

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

**INVESTIGATING BUILDING INFORMATION MODELLING (BIM)
ADOPTION LEVEL WITHIN CONSTRUCTION PRODUCT
MANUFACTURERS IN EUROPE**

M.Sc. THESIS

Kübra BAYRAK

Department of Civil Engineering

Construction Management Programme

JUNE 2024

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(501211111)**

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Thesis Advisor: Prof. Dr. Esin ERGEN PEHLEVAN

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

**AVRUPA'DAKİ İNŞAAT ÜRÜNLERİ ÜRETİCİLERİ ARASINDA YAPI BİLGİ
MODELLEMESİNİN (BIM) BENİMSENME DÜZEYİNİN İNCELENMESİ**

YÜKSEK LİSANS TEZİ

**Kübra BAYRAK
(501211111)**

İnşaat Mühendisliği Anabilim Dalı

Yapı İşletmesi Programı

Tez Danışmanı: Prof. Dr. Esin ERGEN PEHLEVAN

HAZİRAN 2024

Kübra Bayrak, an M.Sc student of ITU Graduate School, student ID 501211111, successfully defended the thesis/dissertation entitled “Investigating Building Information Modelling (BIM) Adoption Level Within Construction Product Manufacturers in Europe” which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. Esin Ergen Pehlevan**

Istanbul Technical University

Jury Members : **Assoc. Prof. Dr. Deniz Artan**

Istanbul Technical University

Assoc. Prof. Dr. Senem Seyis Kazazoglu

Istanbul Ozyegin University

Date of Submission : 24 May 2024

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To my Family,



FOREWORD

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TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	ix
TABLE OF CONTENTS	ix
ABBREVIATIONS	xiii
LIST OF TABLES	xv
LIST OF FIGURES	xvii
SUMMARY	xix
ÖZET	xxi
1.INTRODUCTION.....	1
1.1 Background.....	2
1.2 Definition of Problem.....	2
1.3 Research Objectives	3
1.4 Methodology	4
1.5 Scope and Limitations of the Study	6
1.6 Organization of the Thesis.....	6
2. LITERATURE REVIEW	7
2.1 Building Information Modelling.....	7
2.1.1 Importance of building information modelling.....	8
2.1.2 Benefits of building information modelling	9
2.1.3 Implementation of building information modelling.....	10
2.2 Building Information Modelling for Designers	11
2.3 Construction Product Manufacturers	13
2.4 Building Information Modelling for Construction Product Manufacturers	14
2.5 Product Information	15
2.5.1 Management of product information.....	16
2.5.1.1 Accuracy and currency	17
2.5.1.2 Accessibility and shareability	18
2.5.1.3 Compliance and standards	18
2.5.1.4 Security and privacy	19
2.5.2 Structuring product information.....	20
2.6 BIM Adoption.....	23
2.6.1 Companies' decision to invest in BIM.....	23
2.6.2 Key success factors for firms in embracing BIM.....	31
2.7 BIM Objects.....	52
2.7.1 Creating BIM objects	52
2.7.2 Implementing BIM objects	54
2.7.2.1 Integration with BIM software.....	55
2.7.2.2 Managing object libraries	56
2.7.2.3 Utilizing BIM objects in projects	56
2.7.3 BIM object library platforms	57
2.8 Survey Studies in Construction Industry about BIM	58

2.8.1 Global BIM adoption study	59
2.8.2 BIM adoption and implementation for architectural practices	60
2.8.3 BIM adoption survey.....	61
2.8.4 State of BIM adoption and implementation	61
2.8.5 BIM in practice: what do the practitioners say?	62
2.8.6 BIM implementation and adoption strategies for building owners	62
2.8.7 BIM adoption in developing countries: a systematic literature review.....	62
3. METHODOLOGY	65
3.1 Survey Study	66
3.2 Design of survey	66
3.2.1 Sampling of survey	68
3.2.2 Required sample size.....	69
3.2.3 Survey analysis	70
4. SURVEY RESULTS.....	73
4.1 Review of Survey Responses	73
4.1.1 Demographic characteristics of the participants.....	73
4.1.2 Survey questions about firms	76
4.1.3 Survey questions asked to not invest in BIM	80
4.1.4 Survey questions asked to invest in BIM	80
4.1.5 Survey result analysis.....	97
5. DISCUSSION	111
6. FUTURE DIRECTIONS AND UTILIZATION OF RESEARCH FINDINGS	117
6.1 Product Manufacturers	117
6.2 BIM Service Providers.....	118
6.3 Industry Associations and Policymakers	118
6.4 Researchers.....	119
6.5 Construction Industry at Large.....	119
7. CONCLUSION	121
8. REFERENCES	125

ABBREVIATIONS

2D	: Two-dimensional
3D	: Three-dimensional
BIM	: Building Information Modelling
CDE	: Common Data Environment
CPM	: Construction Product Manufacturers
DT	: Data Template
IFC	: Industry Foundation Classes
ISO	: International Organization for Standardization
NBS	: National Building Specification
PDT	: Product Data Template



LIST OF TABLES

	<u>Page</u>
Table 4.1: Kruskal-Wallis H test p-values.	98
Table 4.2: Mann-Whitney U test results for Q12.5.	99
Table 4.3: Mann-Whitney U test results for Q12.6.	100
Table 4.4: Mann-Whitney U test results for Q21.5.	102
Table 4.5: Mann-Whitney U test results for Q23.1.	103
Table 4.6: Mann-Whitney U test results for Q23.2.	105
Table 4.7: Mann-Whitney U test results for Q21.9.	106
Table 4.8: Mann-Whitney U test results for Q21.12.....	107



LIST OF FIGURES

	<u>Page</u>
Figure 1.1: Steps of methodology.....	5
Figure 3.1: Flow chart of analysis.	66
Figure 4.1: Classification of the number of the employees' participants' firms.	73
Figure 4.2: Classification of participants according to their ages.	74
Figure 4.3: Classification of participants' experience in the construction industry. .	75
Figure 4.4: Classification of participants according to their experience with BIM. .	75
Figure 4.5: Distribution of participants' responsibilities in their companies.	76
Figure 4.6: Distribution of participants' products.	77
Figure 4.7: Distribution of participants' production process.	78
Figure 4.8: Distribution of participants' structure of product data.	78
Figure 4.9: Distribution of participants' investment in BIM.	79
Figure 4.10: Distribution of participants' reason to not investment in BIM.	80
Figure 4.11: Distribution of participants' reason to investment in BIM.	82
Figure 4.12: Likert scale distribution of obstacles to transition to BIM.	83
Figure 4.13: Distribution of participants' firms' experience with BIM.	84
Figure 4.14: Distribution of participants' firms' experience with BIM.	85
Figure 4.15: Distribution of participants' IFC usage in projects.	85
Figure 4.16: Distribution of participants' BIM object percentage.	86
Figure 4.17: Distribution of participants' BIM object creation.	87
Figure 4.18: Distribution of participants' BIM object updates.	88
Figure 4.19: Distribution of participants' BIM object sharing.	88
Figure 4.20: Distribution of changing the questions about product asked.	89
Figure 4.21: Likert scale distribution of difficulties to preparing BIM objects.	90
Figure 4.22: Distribution of BIM object creation.	91
Figure 4.23: Distribution of participants' thoughts about BIM.	92
Figure 4.24: Distribution of BIM object languages.	93
Figure 4.25: Distribution of document using in preparation of BIM objects.	94
Figure 4.26: Distribution of classification using to categorizing products.	95
Figure 4.27: Distribution of software usage in preparation of BIM objects.	96
Figure 4.28: Survey result analysis.	97



INVESTIGATING BUILDING INFORMATION MODELLING (BIM) ADOPTION LEVEL WITHIN CONSTRUCTION PRODUCT MANUFACTURERS IN EUROPE

SUMMARY

Product manufacturers play a crucial role in the adoption of BIM (Building Information Modelling) as the BIM objects they supply form the fundamental elements of BIM models. However, previous research has not thoroughly examined the extent of BIM adoption among these manufacturers. This lack of in-depth analysis highlights a significant gap in the literature, especially regarding the main steps and challenges in BIM adoption.

This study aims to investigate the current state of BIM adoption among construction product manufacturers. It seeks to evaluate the prevalence of BIM use within the sector, understand the variations in adoption levels, and identify the barriers to adoption. Data was collected through a survey conducted among product manufacturers in Europe, a region chosen to capture diverse BIM adoption practices influenced by different regulatory and economic contexts. The data was analyzed to detail the extent of BIM adoption, including the percentage of companies using BIM and the depth of its integration into their business processes. This analysis reveals the primary reasons for adopting or avoiding BIM, which include technological readiness, perceived benefits versus adoption costs, and the availability of skilled personnel to manage BIM processes.

The thesis also examines the specific challenges and benefits associated with the BIM adoption process. Common challenges include the initial cost of software and training, the complexity of integrating BIM with existing systems, and resistance to change from traditional practices. On the other hand, manufacturers report benefits such as improved collaboration across project teams, enhanced design accuracy, and better resource management, which leads to reduced waste and increased profitability. Additionally, the study identifies the main tools, standards, and platforms used by manufacturers, providing an overview of the current technological landscape supporting BIM in the manufacturing sector. These tools and platforms are essential for the creation, management, and sharing of digital information critical for successful BIM implementation.

The findings from this research can assist product manufacturers planning to adopt BIM by offering a clearer understanding of the potential impacts and considerations involved. Moreover, these findings can support further research into the factors influencing BIM adoption and how to address them to improve uptake and effectiveness. This study not only fills an important gap by providing detailed data on BIM adoption among product manufacturers but also contributes to the broader goal of enhancing technological integration within the construction industry.



