantages of BIM, almost everybody participated to the study is eager to work with BIM later on. This is very important.

To the participants who has stated they would like to use BIM in their next project have been asked what they would have wanted to be improved for the system. There was not a strong agreement on the used software and training structure. Integration of as-built information and project baseline to models/ tablets was the most wanted improving suggestion for further use of site BIM.

According to objectives of the study conclusions are as follow:

Objective 1: Illustration of BIM adoption at site including project-specific strategies and implementation details through participatory case study.

- Coordination and collaboration of the project parties in digital environment has been achieved much before construction.
- Subcontractor involvement is achieved in order to circulate the system through all of the participants in the project.

- Effective information management is set-up in order to reach the most updated/accurate project information.
- Formal plans (BIM Execution Plan, Mobile Access Guide, etc.) implemented to transform traditional way of doing an activity to the digital way throughout the project.
- Trainings are considered as continuous process rather than on-off process.
- Construction schedule is considered as the top priority while transferring coordinated models to site.
- Through the use of technology enabled by BIM practices; workflows of construction activities are improved.
- Leadership commitment is significant parameter for a successful implementation.

Objective 2: Identification of cultural& technical barriers/ challenges, advantages and disadvantages through questionnaire study

- Older engineers still tend to follow 2D drawings instead of 3D models because there are still issues with understanding 3D information for them.
- Missing some of the elements which are in place on site such as hangers, formwork in the BIM model created problems while using models in tablets.
- Technical issues such as WI-FI connection on-site or tablet capacity are raised as the main barriers during site implementation of BIM.
- Following design revisions of the complex systems (MEP) from BIM models is not effective as other systems.
- Distance in between construction site and office has been eliminated through digital environment enabled through BIM practices.
- Even though it was the first BIM experience for the survey participants they mostly were stated that BIM use on site eased their daily activities by saving time; increasing efficiency, constructability, decreasing rework.
- Subcontractor involvement achieved by the system provides effective communication with them to resolve any issues.
- By recording from site digitally, problem trends can be discovered and to be addressed before creating any major issues.

- Improved workflows, new ways of managing the information, effective communication and coordination practices has been achieved.

Objective 3: Determination of lessons-learnt and innovative solutions through integration of the observations and survey results

- Site engineers are more open-minded about the possibilities what new technologies can offer to them while doing their daily activities.
- When the benefits of site-BIM is experienced by the professionals, they would like to use the same system for the next projects independent from their age and experience.
- Departments take different roles during construction perceives BIM system differently. They should be trained in the manner in accordance with their needs.
- The data collected through site-BIM implementation is highly significant information to be transferred for project's operations phase.
- The weakest use case of the implementation is identified as resource management. Lack of formal workflow for transforming this activity to digital than traditional, benefits of BIM functions is not fully discovered.
- Tablet users are focused on only the work related functions of tablets with the use of Mobile Device Management (MDM) system.
- By allowing to access to a digital platform that everybody involved in the project can reach, construction related activities are regulated.
- Used software package does not have direct impact on the user perspective on site BIM if it provides the necessary functions needed.
- Structure of trainings should be improved according to user perspective.

6.3 Interview Study of IGA

The aim of the interview was to get an insight in how BIM is used in the construction project on site and to get answers on the research questions. The result of this study illustrates how individual respondents approach mobile BIM implementation on site. The data was collected through twelve semi-structured interviews with the personnel aiming to gain an understanding of the case who were actively involved.

Motivations for innovation has been identified as the complexity and size of the project, distance between site and office, easy access to most accurate project documentation and limited project time.

In order to transfer BIM implementation site, BIM site team has been set up and tasked with different locations in the project. BIM site engineers determined the key contacts on site who are more interested in BIM application. BIM site engineers had to create cultural change in order site team to use BIM. In case of interaction of two or more services, they needed a quick solution to address the problem. The site personnel also experienced the benefits of using BIM and this led a passage to full transformation from traditional method to innovative way of performing work on site. For subcontractors they have been obliged to perform inspections digitally and also resolve any issues raised by BIM site engineers in order to receive their monthly progress payments. When they did not comply with BIM, they had to face with rework which cost them money and time. With these experiences they had to accept the BIM system and do their work accordingly.