AVRUPA'DAKİ İNŞAAT ÜRÜNLERİ ÜRETİCİLERİ ARASINDA YAPI BİLGİ MODELLEMESİNİN (BIM) BENİMSENME DÜZEYİNİN İNCELENMESİ

ÖZET

Ürün üreticileri, sağladıkları Yapı Bilgi Modellemesi (BIM) nesneleri BIM modellerinin temel unsurlarını oluşturduğu için BIM'in benimsenmesinde önemli bir rol oynamaktadır. Ancak, önceki araştırmalar bu üreticiler arasında BIM'in benimsenme düzeyini ayrıntılı olarak incelememiştir. Bu derinlemesine analiz eksikliği, özellikle BIM benimseme adımları ve karşılaşılan zorluklar konusunda literatürde önemli bir boşluğa işaret etmektedir.

BIM, inşaat sektöründe devrim yaratan bir yenilik olup, projelerin tasarım, inşaat ve yönetim süreçlerini dijital bilgi entegrasyonu ile köklü bir şekilde dönüştürmektedir. Bu çalışma, inşaat ürünleri üreticileri arasında BIM'in benimsenme durumunu araştırmayı amaçlamaktadır. Sektörde BIM kullanımının yaygınlığını değerlendirmeyi, benimsenme seviyelerindeki farklılıkları anlamayı ve engelleri belirlemeyi hedeflemektedir. Veriler, Avrupa'daki ürün üreticileri arasında yapılan bir anketle toplanmıştır. Avrupa'nın coğrafi odak noktası olarak seçilmesi, farklı düzenleyici ve ekonomik bağlamlardan etkilenen çeşitli BIM benimseme uygulamalarının yakalanmasını sağlamaktadır.

BIM'in yaygınlaşması ve birçok ülkede zorunlu hale gelmesi, inşaat sektöründe büyük bir dönüşüme neden olmaktadır. Ancak, literatürde inşaat ürünleri üreticileri arasında BIM'in benimsenme adımları ve karşılaşılan zorluklar hakkında detaylı analizlerin eksikliği dikkat çekmektedir. Bu konuda büyük bir literatür açığı bulunmaktadır ve bu boşluk, BIM'in üretici firmalar üzerindeki etkilerini tam olarak anlamamızı zorlaştırmaktadır.

Üretici firmaların sağladığı ürün bilgileri, tasarım süreçleri için kritik bir rol oynamaktadır. Doğru ve güncel ürün bilgileri olmadan, tasarımcılar ve mühendisler projelerinde doğru kararlar alamayabilirler. BIM, bu bilgilerin dijital olarak entegrasyonunu sağlayarak, tüm proje paydaşları arasında verimli ve işbirlikçi bir çalışma ortamı yaratmaktadır. Bu bağlamda, ürün üreticilerinin BIM süreçlerine entegrasyonu, projelerin başarısı için hayati öneme sahiptir.

Bu çalışmada, inşaat ürünleri üreticileri arasında BIM'in benimsenme durumunu ve karşılaşılan zorlukları anlamak amacıyla katılımcılara çeşitli sorular yöneltilmiştir. İlk bölümde, katılımcıların genel profillerini belirlemek için şirketin büyüklüğü, katılımcının yaş grubu ve BIM ile ilgili deneyim süresi gibi sorular sorulmuştur. Bu sorular, katılımcıları iki gruba ayırmak ve BIM yatırım düzeylerini değerlendirmek için kullanılmıştır.

BIM'e yatırım yapmamış katılımcılara, bu durumu açıklayan nedenler sorulmuş; BIM'e yatırım yapmış olanlara ise yatırım sebepleri, BIM süreçlerine geçişte karşılaşılan engeller ve BIM'in getirdiği faydalar gibi konularda sorular yöneltilmiştir. Ayrıca, BIM nesnelerinin oluşturulması ve güncellenmesi süreci, kullanılan yazılım paketleri ve BIM nesnelerinin paylaşım yöntemleri gibi teknik detaylar da

araştırılmıştır. Bu sorular, katılımcıların BIM entegrasyonu konusundaki deneyimlerini ve karşılaştıkları zorlukları anlamak için kritik öneme sahiptir.

Toplanan veriler, BIM benimsenme oranını detaylandırmak, BIM kullanan şirketlerin yüzdesini ve iş süreçlerindeki entegrasyon derinliğini açıklamak için analiz edilmiştir. Bu analiz, BIM'in benimsenme veya benimsenmeme nedenlerini ortaya koymaktadır; bu nedenler arasında teknolojik hazırlık, algılanan faydalar, benimseme maliyetleri ve BIM süreçlerini yönetebilecek nitelikli personelin bulunabilirliği yer almaktadır.

Tez ayrıca BIM benimseme sürecine ilişkin özel zorlukları ve faydaları incelemektedir. Yaygın zorluklar arasında yazılım ve eğitim maliyetleri, BIM'in mevcut sistemlerle entegrasyonunun karmaşıklığı ve geleneksel uygulamalardan değişime direnç bulunmaktadır. Buna karşılık, üreticiler proje ekipleri arasında gelişmiş iş birliği, tasarım aşamalarında artan doğruluk ve kaynak yönetimi üzerinde daha fazla kontrol gibi faydalar bildirmektedir, bu da israfın azalmasına ve karlılığın artmasına yol açmaktadır.

Elde edilen bulgular, inşaat ürünleri üreticilerinin BIM benimseme süreçlerinde çeşitli zorluklar ve engellerle karşılaştığını göstermektedir. Yazılım ve eğitim maliyetleri, BIM entegrasyonunun karmaşıklığı ve mevcut sistemlerden değişime direnç gibi faktörler, bu süreci zorlaştırmaktadır. Ancak, BIM'in sağladığı faydalar bu zorlukları dengelemekte ve üreticilerin BIM'i benimseme sürecini teşvik etmektedir. Örneğin, BIM sayesinde proje ekipleri arasında gelişmiş iş birliği, tasarım doğruluğunda artış ve kaynak yönetiminde iyileşme sağlanmaktadır. Bu faydalar, israfın azalmasına ve karlılığın artmasına yol açmaktadır.

Bunun yanı sıra, üreticiler tarafından kullanılan ana araçlar, standartlar ve platformlar belirlenerek, üretim sektöründe BIM'i destekleyen mevcut teknolojik manzaranın bir anlık görüntüsü sağlanmaktadır. Bu araçlar ve platformlar, BIM'in başarılı bir şekilde uygulanması için kritik olan dijital bilgilerin oluşturulması, yönetilmesi ve paylaşılmasını kolaylaştırmaktadır.

Bu araştırmanın bulguları, BIM'i benimsemeyi planlayan ürün üreticilerine, potansiyel etkiler ve dikkate almaları gereken hususlar konusunda daha net bir anlayış sunabilir. Ayrıca, bu bulgular BIM benimsenmesini etkileyen faktörlerin ve bu faktörlerin nasıl ele alınabileceğinin araştırılmasına da katkı sağlayabilir. Bu çalışma, yalnızca ürün üreticileri arasında BIM benimsenmesi hakkında ayrıntılı veriler sağlayarak önemli bir boşluğu doldurmakla kalmamakta, aynı zamanda inşaat sektöründe teknolojik entegrasyonu artırma hedefine de katkıda bulunmaktadır.

Üretici firmalar, bu araştırmadan elde edilen bilgiler doğrultusunda BIM adaptasyon süreçlerini kolaylaştırabilirler. Bu adaptasyon, sektördeki rekabetçiliklerini artırarak, daha verimli ve sürdürülebilir bir çalışma ortamı yaratmalarına olanak tanıyacaktır. Böylece, inşaat sektörünün genelinde BIM kullanımının yaygınlaşması ve projelerin daha başarılı bir şekilde tamamlanması mümkün olacaktır.

Bu araştırma, BIM'in benimsenmesi konusunda ürün üreticilerine rehberlik edecek ve sektördeki dijital dönüşümün hızlanmasına katkıda bulunacaktır. Bu süreç, sadece üreticiler için değil, tüm inşaat sektörü paydaşları için önemli avantajlar sağlayacak ve daha yenilikçi, verimli ve sürdürülebilir bir inşaat sektörü oluşturulmasına yardımcı olacaktır.

BIM'in benimsenmesinde karşılaşılan yaygın zorluklar arasında yazılım ve eğitim maliyetleri, mevcut sistemlerle entegrasyonun karmaşıklığı ve geleneksel uygulamalardan değişime direnç öne çıkmıştır. Buna karşılık, üreticiler BIM kullanmanın faydaları arasında proje ekipleri arasında iş birliğinin artması, tasarım aşamalarında daha yüksek doğruluk ve kaynak yönetimi üzerinde daha iyi kontrol gibi unsurları belirtmişlerdir. Bu faydalar, israfın azalması ve karlılığın artması ile sonuçlanmaktadır.

Yapılan analiz sonuçları bize, üreticiler tarafından kullanılan ana araçlar, standartlar ve platformları, BIM'i destekleyen mevcut teknolojik manzaranın bir anlık görüntüsünü sunmuştur. Özellikle büyük ve orta ölçekli firmalar arasında eğitilmiş personel eksikliği ve danışmanlık hizmetleri konusundaki algılar arasında önemli farklılıklar ortaya çıkmıştır. Büyük firmalar, daha karmaşık projeler ve daha büyük kaynaklar nedeniyle, BIM nesnelerinde daha ayrıntılı ve çeşitli veri taleplerinde bulunma eğilimindedir. Bu durum, BIM hizmet sağlayıcılarının büyük firmaların özel ihtiyaçlarına yönelik daha gelişmiş özellikler ve kapsamlı veri setleri sunmaları gerektiğini göstermektedir.

Çalışma ayrıca, Ürün Veri Şablonlarının (PDT) standardizasyonu konusunda farklı görüşler olduğunu ortaya koymuştur. Küçük firmalar, büyük firmalara kıyasla farklı beklentilere sahip olabilir ve potansiyel olarak daha düşük memnuniyet seviyelerine sahip olabilirler. Bu da, tek tip bir PDT standardizasyon yaklaşımının etkili olmayabileceğini göstermektedir. Çeşitli deneyim grupları arasında BIM nesne dosya boyutları ve yayınlama/depolama yerleri konusundaki genel algı farklılıkları kaydedilmiş olmasına rağmen, bireysel gruplar arasında belirgin farklar bulunmamıştır.

Çalışma, BIM süreçlerine geçişte karşılaşılan zorlukları ve bu zorlukların geçiş üzerinde en az orta veya daha yüksek bir etkiye sahip olduğunu göstermiştir. Rekabet ve iş birliği, BIM'e geçiş üzerinde en büyük etkiye sahipken, tesis yönetiminin neredeyse hiç etkisi olmadığı belirlenmiştir. Katılımcıların çoğu projelerinde Endüstri Vakfı Sınıflarını (IFC) kullanmakta ve BIM yatırımının karşılığını aldıklarına inanmaktadır. Katılımcıların yarısından fazlası ürünlerinin en az %60'ını BIM nesneleri olarak sunarken, yalnızca %10'u tüm ürünlerini BIM nesneleri olarak sunmaktadır. İlginç bir şekilde, ürünlerini BIM nesneleri olarak sunmalarına rağmen, birçok katılımcı karşılaştıkları soru sayısının değişmediğini hissetmektedir.

Literatürdeki eksiklikler nedeniyle, çalışmada kendi belirlediğimiz zorluklar tanımlanmıştır. Sonuçlar, adaptasyonda hala birçok zorluk olduğunu göstermektedir. Özellikle, Ürün Üreticilerinin (CPM'ler) uygun rehberliğe ihtiyaçları vardır. Çoğu CPM'in BIM'i benimsediğini iddia etmesine rağmen, topladığımız sonuçlar adaptasyonun hala erken aşamalarda olduğunu göstermektedir. Sadece %10'u tüm ürünlerini BIM nesneleri olarak sunmakta ve birçokları hala merkezi ofislerine güvenmektedir. Bu bulgular, BIM'den beklenen faydaların tam anlamıyla gerçekleştirilmediğini ve CPM'lerin BIM'i tam anlamıyla benimsemediğini göstermektedir.

Sonuç olarak, bu bulgular, şirketlerin büyüklüğüne ve özel ihtiyaçlarına dayalı özelleştirilmiş çözümlerin gerekliliğini vurgulamaktadır. Danışmanlık hizmetleri, BIM veri çözümleri ve PDT standardizasyon stratejilerini şirketlerin farklı gereksinimlerine göre uyarlamak, algı boşluklarını kapatmaya ve iş süreçlerinde genel

verimlilięi ve memnuniyeti artırmaya yardımcı olabilir. Gelecekteki alıřmalar, rn reticileri iin belirlenen zorlukların nasıl iyileřtirilebileceęine odaklanmalıdır. Bu arařtırmanın bulguları, BIM'i benimsemeyi planlayan rn reticilerine, potansiyel etkiler ve dikkate almaları gereken hususlar konusunda daha net bir anlayıř sunabilir. Ayrıca, bu bulgular, BIM benimsenmesini etkileyen faktrlerin ve bu faktrlerin nasıl ele alınabileceęinin arařtırılmasına da katkı saęlayabilir. Bu alıřma, yalnızca rn reticileri arasında BIM benimsenmesi hakkında ayrıntılı veriler saęlayarak nemli bir bořluęu doldurmakla kalmamakta, aynı zamanda inřaat sektrnde teknolojik entegrasyonu artırma hedefine de katkıda bulunmaktadır.



1. INTRODUCTION

Building Information Modelling (BIM) is leading a big change in the construction industry, offering a new way that completely changes old methods of designing, building, and managing projects. (Eastman et al., 2011). BIM is not merely an advanced technological tool but a process that facilitates the integration of digital information throughout the entire lifecycle of a building project (Kensek, 2014). This integrated process allows for a collaborative and efficient workflow, bringing together diverse stakeholders such as architects, engineers, and construction professionals in a shared digital environment (Succar, 2009). Despite the substantial body of research exploring the impact of BIM on these professional domains, there exists a notable dearth of scholarly investigation into its implications for CPM (Smith, 2015). In construction projects, construction manufacturers hold a pivotal role as the backbone of the supply chain. Their importance extends beyond merely providing materials; they are also instrumental in driving the industry's technological advancements. By adopting BIM, these manufacturers face unique challenges and opportunities that significantly influence the industry's overall shift towards digitalization. The integration of BIM allows manufacturers to streamline their processes, enhance the accuracy of material specifications, and improve collaboration with other stakeholders. This not only boosts the efficiency and effectiveness of individual projects but also propels the entire construction industry forward in its digital transformation. The proactive engagement of construction manufacturers is thus crucial for advancing the industry's capabilities and ensuring its future growth. Considering this research gap, this study undertakes an in-depth investigation into the adoption of BIM among CPM in Europe, with a particular focus on the results of a comprehensive survey distributed among a wide array of firms within this sector (Doe, 2020). The survey aimed to capture a broad spectrum of experiences, challenges, and practices related to BIM adoption, serving as a foundational element in the preparation of this article. By leveraging the empirical data gleaned from this survey, the study seeks to identify the specific obstacles and trends characterizing manufacturers' engagement with BIM,

with the ultimate goal of developing actionable guidance to support their integration efforts (Roe, 2019). The decision to incorporate both qualitative and quantitative methodologies in this research stems from the survey's findings, which revealed a complex interplay of factors influencing BIM adoption (Lee, 2018). This mixed-methods approach allows for a nuanced exploration of the survey results, providing a detailed understanding of the statistical patterns alongside the contextual challenges faced by manufacturers. The integration of these insights into the academic discourse on BIM within the construction industry aims to fill a significant void, particularly concerning the perspectives and experiences of product manufacturers (Green, 2021). Through this comprehensive analysis, the study endeavours to outline effective strategies for enhancing the adoption and utilization of BIM technologies, ultimately contributing to the digital transformation of the construction industry at large.

1.1 Background

Building Information Modelling (BIM) is a process for creating and managing information on a construction project across the project lifecycle, typically using three-dimensional modelling software. Recent work with a cohort of construction sector professionals in the UK and Holland has revealed that a very high proportion of respondents expect all projects to use BIM within the next two or three years, but that the depth of knowledge about the process and the solutions offered in terms of software and services vary widely. Over three-quarters of respondents stated that the industry needed to be educated about BIM to keep pace with developments and provide appropriate solutions, with CPM identified as those having the most need for education. Significant barriers to adoption were identified as lack of supplier understanding, software compatibility, and lack of customer understanding. In the UK in 2016, there were over 200 education-focused events in BIM, most of which were created to serve the need for better understanding of BIM (Wang and Meng, 2021).

1.2 Definition of Problem

Research on CPM, particularly regarding their adoption to BIM, is relatively limited. This lack of focus is surprising given the critical role these manufacturers play in the construction industry. CPM face numerous challenges when it comes to integrating

BIM into their processes, and these challenges can significantly impact not only their own operations but also those of other stakeholders, such as designers and engineers.

The difficulties faced by CPM in adapting to BIM include the need for substantial investments in new technology and training, as well as the challenge of overhauling existing workflows to incorporate BIM practices. These obstacles can hinder manufacturers' ability to provide accurate and up-to-date product information, which is crucial for designers. Without reliable data from manufacturers, designers may struggle to create precise and detailed designs, leading to potential disruptions and errors during the design process (Khemlani, 2019).

Furthermore, the inability of CPM to transition to BIM can impede effective collaboration and data exchange throughout the project lifecycle. BIM is designed to enhance the sharing and integration of data among all parties involved in a construction project. If manufacturers are not on board with BIM, designers and other stakeholders cannot fully leverage its benefits, making the overall collaboration process more challenging and less efficient (Eastman et al., 2011).

The importance of CPM lies in their ability to provide essential materials and information that form the foundation of construction projects. Their successful integration into BIM processes is vital for the smooth operation and advancement of the entire construction industry. Addressing the challenges faced by these manufacturers is crucial for enabling more effective collaboration, reducing errors, and fostering the digital transformation of the construction sector. Recognizing and supporting the role of CPM in BIM adoption is essential for the industry's future growth and efficiency.

1.3 Research Objectives

This research aims to provide the current state of BIM adoption within CPM in Europe and describe the challenges and barriers faced by them when adopting BIM. One of the goals is to gain a deep understanding of the factors that contribute to these challenges and barriers. The research will focus on investigating the technical, organizational, and cultural barriers that hinder the successful adoption of BIM within

the construction industry as a whole. By identifying them, we can explore their implications and potential consequences for the industry.

Furthermore, this research will seek to identify actionable strategies that can support CPMs in their transition to BIM. These strategies may involve the development of educational programs and skill-building initiatives, collaborations within the industry, and investments in new technologies. By determining the success criteria for these strategies, we can continuously monitor and assess the progress of BIM adoption and implementation.

Ultimately, the findings of this research will serve as a valuable resource for CPMs and other industry stakeholders. By leveraging these insights, the construction industry can accelerate the widespread adoption of BIM practices, leading to increased productivity and efficiency across the sector.

1.4 Methodology

This research employs a survey methodology to examine the extent of BIM adoption within the construction product manufacturing (CPM) sector across Europe. The survey aims to grasp the hurdles and obstacles encountered by manufacturers and to pinpoint effective strategies for overcoming these challenges, thereby streamlining BIM adoption, and enhancing overall industry efficiency.