Main functions of BIM has been stated by the interviewees that instruction of construction with BIM model, registration of inspection forms, creating observation; supervision reports for the problems on site, progress monitoring, registering punch lists, and registration of test and commissioning reports.

Main challenges has been identified as cultural change of the site engineers in the projects by site BIM engineers. It was managed in this project it was not a straightforward process to be overcome. It was also identified as challenge that construction on site cannot be performed with the same precision as BIM model.

Main advantages of the system access to most updated and coordinated project information. It was founded very practical to conduct installation according to coordinated BIM model and reworks are avoided. Formal procedures has been eliminated through supervision of BIM due to common digital environment.

Main disadvantage for site engineers was to learn a new technology and get used to it in a short period of time. Their work had to be accountable to site BIM engineers during construction. They had to compensate from their own traditional ways. Disadvantage of site BIM engineers was that they had to spend very long time for training and

adopting site staff to the new system. They had to break the unwelcoming environment to their existence because of site personnel's resistance to change.

The success of the project is achieved with having an on-site BIM team and their close follow-up on daily activities. Successful personal connections of BIM site engineers and managerial support has also big impact on successful implementation.

Further development suggestions include sectioning and progress tracking functions on BIM models from tablets. Determination of BIM department's position in the organization schema of the company in order to enable authority to enforce other departments.





7. CONCLUSIONS AND FUTURE WORK

7.1 General Conclusions

Delivery of constructible BIM Models to the site made site teams to conduct installations by the guidance of cross coordinated virtual environment. It was ensured that the site team had the accurate application information much before the starting of actual installation. Inspections are tracked through BIM360 systems. Besides, all the process from the documentation to site inspections are held by BIM360 platform and relevant attachments including checklists directly on site via tablets. Improved workflows, new ways of managing the information, effective communication and coordination practices which increased the productivity on site by improving quality, saving time and money. This outcome realized not only with technology, but strategic implementation and transformation of organization. It is important to note that the focus of this study was to explore how and with which strategies BIM can be effectively transferred to site and how the site engineers correspond these BIM enabled workflows.

Whilst BIM utilization is mostly limited with the tasks performed in the office environments in the design phases for many of the cases in the industry, this study examined barriers/challenges, advantages and disadvantages of implementing BIM at the construction site for the use cases derived from literature study in a complex infrastructure project. To describe the case, BIM processes commencing with design and engineering and transforming to construction have been analyzed.

It has been identified that through the use of technology enabled by BIM practices; workflows of construction activities are improved. Even though it was the first BIM experience for the survey participants they were stated that BIM use on site eased their daily activities by saving time; increasing efficiency, constructability, decreasing rework. When the benefits of site-BIM is experienced by the professionals, they would like to use the same system for the next projects independent from their age and experience. It has been also found that use of mobile devices instead of papers are highly preferred onsite independent from age and experience. The weakest use case of the implementation is identified as resource management, which is also the least

researched issue in the literature. Technical issues such as WI-FI connection on-site or tablet capacity are raised as the main barriers during site implementation of BIM. There has to be a formal plan/workflow implemented to transform traditional way of doing an activity to the digital way by all means. The data collected throughout site-BIM implementation found to be significant for project's operations phase.

It has been identified through the interviews that motivations for innovation has been seem as the complexity and size of the project, distance between site and office, easy access to most accurate project documentation and limited project time. In order to transfer BIM implementation site, BIM site team has been set up and tasked with different locations in the project as the adoption strategy. Resistance of the site personnel has been overcome when they have experienced the benefits of using BIM and this led a passage to full transformation from traditional method to innovative way of performing work on site. Subcontractors they have been obliged to perform inspections digitally and also resolve any issues raised by BIM site engineers in order to receive their monthly progress payments. Main functions of BIM has been stated by the interviewees that instruction of construction with BIM model, registration of inspection forms, creating observation; supervision reports for the problems on site, progress monitoring, registering punch lists, and registration of test and commissioning reports. Main challenges has been identified as cultural change of the site engineers in the projects by site BIM engineers. It was also identified as challenge that construction on site cannot be performed with the same precision as BIM model. Main advantages of the system access to most updated and coordinated project information. It was founded very practical to conduct installation according to coordinated BIM model and reworks are avoided. Formal procedures has been eliminated through supervision of BIM due to common digital environment. Main disadvantage for site engineers was to learn a new technology and get used to it in a short period of time. It was also a disadvantage for them that their work had to be accountable to site BIM engineers during construction. Disadvantage of site BIM engineers was that they had to spend very long time for training and adopting site staff to the new system. They had to break the unwelcoming environment to their existence because of site personnel's resistance to change.

The success of the project is achieved with having an on-site BIM team and their close follow-up on daily activities. Successful personal connections of BIM site engineers and managerial support has also big impact on successful implementation.

7.2 Future Work

This research has revealed a number of areas for further research and development. These are discussed as follows:

- Development of resource management functions of site-BIM to fulfill its maximum benefits.
- Technical improvements for mobile devices and technologies in order to resolve issues for site-BIM purposes.
- Implementation strategies needs to be further illustrated with the study of several number of applications.
- Exploration of a formal workflows for site-BIM implementation to be executed cross-projects which will give authority to enforce to BIM department.
- Further investigation of how the data collected throughout site-BIM implementation can be effectively transferred to operations phase.



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APPENDICES

Appendix A: Literature Analysis

Appendix B: Survey Questions

Appendix C: Questionnaire Results



Table A.1: Literature analysis table.

No	DM	IM	QA/QC	RM	PM	Methodology	Used Tool	Year	Authors	Paper Name
1	-	-	x	-	x	Framework	N/A	2010	Sacks et al	Interaction of Lean and Building Information Modelling in Construction
2	-	-	x	-	x	Real Case Implementation	Prototype	2017	Han and Golpavar-Fard	Potential of big visual data and building information modeling for construction performance analytics: An exploratory study
3	-	-	x	-	x	Framework	N/A	2017	Xu and Wang	Study on Construction Quality Control of Urban Complex Project Based on BIM
4	-	-	x	-	-	Experiment on Real Case	Prototype	2017	Zhou et al	Implementation of augmented reality for segment displacement inspection during tunneling construction
5	x	x	x	x	x	Report	N/A	2016	Agarwal et al	Imagining Construction's Digital Future
6	x	-	-	-	-	Real Case Implementation	Commercial software	2016	Bråthen and Moum	Bridging the gap: bringing BIM to construction workers
7	-	x	x	x	x	Literature analysis	N/A	2016	Martinez-Rojas et al	The Role of Information Technologies to Address Data Handling in Construction Project Management
8	x	x	x	-	x	Literature Analysis	Commercial software	2016	Oesterreich and Teuteberg	Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry
9	-	-	-	-	x	Experiment on Real Case	Prototype	2015	Golpavar et al	Image-Based Localization and Content Authoring in Structure-from-Motion Point Cloud Models for Real-Time Field Reporting Applications
10	-	-	-	x	-	Laboratory test	Prototype	2015	Lin et al	Motion Planning and Coordination for Mobile Construction Machinery
11	-	x	-	-	x	Real Case Implementation	Commercial software	2015	Matthews et al	Real time progress management: re-engineering processes for cloud-based BIM in construction
12	-	x	-	-	-	Report	N/A	2015	Sattineni and Schmidt	Implementation of Mobile Devices on Jobsites in the Construction Industry
13	-	-	-	-	x	Experiment on Real Case	Prototype	2014	Bosche et al	Tracking the built status of MEP works: assessing the value of a scan-vs.-BIM system
14	-	x	-	-	-	Report	Commercial software	2014	Chong et al	An explanatory case study on cloud computing applications in the built environment
15	-	x	-	x	x	Experiment on Real Case	Prototype	2014	Cus-Babic et al	Supply-chain transparency within industrialized construction projects
16	-	-	-	x	-	Experiment on Real Case	Prototype	2014	Dimitrov and Goparvar	Vision-based material recognition for automated monitoring of construction progress and generating building information modelling from unordered site image collections
17	-	-	x	-	-	Experiment on Real Case	Prototype	2014	Kwon et al	A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality
18	-	-	-	x	-	Experiment on Real Case	Prototype	2014	Lin et al	A user-centered information and communication technology (ICT) tool to improve safety inspections
19	x	x	-	-	x	Experiment on Real Case	Prototype	2014	Meza et al	Component based engineering of a mobile BIM-based augmented reality system