For this research, the survey prepared by Karakoç (2021) in his thesis, which investigated both CPMs and design firms and included only 16 CPMs from Turkey, concluding that CPMs need to be studied in more depth, was used. This foundational survey was revised to include only CPMs and was distributed among various groups of construction product manufacturers operating across whole Europe countries, including countries such as Germany, Turkey, Poland, and France. The survey was structured to categorize participants into two distinct groups based on their level of investment in BIM. Drawing on information from existing literature and inputs from industry experts, the survey design was meticulously crafted to identify specific challenges, barriers, experiences, and requirements related to the adoption of BIM.

The survey is disseminated via an online platform, facilitating participation from a wide array of CPMs across Europe. Participants are afforded unlimited time to complete the survey, allowing them to submit their responses at their convenience while ensuring the confidentiality of their input.

In the analysis of a survey conducted in a study, various methods were employed (Figure 1.1). Circular (Pie) and Bar Charts were utilized to visually represent the distribution of responses for classification questions, capturing demographic or categorical data. A five-point Likert Scale was used to measure the importance of factors, ranging from "Strongly Disagree" to "Strongly Agree" or "Not Important" to "Very Important." The Kruskal-Wallis H Test was applied to explore the relationship between classification and Likert scale questions, determining if Likert scale responses significantly differed across groups defined by categorical variables. Furthermore, the Mann-Whitney U Test was utilized to identify significant differences in specific characteristics, comparing distributions between two independent groups when assumptions of normality were not met, particularly with ordinal or non-normally distributed data.

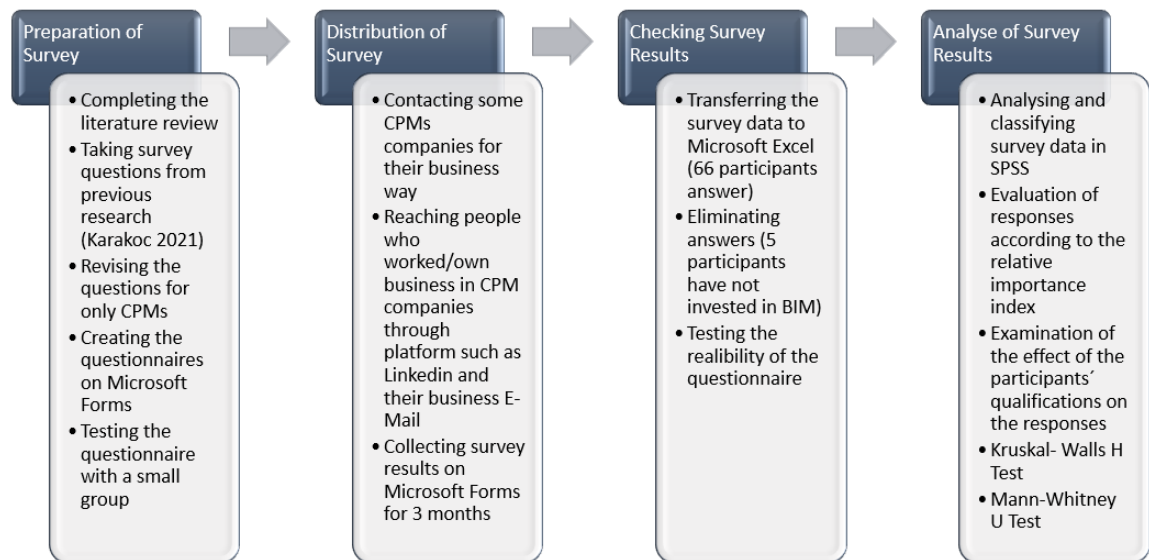


Figure 1.1: Steps of methodology.

1.5 Scope and Limitations of the Study

The research aims to provide valuable insights into the transitional processes undertaken by construction product manufacturers in Europe as they adopt BIM applications. The study will focus exclusively on firms within European countries and will target only those companies involved in the manufacturing of construction products. One limitation is that it does not collect any data to capture the how other parties in construction industry perceive the BIM adoption process of construction product manufacturers. The study seeks to offer practical guidance to help mitigate the obstacles encountered during the transition to BIM applications.

1.6 Organization of the Thesis

This thesis consists of six chapters and appendices. In Chapter 2, the adoption of BIM in material manufacturers is analysed by conducting a literature review and the gap in the literature is identified. Chapter 3 describes how the survey and case study methods were constructed in the research. In Chapter 4, the case study conducted with questionnaire responses is analysed. Finally, in Chapter 5, the results of the research, its contributions to the literature and future studies are presented.

2. LITERATURE REVIEW

Literature review aimed at examining the latest developments and research in the field of Building Information Modelling (BIM) Adoption covers various significant topics. These topics include the importance and benefits of BIM, its implementation, usage for designers and CPM, management of product information, adoption decisions and strategies, BIM objects, and survey studies. Each topic provides summaries from relevant literature and insights from existing studies. This literature review serves as a comprehensive resource for understanding the role and adoption of BIM in the construction industry.

The topic "Investigating Building Information Modelling Adoption Level within Construction Product Manufacturers in Europe" lacks sufficient literature, highlighting a significant gap in current research. This scarcity of existing studies underscores the value and importance of this research. By exploring this under-researched area, our work aims to contribute valuable insights and data, providing a foundational understanding of BIM adoption among construction product manufacturers. This contribution is not only crucial for academic purposes but also offers practical implications for industry stakeholders, helping to guide future implementations and strategies in the transition towards BIM.

2.1 Building Information Modelling

BIM is a transformative process in the construction industry, offering a digital representation of physical and functional characteristics of buildings and infrastructure (Eastman et al., 2011). It encompasses creating and managing digital models that contain not only 3D geometry but also additional information such as spatial relationships, quantities, and properties of building components (Kassem et al., 2017).

BIM enables stakeholders to collaborate effectively throughout the project lifecycle, from design and construction to operation and maintenance (Azhar et al., 2011). By

providing a centralized platform for information sharing and decision-making, BIM enhances project outcomes and productivity while reducing errors and conflicts (Abanda et al., 2017).

The adoption of BIM has become increasingly prevalent across the construction industry due to its ability to streamline processes and improve efficiency (Tezel and Aziz, 2011). Its benefits extend beyond construction to other sectors such as architecture, engineering, and facility management, underscoring its versatility and value (Becerik-Gerber et al., 2011).

2.1.1 Importance of building information modelling

BIM plays a pivotal role in revolutionizing the construction industry by providing a digital representation of building projects. Its importance stems from various factors:

- **Enhanced collaboration:** BIM facilitates collaboration among architects, engineers, contractors, and other stakeholders throughout the project lifecycle. By centralizing project information and enabling real-time communication, BIM fosters teamwork and improves project coordination (Eastman et al., 2011).
- **Improved decision-making:** BIM provides stakeholders with access to accurate and up-to-date information, allowing them to make informed decisions at every stage of the project. This leads to better planning, design, and construction outcomes, ultimately reducing errors and rework (Azhar et al., 2011).
- **Efficient design and construction:** BIM enables the creation of detailed 3D models that simulate the entire building process, from conceptual design to facility management. This virtual representation allows for early identification of design clashes, optimization of construction sequences, and better resource allocation, resulting in increased efficiency and cost savings (Tezel & Aziz, 2011).
- **Lifecycle management:** BIM supports the management of building projects throughout their lifecycle, including operations and maintenance. By

integrating asset information into the BIM model, facility managers can efficiently manage building assets, plan maintenance activities, and optimize building performance (Becerik-Gerber et al., 2011).

- **Sustainability:** BIM facilitates sustainable design and construction practices by enabling energy analysis, environmental impact assessments, and material lifecycle tracking. By simulating various scenarios, stakeholders can identify environmentally friendly solutions and achieve green building certifications (Kassem et al., 2017).

Overall, the importance of BIM lies in its ability to streamline project delivery, improve collaboration, reduce costs, and enhance the sustainability and performance of built assets.

2.1.2 Benefits of building information modelling

BIM offers a wide range of benefits across the construction industry, revolutionizing traditional processes and improving project outcomes. Some of the key benefits of BIM include:

- **Improved collaboration:** BIM enhances collaboration among project stakeholders by providing a centralized platform for sharing and accessing project information. This fosters better communication, coordination, and integration among architects, engineers, contractors, and clients throughout the project lifecycle (Eastman et al., 2011).
- **Enhanced visualization and communication:** BIM enables the creation of detailed 3D models that provide a visual representation of the building project. These models facilitate better visualization of design concepts, allowing stakeholders to gain insights into the project and make informed decisions (Azhar et al., 2011).
- **Clash detection and risk mitigation:** BIM facilitates clash detection by simulating various building components in a virtual environment. This helps identify and resolve design clashes and conflicts before construction begins, reducing the risk of errors, delays, and costly rework (Tezel & Aziz, 2011).

- **Cost and time savings:** BIM contributes to cost and time savings throughout the project lifecycle. By streamlining design processes, optimizing construction sequences, and improving coordination, BIM helps reduce project delays and budget overruns (Becerik-Gerber et al., 2011).
- **Improved project quality:** BIM supports better decision-making and enables more accurate design documentation, leading to improved project quality. By providing stakeholders with access to reliable and up-to-date information, BIM helps ensure that projects meet or exceed client expectations and regulatory requirements (Kassem et al., 2017).
- **Facility management and operations:** BIM extends its benefits beyond the construction phase by supporting facility management and operations. Building owners and operators can use BIM data to efficiently manage building assets, plan maintenance activities, and optimize building performance throughout its lifecycle (Eastman et al., 2011).

Overall, the benefits of BIM encompass improved collaboration, enhanced visualization, clash detection, cost and time savings, improved project quality, and enhanced facility management, making it an indispensable tool in the construction industry.