Table A.1 (continued): Literature analysis table.

20	x	-	-	-	-	Laboratory test	Prototype	2014	Parfitt and Whyte	Developing a Mobile Visualization Environment for Construction Applications
21	-	-	x	-	-	Framework	Prototype	2014	Tsai et al	ABIM-enabled Approach for Construction Inspection
22	x	x	-	-	-	Laboratory test	Prototype	2014	Wang et al	Integrating augmented reality with building information modeling: onsite construction process controlling for liquefied natural gas industry
23	x	-	-	-	-	Laboratory test	Prototype	2014	Yang and Kang	BIM Navigation with Hand-Based Gesture Control on Sites
24	x	-	-	-	-	Laboratory test	Prototype	2013	Akula et al	Real-time drill monitoring and control using building information models augmented with 3D imaging data
25	x	-	x	-	x	Real Case Implementation	Commercial software	2013	Davies and Hart	Implementing site BIM: a case study of ICT innovation on a large hospital project
26	-	x	-	x	x	Experiment on Real Case	Prototype	2013	Kim et al	On-site Construction Management using mobile computing technology
27	-	-	x	-	-	Laboratory test	Prototype	2013	Park et al	A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template
28	-	x	-	x	-	Report	N/A	2012	McGraw Hill Construction	The business value of BIM in North America: Multi-year trend analysis and user ratings (2007–2012)
29	-	x	x	-	x	Laboratory test	Prototype	2012	Noubakhsh et al	Mobile application prototype for on?site information management in construction industry
30	-	x	-	-	-	Report	N/A	2012	Redmond et al	Exploring how information exchanges can be enhanced through cloud BIM
31	x	-	-	-	-	Experiment on Real Case	Prototype	2012	Shen and Jiang	An Augmented 3D iPad Mobile Application for Communication, Collaboration and Learning (CCL) Of Building MEP Systems
32	x	x	-	x	x	Framework	N/A	2012	Wang et al	A Framework of Bringing BIM to Construction Site
33	-	x	-	-	-	Laboratory test	Prototype	2012	Yeh et al	On-site building information retrieval by using projection- based augmented reality
34	x	x	-	x	x	Real Case Implementation	Framework	2011	Chen and Kamara	A framework for using mobile computing for information management on construction sites
35	-	-	-	-	x	Experiment on Real Case	Prototype	2011	Elbeltagi and Dawood	Integrated visualized time control system for repetitive construction projects
36	x	-	-	-	-	Experiment on Real Case	Prototype	2011	Roh et al	An object-based 3D walk-through model for interior construction progress monitoring
37	-	-	x	-	-	Laboratory test	Prototype	2010	Shin and Dunston	Technology development needs for advancing Augmented Reality-based inspection
38	-	-	-	-	x	Experiment on Real Case	Prototype	2009	Sacks et al	Visualisation of work flow to support lean construction
39	-	x	-	-	-	Experiment on Real Case	Commercial software	2003	Elvin	Tablet and Wearable Computers for Integrated Design and Construction
40	-	x	x	x	x	Laboratory test	Prototype	2002	Cox et al	Construction field data inspection using pocket PC technology

Table B.1 : Survey questions in Turkish.

Meslek						
Departman						
Pozisyon						
Yaş						
Tecrübe(Ay)						
BIM tecrübesi(Ay)						
		Hiç Katılmıyorum	Kısmen Katılmıyorum	Emin Değilim	Kısmen Katılıyorum	Tamamen Katılıyorum
A	Tasarım Yönetimi					
A.1.	Sahada BIM Modeline Erişim					
1	Birleştirilmiş BIM modellerine sahada tablettten erişmek imalatı kolaylaştırdı.					
2	Tabletteki modelin elle kontrol etmek kolaydır.					
A.2.	Revizyonların Takibi ve Erişim					
3	Tasarımdaki revizyonlar tabletteki BIM modeli üzerinden sahada takip edilebilmektedir.					
B	Bilgi Yönetimi					
B.1.	Uygulama Çizimlerine erişim					
4	Sahada 2D paftalara ve shop drawinglere tablettten erişmeyi kağıt pafta kullanmaya tercih ederim.					
5	Shop drawinglerin tabletlere yüklenerek güncel tutulması son revizyon takibini kolaylaştırdı.					
B.2.	Material Approval Formlarına (MAF) Erişim					
6	MAF'lara tablettten erişilmesi inspection yapılırken döküman takibini kolaylaştırdı.					
7	MAF'ların sahada tablettten erişilebilir olması sahadaki malzemenin takibini kolaylaştırdı.					
B.2.	Method Statement'lara (MS) Erişim					
8	Method Statement'lara mobil erişim sağlanması sahadaki imalatın takibinde fayda sağladı.					
C	Kalite Kontrol Kayıtları					
C.1.	Saha Denetlemeleri (Inspection)					
9	Inspection Formlarının dijital olarak doldurulması kağıt üzerinden yapılmasına nazaran zaman tasarrufu sağladı.					
10	Inspection Formlarının dijital olarak doldurulması eksik bilgi probleminin önüne geçti.					
11	Inspection formlarının tablettten dolduruluyor olması inspection sırasında kaydedilen konuların sonrasında takibini düzenli hale getirdi.					
C.2.	Saha İncelemeleri (Observation)					
12	Sahada imalatla ilgili sorunların tablet üzerinden obervation olarak kaydedilmesi taşeronların sorunları daha hızlı çözmesini sağladı.					
D	Kaynak Yönetimi					
D.1.	İşçi Takibi					
13	Sahada imalatların aksamadan devam etmesi için işçi takiplerinin anlık olarak sahada tabletlerden yapılması planlanan zamanda işin tamamlanmasını sağladı.					

Table B.1 (continued): Survey questions in Turkish.

		Hiç Katılmıyorum	Kısmen Katılmıyorum	Emin Değilim	Kısmen Katılıyorum	Tamamen Katılıyorum
D.2.	Saha Planlaması					
14	Malzeme ve lojistik ile ilgili imalatı engelleyen konuları anında tablet üzerinden paylaşmak bu konuların gündeme gelerek daha hızlı çözülmesini sağladı.					
E	Performans Yönetimi					
E.1.	Raporlama					
15	Taşeronların performans takibi, BIM360 sisteminden otomatik olarak alınan raporlar yardımıyla daha kolay hale geldi.					
E.2.	İş programı takibi					
16	İş programının sahada takibi ve problemleri konuların anında tabletlere kaydedilmesi iş takibini kolaylaştırdı.					
F	Genel Sorular					
17	Tablet ekranlarının büyüklüğü sahada çalışma yapmak için yeterliydi.					
18	Sahada sağlanan internet erişimi tablet üzerinden yapılan çalışmaları olumsuz yönde etkilemedi.					
19	3 boyutlu modeli anlamak ve modelde navigasyon yapmak kolaydı.					
20	3 boyutlu model üzerinden saha formları ve işçilerine yapılacak imalatı açıklamak kolay oldu.					
21	Sahada bulunan lokasyonu modelde bulmak kolaydı.					
22	Modelde sahadaki tüm elemanların (askı, kalıp, vb.) bulunmaması bir problem yaratmadı.					
23	Tasarımdaki revizyonların tabletteki modellere yansıtılması periyodu yeterliydi.					
24	Sahadaki BIM uygulamaları için verilen eğitimler yeterliydi.					
25	Projede BIM kullanılması sahadaki çalışmaların daha etkin yürütülmesini sağladı.					
26	Projede BIM kullanılması iş programının sıkıştırılarak proje tamamlanma süresini kısalttı.					
27	Kötü hava koşullarında kağıt pafta veya formlar yerine tablet kullanmak avantajlı oldu.					
28	Projede BIM kullanılması riskleri azalttı.					
29	Projede BIM kullanılması tasarımın yapılabilirliğini arttırdı.					
30	Projede BIM kullanılması uygulama projelerinin kalitesini arttırdı.					
31	Projede BIM kullanılması QA/QC sürecini iyileştirdi.					
32	Projede BIM kullanılması RFI sayısını azalttı.					
33	Projede BIM kullanılması değişiklik talimatı sayısını azalttı.					
34	Projede BIM kullanılması verimliliği arttırdı.					
35	Projede BIM kullanılması planlamayan değişiklikleri azalttı.					
36	Projede BIM kullanılması iş programındaki iş sırasını takip etmeyen imalatları azalttı.					
37	Projede BIM kullanılması yeniden yapmayı (rework) azalttı.					