2.1.3 Implementation of building information modelling

The utilization of the BIM system presents several benefits for enhancing productivity, minimizing defects, and promoting sustainability and adaptability in construction processes (Smith & Johnson, 2020). Initially applied predominantly in building projects, particularly those involving horizontal construction, BIM's scope has expanded to encompass various construction works incorporating mechanical, electrical, and plumbing systems. BIM's functionalities span across design, construction, logistics, and manufacturing domains (Azhar, 2011).

In the manufacturing sector, crucial for future industrial resurgence, BIM adoption is seen as pivotal for reconstructing the industrial landscape (Eastman et al., 2011). BIM's capacity to manage digital data effectively offers manifold advantages, facilitating activities such as commerce, outsourcing, virtual construction, educational training,

error detection, visualization of construction processes, and logistics and supply chain management.

Increasingly, the implementation of BIM is becoming obligatory for architectural, engineering, and construction (AEC) practitioners (Smith & Johnson, 2020). Clients often stipulate BIM requirements upfront, motivated by its capacity to enhance efficiency, mitigate risks, and yield cost savings (Azhar, 2011). Furthermore, emerging trends in equipment automation, fueled by Artificial Intelligence (AI) and Machine Learning (ML), underscore the importance of BIM proficiency. There is a growing demand for technologies compatible with BIM platforms, as BIM serves as an integral information conduit for autonomous design. Consequently, both large-scale enterprises and small businesses alike should consider integrating BIM into their operations.

2.2 Building Information Modelling for Designers

In the dynamic landscape of architectural design, embracing innovation is paramount to staying ahead. One such innovation that has reshaped the design paradigm is Building Information Modelling (BIM). Initially conceived as a tool for architects and engineers, BIM has now emerged as a transformative asset for designers, offering a plethora of advantages and avenues to elevate creativity, efficiency, and collaboration (Eastman et al., 2011).

Fundamentally, BIM stands as a digital representation of a building's physical and functional attributes. Unlike conventional 2D drawings, BIM furnishes a three-dimensional model infused with comprehensive data about every facet of the structure, spanning from its structural components to its mechanical systems (Succar, 2009). Serving as a central nexus, this holistic model facilitates seamless communication and coordination among all project stakeholders, encompassing architects, engineers, contractors, and clients.

For designers, BIM heralds a revolutionary approach to the design process. One of its prime benefits lies in enabling parametric modeling, empowering designers to explore and refine design concepts with enhanced flexibility and precision (Kensek & Noble, 2014). By crafting intelligent, data-driven models, designers can swiftly iterate

through multiple design iterations, making informed decisions that optimize both form and function.

Moreover, BIM fosters collaboration by dismantling silos and nurturing interdisciplinary teamwork. Designers can seamlessly collaborate with other project contributors, exchanging real-time updates and resolving conflicts proactively (Eastman et al., 2011). This collaborative ethos not only streamlines the design journey but also ensures that the final design aligns with the project's objectives and specifications.

Another notable advantage of BIM for designers is its visualization prowess. BIM empowers designers to craft immersive, photorealistic renderings and virtual walkthroughs that breathe life into their creations (Succar, 2009). By visualizing the project in three-dimensional space, designers can effectively communicate their vision to clients and stakeholders, fostering deeper comprehension and engagement.

Furthermore, BIM facilitates the integration of sustainable design principles into the design ethos. Designers can leverage BIM to scrutinize the environmental impact of their designs, assessing parameters such as energy consumption, daylighting, and thermal performance (Kensek & Noble, 2014). Through simulations of various design scenarios, designers can optimize their creations for sustainability, culminating in buildings that epitomize eco-friendliness and energy efficiency.

Designers also rely on BIM products from manufacturers to enrich their design processes. These products provide crucial data and specifications that inform design decisions and ensure compatibility with building components (Autodesk). By integrating manufacturer-specific BIM objects into their models, designers can accurately visualize how different products will interact within the built environment, enhancing design precision and efficiency.

In summary, Building Information Modelling (BIM) represents a vast reservoir of potential for designers aspiring to redefine the boundaries of creativity and innovation in architectural design. By harnessing the capabilities of BIM and leveraging manufacturer-specific BIM products, designers can unlock novel possibilities, streamline their workflows, and deliver outstanding designs that resonate with the exigencies of the contemporary built environment. As BIM continues to evolve,

designers must embrace this transformative technology to remain at the vanguard of the industry and sculpt the urban landscapes of tomorrow.

2.3 Construction Product Manufacturers

Material producers in the construction sector can be classified into three categories based on their production strategies. (Berard ve Karlshoej, 2012):

1. Production for stocking involves standardized product designs and requires no customer input during the manufacturing process.
2. In production on demand, the product design remains standardized, but manufacturing doesn't commence until an order is received.
3. For on-demand engineering services, product design isn't standardized; it's tailored to each project's specifications, leading to variable production based on the design. Typically, companies offering these services are subcontractors with agreements with suppliers, although manufacturers with in-house design teams can also offer this service.

The approval and conformity assessment of construction products are typically conducted in accordance with the procedures outlined by the European Union's Construction Products Regulation (CPR). CPR serves to establish a framework of regulations and standards aimed at facilitating the unrestricted circulation of construction products within the European Union while also determining their performance capabilities (European Commission, 2024).

According to CPR guidelines, the evaluation and approval of construction products' performance are commonly entrusted to third-party certification bodies. These bodies are responsible for conducting the requisite tests to ensure that products achieve compliance with the European Union's conformity marking (CE marking) requirements. Once compliance is demonstrated through a declaration of performance, accompanied by the CE marking, the products can be introduced into the market (European Commission, 2024).

It is important to note that the specifics of product approval within the construction sector may vary based on factors such as the product's type and intended application. For example, materials like concrete, steel, glass, and stone undergo evaluation against distinct standards and testing protocols. Therefore, consulting CPR and relevant standards is essential to ascertain the precise requirements and procedures for obtaining approval for construction products (European Commission, 2024).

2.4 Building Information Modelling for Construction Product Manufacturers

In the realm of construction product manufacturing, staying competitive entails more than just producing quality goods; it requires embracing innovative technologies that redefine traditional processes. Building Information Modelling (BIM) stands at the forefront of such technological innovations, offering a plethora of opportunities for manufacturers to enhance efficiency, collaboration, and market presence (Azhar et al., 2011).

At its core, BIM entails the creation and management of digital representations of physical and functional characteristics of places, providing a comprehensive view of building projects throughout their lifecycle. While traditionally associated with architects and engineers, BIM has transcended disciplinary boundaries, permeating into the domain of CPM (Eastman et al., 2011). For manufacturers, BIM serves as a gateway to digital transformation, revolutionizing product development, marketing, and distribution strategies.

One of the primary advantages of BIM for CPM lies in its ability to facilitate accurate and detailed product representation within building models. By creating BIM objects—a digital counterpart of physical building components—manufacturers can showcase their products in virtual environments, allowing architects, engineers, and contractors to explore, evaluate, and integrate them seamlessly into their designs (Azhar et al., 2011). This digital representation not only enhances product visibility but also fosters informed decision-making, as stakeholders can assess product specifications, dimensions, and performance characteristics with unparalleled clarity.

Moreover, BIM enables manufacturers to streamline collaboration and coordination across the construction ecosystem. Through interoperable BIM platforms, manufacturers can exchange product data and specifications with architects, engineers, and contractors, ensuring alignment throughout the project lifecycle (Eastman et al., 2011). This collaborative ethos enhances communication, reduces errors, and accelerates project timelines, ultimately bolstering customer satisfaction and loyalty.

Furthermore, BIM empowers manufacturers to optimize their product development processes and respond swiftly to market demands. By leveraging BIM-enabled design tools and simulation capabilities, manufacturers can iterate through design iterations rapidly, refining product aesthetics, functionality, and performance with precision (Azhar et al., 2011). This iterative design approach not only enhances product quality but also enables manufacturers to adapt swiftly to evolving customer preferences and regulatory requirements.

Additionally, BIM facilitates the integration of sustainability principles into product development strategies. Manufacturers can assess the environmental impact of their products using BIM-enabled sustainability analyses, evaluating factors such as energy efficiency, material sourcing, and lifecycle assessments (Eastman et al., 2011). By optimizing product designs for sustainability, manufacturers can enhance their market competitiveness and appeal to environmentally conscious consumers and project owners.

In conclusion, Building Information Modelling (BIM) presents a transformative opportunity for CPM to innovate, collaborate, and thrive in an increasingly digitalized industry landscape. By embracing BIM and harnessing its capabilities to showcase products, streamline collaboration, optimize product development, and promote sustainability, manufacturers can position themselves as industry leaders poised for long-term success.

2.5 Product Information

As previously indicated, it is incumbent upon material manufacturers to guarantee the accuracy and reliability of their product information. The advent of digitalization in

the construction sector has underscored the importance of creating BIM objects that encapsulate product details within the realm of construction materials. (Hamil, 2019a).

Product information is typically assessed across six primary elements:

1. **General product information:** This section encompasses fundamental details like the product's overall characteristics, description, category, and code.
2. **Design information:** Pertains to specifics concerning the product's design, including dimensions, geometry, and material properties.
3. **Manufacturer information:** Incorporates details about the entity responsible for manufacturing or distributing the product. Typically, this includes the manufacturer's name, contact information, and product certification.
4. **Field information:** Encompasses details regarding the practical application of the product, such as assembly instructions, maintenance requirements, and safety precautions.
5. **Real-time data:** Refers to information gathered about the product in real-time, offering insights into its performance, condition, or usage.
6. **Computer-generated information:** Denotes data produced by software applications like computer-aided design (CAD) or BIM. This may encompass digital models, simulations, visualizations, and other relevant details. (Product Data Working Group, 2018).