Table B.1 (continued): Survey questions in Turkish.

		Hiç Katılmıyorum	Kısmen Katılmıyorum	Emin Değilim	Kısmen Katılıyorum	Tamamen Katılıyorum
38	Projede BIM kullanılması maliyeti azalttı.					
39	Sahada BIM uygulaması ve toplanan veri projenin işletme aşamasındaki uygulamaları için önemli olacaktır.					
40	Bir sonraki projede BIM kullanmayı isterim.					
41	Katılıyor iseniz bir sonraki projede BIM ile ilgili aşağıdakilerden hangisinin/hangilerinin iyileştirilmesi gerekir?					
41.1	Kullanılan yazılımın/yazılımların değiştirilmesi gerekir. (Gerekirse sebebini belirtiniz)					
Açıklama:						
41.2	Malzeme takibinin BIM üzerinden yapılması gerekir.					
41.3	Planlamanın tablet üzerinden takip edilebilmesi gerekir.					
41.4	Verilen eğitimlerin yapısının değiştirilmesi gerekir. (Gerekirse açıklayınız)					
41.5	Tasarım revizyonlarının tablet üzerinden saha ile daha sık paylaşılması gerekir. (Gerekirse açıklayınız)					
Açıklama:						
41.6	Sahadaki as-built bilgisinin BIM modelinde güncellenmesi gerekir.					
41.7	İş güvenliği ile ilgili çalışmaların BIM ile entegre edilmesi gerekir.					
41.8	Diğer-Belirtiniz					

Table C.1 : Survey responses.

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
A	Design Management (Average %)	1	7	10	37	45
A.1	Access to interdisciplinary BIM model eased the production.	0	1	2	18	30
A.2	It is easy to navigate the BIM model in the tablet.	0	2	6	16	27
A.3	Revisions on the design can be followed from BIM model in the tablet.	2	7	7	23	12
B	Information Management (Average %)	1	1	14	44	39
B.4	I would prefer to use 2D shop drawings on the tablet to print-outs.	0	3	2	18	28
B.5	It was easy to follow the revisions from 2D drawings periodically updated in the tablets.	0	2	2	24	23
B.6	Being able to access to MAF documents from the tablets eased the document control process during inspections.	0	2	5	19	25
B.7	Being able to access to MAF documents from the tablets eased the material tracking process on site.	0	0	5	25	21
B.8	Being able to access to Method Statement documents from the tablet was beneficial for production follow-up.	1	0	12	24	14
C	Quality Control and Assurance (Average %)	0	0	12	44	43
C.9	Filling the inspections forms on tablet provided time-saving according to paperwork.	0	0	7	18	26
C.10	Missing information during the inspections are avoided since the forms are filled through tablets.	0	0	8	25	18
C.11	Filling the inspections forms on tablet regulated the follow-up procedure of the issues saved during inspection.	0	0	4	22	25
C.12	Saving of the issues as observations, regarding the problems about production, ensured that the responsible subcontractor to fix the issue faster.	0	0	7	21	23
D	Resource Management (Average %)	5	4	22	37	32
D.13	Reporting any issues regarding crew resource with tablets in order to avoid any delays provided completion on-time.	3	2	18	16	12
D.14	Reporting the issues regarding material and logistics that are preventing production with tablets provided fast solutions by raising the issues.	4	4	10	18	15
E	Performance Management (Average %)	4	3	15	41	37
E.15	Performance tracking of subcontractors got easier with reports exported from BIM360 system.	0	3	4	20	24