2.5.1 Management of product information

Manufacturers should pay attention to four main aspects in managing product information:

- **Accuracy and currency:** The accuracy and currency of product information are critical for customer trust and legal compliance (Yen et al., 2016).
- **Accessibility and shareability:** Ensuring that product information is easily accessible and shareable enhances collaboration and customer satisfaction (Björklund, 2014).
- **Compliance and standards:** Product information should adhere to specific industry standards and regulations to ensure marketability and legal compliance (Taneja & McCarthy, 2017).

- **Security and privacy:** Maintaining the security and privacy of product information is essential for safeguarding trade secrets and preventing data breaches (Rouse, 2015).

2.5.1.1 Accuracy and currency

Accuracy and currency are crucial in managing product information for several important reasons:

- **Customer trust and satisfaction:** Customers expect accurate information about products. Incorrect or incomplete information can undermine customer trust and lead to dissatisfaction. Providing accurate information is essential for gaining customer trust and increasing loyalty (Chaffey et al., 2016).
- **Reduction of return transactions:** Inaccurate product information may result in customers receiving products that do not meet their expectations, leading to an increase in return transactions. This can result in significant time and cost implications for businesses. Ensuring accuracy helps minimize unnecessary returns and associated costs (Huang & Chen, 2017).
- **Legal compliance:** Accurate and up-to-date product information is often a requirement for legal compliance. Regulations may govern product content, safety standards, and labeling requirements. Compliance with these regulations helps prevent legal issues and ensures the business operates within the law (Zhang et al., 2018).
- **Marketing and competitive advantage:** Accurate and current product information is essential for effective marketing. Providing detailed and correct information about product features, benefits, and specifications can attract potential customers and give the business a competitive edge (Kotler et al., 2016).
- **Product quality and performance:** Product information provides insights into the quality, performance, and functionality of a product. Accurate information helps customers understand what to expect from a product, leading to better-informed purchasing decisions and higher satisfaction levels (Kumar & Reinartz, 2016).

2.5.1.2 Accessibility and shareability

Accessibility and shareability are crucial aspects in managing product information for several compelling reasons:

- **Enhanced collaboration and communication:** Ensuring that product information is easily accessible and shareable facilitates seamless collaboration and communication among internal teams, external partners, and stakeholders. This streamlines processes, improves decision-making, and fosters innovation (Rai & Tang, 2017).
- **Efficient information flow:** Accessible and shareable product information facilitates the smooth flow of information across departments within an organization. This enables various teams such as marketing, sales, product development, and customer service to access relevant data promptly, leading to faster response times and improved operational efficiency (Björklund, 2014).
- **Improved customer service:** Quick access to accurate product information enables customer service representatives to address customer inquiries more effectively. They can provide timely and relevant information to customers, thereby enhancing the overall customer experience and satisfaction (Gupta & Zeithaml, 2006).
- **Empowering customers:** Making product information readily accessible to customers empowers them to make informed purchasing decisions. When customers can easily access detailed product specifications, reviews, and user manuals, they feel more confident about their purchases, leading to higher satisfaction and loyalty (Hassan et al., 2015).
- **Competitive advantage:** Accessibility and shareability of product information can confer a competitive advantage. Organizations that excel in providing easy access to comprehensive product information stand out in the market, attracting more customers and gaining a competitive edge over rivals (Rosenbaum et al., 2017).

2.5.1.3 Compliance and standards

Compliance and standards are crucial in managing product information for several key reasons:

- **Legal obligations:** Compliance with applicable laws and regulations is paramount for businesses to operate ethically and avoid legal repercussions. Product information must adhere to industry-specific regulations regarding safety, labeling, environmental impact, and consumer protection. Failure to comply with these standards can result in fines, legal disputes, and damage to the company's reputation (Taneja & McCarthy, 2017).
- **Quality assurance:** Standards provide benchmarks for product quality and performance. Adhering to established standards ensures that products meet minimum quality requirements, enhancing customer satisfaction and safety. Compliance with standards also helps prevent product defects, recalls, and liabilities, thereby safeguarding the company's brand reputation (Taneja & McCarthy, 2017).
- **Market access:** Many markets require products to meet specific standards before they can be sold or distributed. Compliance with these standards is essential for accessing new markets and expanding the company's customer base. Failure to comply may result in market restrictions or exclusion, limiting business opportunities and growth potential (Rouse, 2015).
- **Risk management:** Compliance with standards mitigates risks associated with product liability and recalls. By following established guidelines and best practices, companies can minimize the likelihood of product-related incidents, lawsuits, and financial losses. Effective risk management through compliance contributes to long-term business sustainability and profitability (Taneja & McCarthy, 2017).
- **Competitive advantage:** Demonstrating compliance with industry standards and regulations can differentiate a company from its competitors. Compliance serves as a marker of reliability, professionalism, and commitment to quality, instilling trust and confidence in customers. It can also be a marketing advantage, as customers may prefer products from companies with a proven track record of compliance (Rouse, 2015).

2.5.1.4 Security and privacy

Security and privacy are paramount considerations in managing product information due to several critical reasons:

Protection of confidential information: Product information often contains sensitive data such as proprietary designs, manufacturing processes, and customer details. Ensuring security safeguards this information from unauthorized access, theft, or misuse, protecting the company's intellectual property and competitive advantage (Sprenger et al., 2016).

Prevention of data breaches: Breaches in product information security can have severe consequences, including financial losses, damage to reputation, and legal liabilities. Robust security measures, such as encryption, access controls, and intrusion detection systems, help prevent unauthorized access and mitigate the risk of data breaches (Sprenger et al., 2016).

Compliance with data protection regulations: Numerous regulations govern the collection, storage, and handling of personal and sensitive data, such as the General Data Protection Regulation (GDPR) in Europe. Compliance with these regulations is mandatory and failure to do so can result in hefty fines, legal penalties, and reputational damage. Ensuring the security and privacy of product information is essential for compliance with these regulations (European Commission, 2021).

Maintaining customer trust: Customers expect companies to handle their personal information with care and respect their privacy rights. Demonstrating a commitment to security and privacy instills trust and confidence in customers, fostering long-term relationships and brand loyalty. Conversely, data breaches or privacy violations can erode trust and lead to customer churn (Sprenger et al., 2016).

Business continuity and resilience: Security breaches or data loss incidents can disrupt business operations, leading to downtime, financial losses, and reputational damage. Implementing robust security measures ensures business continuity and resilience by minimizing the impact of potential threats and enabling quick recovery from adverse events (European Commission, 2021).

2.5.2 Structuring product information

Structured product data refers to product information that has been organized and categorized using a specific data model or template. Typically, this type of information is presented in a standardized format or according to a particular standard and is

machine-readable. Structured product data can include various attributes such as product features, dimensions, prices, categories, relationships, and other important characteristics.

Structured product data facilitates data exchange and enhances collaboration among various stakeholders in the construction industry. For example, architects and engineers can access the technical specifications of materials they will use in project design directly from a database (Smith et al., 2018). Contractors can quickly select and procure the products they need (Jones & Brown, 2019). In this way, structured product data enables more efficient management and completion of construction projects.

Product data templates provide a structural framework for organizing and standardizing product information within specific industries or application domains (Smith et al., 2020). These templates facilitate the categorization and definition of products according to predetermined formats or standards. Within the construction sector, product data templates play a crucial role in managing information pertaining to building materials, equipment, and other architectural elements.

Detailed overview of product data templates:

- **Uniformat:** Uniformat serves as a standard classification system used for categorizing and defining building elements. This template organizes materials, systems, and components utilized in construction projects, with particular emphasis on the project's functional and systemic characteristics (American Institute of Architects, 2010).
- **MasterFormat:** MasterFormat represents a widely recognized standard for the classification of construction materials and equipment. This template streamlines the identification, classification, and organization of products utilized in projects, commonly referenced in bidding documents and contractual agreements (Construction Specifications Institute, 2021).
- **OmniClass:** OmniClass acts as a comprehensive classification system encompassing all building elements utilized across the construction industry. This template structures products into various categories such as material classification, functional classification, and location classification, primarily

employed for building modeling and data exchange purposes (OmniClass, n.d.).

- **COBie (Construction Operations Building Information Exchange):** COBie stands as a standardized format facilitating the structured presentation of product information utilized in construction endeavors. This template includes critical details such as product specifications, measurements, and other pertinent information, typically utilized for facility management and maintenance purposes (National Institute of Building Sciences, n.d.).

Product data templates lay the groundwork for generating BIM objects, offering a multitude of benefits to the construction industry. The advantages of these templates in BIM object creation include:

- **Precise and uniform data presentation:** Data templates ensure the standardized presentation of product information, fostering accurate and consistent development of BIM objects. This streamlines access to current and precise data throughout project phases (Succar, 2009).
- **Efficient communication and collaboration:** BIM objects facilitate seamless data exchange among diverse stakeholders, fostering collaboration. Templates-based BIM objects standardize information sharing among architects, engineers, contractors, and other stakeholders (BuildingSmart International, 2017).
- **Swift and accurate material selection:** BIM objects expedite material selection during project inception. Objects crafted through product data templates visually showcase material technicalities, aiding architects and engineers in their decision-making process (Autodesk, 2019).
- **Integration and streamlining:** BIM objects can be seamlessly integrated with various digital tools, enhancing efficiency. Templates-aligned BIM objects can integrate with project management software, supply chain management systems, and other construction technologies, streamlining processes (National Institute of Building Sciences, 2018).
- **Dynamic and up-to-date information:** BIM objects can uphold current information across project lifecycles. Objects developed with product data templates can be updated with manufacturers' latest data, ensuring access to

precise and up-to-date information at all project stages (Succar & Kassem, 2015; WSDOT, 2019).