Table C.1 (continued): Survey responses

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
E.16	Production follow-up got easier with construction schedule tracking on-site and reporting of any problems spontaneously.	4	0	7	24	16
F	Feedback on BIM functions (Average %)	0	1	10	35	54
F.17	The size of the tablet screen is enough to work on site.	1	3	5	25	17
F.18	Wi-Fi provided on site did not affect the works requires tablet use negatively.	2	6	8	25	10
F.19	It is easy to understand and navigate 3D model.	1	1	6	21	22
F.20	It is easy to explain work to be performed from 3D model to foremen and workers.	0	0	6	20	25
F.21	It is easy to find the location within the model.	1	2	3	24	21
F.22	It did not create any problem that the BIM model did not include all of the elements which are in place on site such as hangers, formwork, etc.	6	6	10	19	10
F.23	The period of getting revisions made in the design on the tablets was necessary.	5	5	13	17	11
F.24	The trainings given for the use of mobile BIM was adequate.	0	1	12	20	18
F.25	Utilization of BIM increased the efficiency of the work on site.	0	1	6	24	20
F.26	Utilization of BIM shortened the work completion duration by compressing the project schedule.	0	0	9	17	25
F.27	Using tablets instead of drawings or forms as printed papers was advantageous in bad weather conditions.	0	0	4	16	31
F.28	Implementation of BIM in the project mitigated the risks.	1	3	8	12	27
F.29	Implementation of BIM in the project increased the constructability of the design.	0	0	4	18	29
F.30	Implementation of BIM in the project increased the quality of shop drawings.	1	1	5	18	26
F.31	Implementation of BIM in the project improved the QA/QC processes.	1	1	1	17	31
F.32	Implementation of BIM in the project decreased number of RFIs.	0	1	17	14	19
F.33	Implementation of BIM in the project decreased number of change orders.	1	0	11	27	12
F.34	Implementation of BIM in the project increased the efficiency.	0	1	4	25	21

Table C.1 (continued): Survey responses

No.	Statement	Scale (Frequency)				
		1	2	3	4	5
F.35	Implementation of BIM in the project decreased the unplanned changes.	0	1	6	25	19
F.36	Implementation of BIM in the project decreased the number of activities which do not proceed according to the project baseline.	1	1	9	22	18
F.37	Implementation of BIM in the project decreased rework.	0	1	4	25	21
F.38	Implementation of BIM in the project decreased the cost overruns.	0	1	10	19	21
F.39	Implementation of BIM in the project and collected data throughout the project will be significant for project's operations phase.	0	1	3	23	24
F.40	I would like to use BIM in the next project.	0	0	2	11	38
G	Further Improvement Suggestions					
G.41	If you agree to F.40, which one(s) of the followings should be improved in the next project?					
G.41.1	Softwares used in the project should not be changed.	4	10	26	10	1
G.41.2	Material tracking should be done through BIM.	2	2	9	17	21
G.41.3	Project baseline should be tracked from the tablets.	0	1	9	17	24
G.41.4	Structure of the trainings should not be changed.	4	11	19	14	3
G.41.5	Revisions on the design should be shared more frequently with site through tablets.	2	2	11	16	20
G.41.6	As-built information on-site should be updated in BIM model.	0	1	5	18	27
G.41.7	Practices regarding work safety should be integrated with BIM.	1	2	14	17	17



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