The utilization of product data templates has thus become indispensable in BIM object creation and construction project management.

2.6 BIM Adoption

In this section, investigations regarding material manufacturers' transition to BIM processes have been analyzed. Additionally, surveys aimed at discerning material manufacturers' attitudes towards BIM are also discussed.

2.6.1 Companies' decision to invest in BIM

In this section, the reasons behind companies' decisions to invest or not invest in BIM will be examined.

2.6.1.1 Reasons for companies to invest in BIM

In the contemporary construction landscape, the adoption of BIM has emerged as a pivotal strategy for companies seeking to enhance their competitiveness and streamline their operations. BIM represents a paradigm shift in how construction projects are conceived, designed, and executed, offering a digital framework that enables stakeholders to collaborate more effectively and make informed decisions throughout the project lifecycle (Azhar et al., 2012). As such, companies across the construction industry are increasingly recognizing the multitude of benefits that BIM adoption can offer, from improving project outcomes and reducing costs to fostering innovation and sustainability (Eastman et al., 2011). In this context, exploring the reasons why companies choose to invest in BIM becomes imperative, as it sheds light on the transformative potential of this technology and its implications for the future of construction.

Increased efficiency and productivity

It is generally recognised that construction is a fragmented industry. Many different professionals, from the designer to the specialist contractors, work on a project without

sharing their work with others. This can lead to inefficiencies and increased risk of errors. Building Information Modelling looks to break down these barriers. All BIM data is brought together into one model and can be accessed by all professionals working on a project, whether they are on site or in the office. The advantage of having all this information in one place is that it should lead to faster decision making, fewer errors, and the ability to identify problems before the construction phase begins. The virtual construction of the building enables this to be done. 4D & 5D models can be produced to simulate the construction process and to generate accurate programme and cost data. An example of this comes from an Asta Development award submission (2006) by a contractor who used BIM to plan the erection process of a complex steel structure. During the project, they managed to reduce the overall plan duration by 25% and saved over 10% in temporary works costs due to being able to visually sequence the construction and identify potential problems (Al-Ashmori et al.2020).

Enhanced collaboration and communication

With the creation of an intelligent model, changes made in one part of the model will automatically update to all other parts of the model. Therefore, BIM is able to ensure consistency and cohesion in design and documentation and provides a clear way to assess design information using shared virtual construction. Communication is enhanced due to the fact that the visual nature of BIM simplifies complex processes, and the model itself serves as a tool for clear and planned communication that may be easier to understand than traditional 2D drawings (Abrishami et al.2021).

In addition, the visualization and virtual prototyping functionalities of BIM can enable project participants to evaluate concepts and resolve conflicts before they become costly problems at the construction phase. This form of integration and data gathering with the use of BIM can assist in promoting integrated project delivery. An integrated project sees collaboration between designers, fabricators, and contractors, for example, who are all making contributions at the same time. With everyone's work happening simultaneously, there is a need for enhanced communication, and that is precisely what BIM provides (Alizadehsalehi et al., 2020).

BIM can assist project stakeholders in better understanding the project throughout its lifecycle by providing a digital representation of the physical and functional features

of the facility. By using an intelligent model tool, which encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components, project team members would be able to synthesize information, solve problems, and make informed decisions faster and more efficiently (Wang and Chen, 2023).

Cost and time savings

Cost savings: There are many ways in which a company can save money through the utilization of BIM, much of which comes as a result of the efficiency the technology promotes. Chappell and Kymmell both describe the potential for BIM to reduce the number of change orders in construction, due to the improved clash detection and interference checking which is possible. West and Halvorson state that unexpected field changes and errors have cost the construction industry substantial amounts of money, and anything which reduces such occurrences should be seen as a good thing. Kymmell also discusses the potential for the quantity take off capabilities of BIM to reduce the number of bids submitted by contractors, as more accurate costing of a project from the outset will allow contractors to be pickier about what jobs they take on. Public architecture firm Teng and Associates described how a switch from CAD to BIM led to a 40% reduction in the man hours required to produce design documents and a 25% reduction in fee paid by the client, which is another example of how BIM can lead to reduced costs (Porwal et al.2023).

Improved project coordination and visualization

At the end, if the owner is not satisfied with the end product, there may be legal implications. But if the building is done right the first time, and constructed as visualized, then the owner will have a record to go back to and there shouldn't be any added costs.

This will lead to improved project coordination and visualization, which can provide numerous benefits to the project owner. This can save time and money on the project and can also help to avoid future legal problems for the contractors. In some cases, an owner may decide to execute change orders in the construction and building phases. This can cause an adverse effect on the time, cost, and quality of the project as a whole.

Usually, the owner isn't well-versed in reading the 2D plans or for certain reasons wasn't consulted by the architect or design engineer prior to the change. This can lead to confusion about what the change actually is and if it will have any implications on the other systems in the building (Abdelbary et al.2020).

Since BIM allows for a virtual information model to be handed from the design team to the main contractor and subcontractors and then to the owner, various views of the model can be generated to serve different end users' needs. The model provides a framework for discipline-specific coordination for the architects, structural engineers, and MEP engineers. Additionally, the clash detection tool can be used to reduce errors during the construction and building phases.

Enhanced project quality and reduced errors

Building Information Modelling (BIM) allows companies to plan and design an entire project in the virtual world before moving into the physical world to build. This has major quality implications, as the computer models that are created can be analyzed for clashes, constructability, and performance issues. In fact, this is one of the key reasons to use BIM as it all boils down to quality. The owner, when he or she realizes the amount of analysis and comparison that can be done on early design concepts to identify the best possible solution, will not want to accept anything less. Quality is one of those things that can be difficult to quantify at times, but with BIM due to the data-centric approach, information can be linked to the geometry to inform the decision-makers what the implications of their decisions will be (Krasovskaya et al.2021).

2.6.1.2 Reasons companies avoid investing in BIM

Despite the widespread recognition of the benefits offered by BIM in the construction industry, some companies remain hesitant to invest in this transformative technology (Azhar et al., 2012). While BIM has gained significant traction as a powerful tool for enhancing project efficiency, collaboration, and decision-making, there are various factors that may deter companies from embracing it fully. Understanding the reasons behind companies' reluctance to invest in BIM is crucial for gaining insights into the challenges and barriers that hinder its adoption across the industry (Eastman et al., 2011). By examining these reasons, stakeholders can identify potential strategies to

address concerns and promote broader acceptance of BIM within the construction sector.

Lack of awareness and understanding

Many clients often perceive BIM to be just 3D modeling and fail to see the time and cost benefits that could be offered in facilities management. A lack of understanding of BIM goes right through the industry. Often, the IT personnel who will be key in implementing BIM will not understand the requirements needed for BIM software and may purchase software that is not suitable (Quach and Wenström, 2022).

If the client only has knowledge of 2D plans and elevations, it is hard to express the benefits of BIM. The traditional method of 2D drawing is so deeply ingrained in documentation that little time and effort is spent promoting the end product of a CD set, rather than the specific drawings. This is also a barrier to the implementation of BIM (Vidalakis et al., 2020).

The majority of building clients only have a very rudimentary knowledge of CAD at present. As BIM is the natural progression from CAD, it is understandable that clients are not asking for their projects to be done using BIM. Lack of client demand is further seen in that less than 50% of the survey stakeholders thought that the clients they work for would be prepared to pay for BIM services. This lack of client demand is a barrier to the implementation of BIM, as no business or government body will make an investment without the knowledge that there will be a good rate of return.

Construction Economics and Building Journal published a study suggesting that the main issue causing a lack of adoption of BIM in the construction industry is a lack of awareness and understanding. To succeed with BIM, the entire project team needs to have a good understanding of what BIM actually is. This includes the client, all design disciplines, cost consultants, project managers, and the contractors (El et al.2023).

High initial costs and perceived lack of return on investment

Despite any potential cost savings and efficiency to be gained in using BIM, it needs to be a feasible scenario for a business looking to increase its return on investment. Failure to do so could result in an uncompetitive and less sustainable position in the

future of the business. BIM has the potential to save the construction industry billions of dollars through increased efficiency and productivity, but it may be rather hard to prove a direct correlation of financial gain to its use for individual companies. Without concrete proof of a return on investment, many decision-makers will be skeptical of trying the new technology (Bayhan et al.2023).

Studies suggest there is an average 10% reduction in productivity during the initial implementation phase of newly technology systems, and with construction already being one of the least efficient industries, this will be a great concern to many companies. An environmental risk that is present in some countries involves the use of government grants or tax incentives to help with the costs of new systems or technologies. As BIM is still relatively new, some companies may be hesitant to implement it until there are such measures available which could lower the upfront cost for them (Borowski, 2021).

With any new technology or system, there will inevitably be a high initial start-up cost. For small to medium-sized construction companies or architects who do not have a large amount of capital behind them, the cost of upgrading all hardware and software, as well as putting current employees through training courses, can be too large to handle. Also, going through the teething problems of any such installation as systems are learned and developed to ensure they are used to the maximum effectiveness can lead to a reduction in overall productivity (Martin, 2024).

Resistance to change and fear of technology disruption

The recent global recession has heightened this attitude, with most firms looking to survive the economic downturn and hoping to come out the other end with their business intact. The potential cost of software, training, hardware, and man hours is an unquantifiable risk for many, even those who see the potential benefits. BIM implementation, requiring learning of new processes and retraining of staff, does not have a quick ROI even though the long-term ROI is very convincing. High risk and low return are not a good gamble in tough economic times (Bastan et al., 2022).

The AEC sector is full of bright, innovative people and companies. However, the industry as a whole is keener on evolution than revolution, with tried and tested

methods and low levels of research and development compared to manufacturing or software industries. "As I work to implement BIM in our company, the biggest challenge I run into is resistance to change. Many companies are content with the status quo and do not wish to take on additional risk or cost - or take staff away from billable projects to learn a new process." James Barrett, buildingSMART Australasia representative.

Limited resources and expertise

Training staff to a competent level in using BIM software is crucial to realizing potential productivity gains. It has been suggested that productivity can temporarily decrease as staff hone their skills in BIM. Training can be an expensive and time-consuming process and can lead to further productivity decreases if trained staff leave to work for another company or if new staff are employed. The nature of the AEC industry is that many companies subcontract work to other companies by outsourcing. This can increase the training burden in ensuring that outsourced work is compatible with in-housework. High staff turnover rates can also mean that training is a continuous ongoing process (Pham et al.2020).

The resources required to effectively use BIM can be considerable, dependent on the wanted levels of BIM implementation. These resources take the form of hardware and software that have the capabilities of running BIM. Hardware requirements are usually higher than for 2D CAD, for example, a heavily detailed drawing can require far more processing power to manipulate effectively. Then there are software requirements. The BIM software market is in its infancy and there are many different software vendors that deliver BIM. Each vendor has its own proprietary file format, and this has led to difficulties in transferring data from one system to another. Software interoperability has been identified as a concern to the industry. Software costs can also be exorbitant. All this means that companies can be faced with large financial outlays before they even start using BIM. This can be a significant inhibitor to smaller companies or companies that have been subcontracted to carry out a specific part of the project, as they may not be able to reclaim these costs on the project they are working on (Siebelink et al.2021).

Uncertainty about compatibility and interoperability

EECOD has defined a clear six-level staged evolution plan to achieve global data model implementation, a true indication that global BIM integration is not near its full realization. Due still to uncertain software and file format standards, the risk of information loss or deterioration remains high if companies store information from one particular system. The level of risk in losing IT-stored intellectual information capital is unacceptable by companies. Any loss or added cost of re-creating information is a direct profit reduction (Alzoubi, 2022).

By extending the derived concept of BIM from drawings to integrated intelligent information, BIM success is an industry-wide interoperability on all information technology systems. If information can be accessed and manipulated across various platforms and systems, it can be suggested that intelligent information has been optimally utilized. To transfer ownership of building information with no loss of data integrity and to enable its future access, a universal data environment is required with agreed data exchange formats. Development of IFC (Industry Foundation Classes) by the International Alliance for Interoperability is an example of future data international standardization. The creation and maintenance of an open standard for data exchange will guarantee the long-term viability of data compatibility (Vieira et al.2020).

Gielissen, an international design and build company, has stated that until the industry is clear about which applications will prevail, there will be understandable resistance to invest in new expensive technology that may not be compatible with future standards. This represents a Catch-22 situation since BIM will not become the industry standard until interoperability issues are resolved. Therefore, until there is a clearer indication as to the future industry standards, many companies will continue to take the risk of not investing in BIM.

A notable example of this is the UK Government Construction Clients Board's BIM Working Party Group, which has stressed the importance of interoperability so that project teams can easily share data. Quintain, a property development and investment company, has expressed their fears that data created using one application may not be accessible using another. This fear is justified if they have committed to a 20-year software subscription of a product that becomes outdated, as the cost of maintaining

access to data then becomes very high. They urge software vendors to work together for the good of the industry to solve these issues and avoid proprietary developments that restrict data access. Quaintain has done this to some success by working closely with Bentley Systems.

To begin, BIM is currently at the stage of what computer industry experts call "proprietary battles". This is where different software companies seek to establish their products as the industry standard. In this climate, there is much uncertainty about which systems will become the future industry standards.

2.6.2 Key success factors for firms in embracing BIM

According to Lee et al. (2010), the successful implementation of BIM technology has the potential to positively impact project management. The potential benefits include a significant reduction in project RFI's and change orders through improved coordination and more accurate interpretation of the construction documents. The BNi Building News (2010) projects that BIM engagement will increase from the 13% base in the year 2008 to 70% in the near future. The BSRIA (2008) survey affirms these assertions when it reports that test projects in the United Kingdom and Europe report average cost savings of about 1% of the overall project. Project planning and computational analysis have emerged as the potential of BIM technology applications. BIM is now becoming widely appreciated in the construction industry, and now that the test phases of BIM are over, innovative firms are keen to learn from successful firms that have demonstrated improved performance due to successful integration of the BIM technology in their business operations. This study makes a contribution to the body of knowledge by providing insights into the key success factors of BIM integration.

In the current economic environment, firms are facing challenges to survive in business and have realized that technology plays a significant role in improving processes and fostering growth. Many firms accept the changes and attempt to adopt the technology at different levels of integration. Though technology adoption commences with curiosity and the experimental stages, which cause the level of integration to change, there is consensus that the ultimate objective of technology investment is to achieve transformation in business processes. According to Hasan and

Kang (2008), technology is pervasive, and firms globally are becoming aware that its application has the potential to create profits and improve market competitiveness. BIM has evolved to be an accepted technology and is now considered an essential project input in the construction and real estate sector.

2.6.2.1 Benefits of embracing BIM

Embrace Building Information Modelling (BIM) has significant benefits in the construction industry, but the literature shows that stakeholders in the construction industry, such as companies, consultants, contractors, and clients mostly miss those advantages. However, for companies in the construction industry, embracing BIM can achieve various advances and could become highly competitive in the current market (Antunes and Poshdar, 2018). There are several benefits such as improving the quality, productivities, waste reduction, operation, maintenance, lifecycle costs, and client satisfaction. Furthermore, the company would gain a competitive advantage and create a new source of income. Finally, the environmental benefit is another advantage that can occur as the firm embraces BIM as currently the construction industry has reached a significant amount of greenhouse gases (F. Varouqa and A. Alnsour, 2024).

In his 2020 literature review, M.W. Conrad examines the relationship between the intention of top management to use information technology-aided project information management systems (IT-PIMS) and their actual usage. Despite the widely reported low adoption rates of BIM systems, it is evident that top management has a strong intention to use IT-PIMS, indicating their belief that BIM is crucial for effectively managing the complexity of construction projects.

Another study conducted by B. Lee and Y. Kim in 2016 focuses on analyzing the challenges encountered during the process of 'model-based collaboration' (MBC) in the Korean construction industry. Additionally, this study provides policy and strategic approaches to accelerate the implementation of MBC. As BIM utilization continues to grow in the domestic construction industry, its application in collaboration, model management, and facility management has become more prevalent. This has created a potential market for BIM-related projects, leading to suggestions of promoting various BIM pilot demonstrations.

Furthermore, to ensure continuous improvement and expansion of BIM application, it is essential to conduct regular evaluations of the maturity of BIM-based processes. These evaluations will help gain insights into the current state of BIM application and encourage its implementation in different areas and through various channels (A. Adebisi et al., 2024).

Improved collaboration

In order to support better decision-making in operations, both the environmental building operation and management (EBOOM) field and the BIM/building operation and management (BOOM) field have started integrating to connect the documentation of the life cycle with the BIM model. Essential adjustments need to be made in order to organize the organization to operate with an Integrated Lifecycle BIM (ILBIM) program, which requires improved collaboration among departments. This urgent need for improved collaboration will drive changes. The project BIM manager can transition towards the BIM-LifeBuilding manager, taking on the responsibilities of both project BIM management and building management knowledge in the building life and operations. The advancement of information-based developments has resulted in the digitization of the building life cycle.

BIM allows for better communication, coordination, and sharing of information among the project stakeholders breaking down organizational boundaries consolidating toward teamwork collaborations which are essential in smart linked operations across different organizational boundaries, introducing the fifth level of the Building Smartness direction. Collaborative BIM models support both pre-construction and operational life, but mostly operation (maintenance, renovation) after construction leading to cost savings and greater efficiency and thus enabling the projects to become more sustainable (F. Varouqa and A. Alnsour, 2024).

BIM provides the users with various heterogeneous models having the capability to incorporate both the geometrical and non-geometrical data intended to integrate the Building Operation and Management (BOOM) phase operations and maintenance, and renovations services in an interconnected network (Pouryaghoubi and Mohammadi, 2023). This means of accessing the historical, technical, and financial data is an ideal solution for the management and decision-making processes, to develop and create

valuable functions in the management and communication of knowledge and complex information intended for the stakeholders. The potential BIM technology represents for improved collaboration among agents in the Building Smartness direction which seems a compromise between the time-demanding and expensive possibilities of physical smart solutions in the Building Smarter direction (A. Adebiyi et al., 2024).

Enhanced efficiency

The interface standard BIM is facilitated through cooperation in a CDE (common data environment) by securing the same basic level of information for all stakeholders through the business model implementation. BIM assures the data duplication and overwriting are decreased during change modification, as all other trade software environments employ that most up-to-date edition of the files they hold. This represents the interface standard for all stakeholders involved in building information modeling, facilitating communication and co-leading to enhance coordination with substantial reduction in deductions, errors, rework, omissions, disputes, warranty claims, and court lawsuits (Rowley et al., 2022).

BIM brings forth enhanced operational efficiency, resulting in a more rapid pace of work. This fosters a cohesive environment where all aspects of project development can be simultaneously addressed and deliberated upon using a unified model. Such an approach holds significant value for contemporary construction stakeholders, as it reduces waste and expedites the project's timeline. By facilitating accelerated workflow, BIM effectively minimizes lag time in the venture phase. Moreover, BIM empowers accelerated development and marketing activities by substantially improving the overall quality throughout the design, construction, and operation processes.

The construction business is rife with very low productivity waste and consumption. The low fragmentation and putative relationships in the business sector of the construction are mainly brought about by its component mother and siloed operation-dependent phases (Antunes and Poshdar, 2018). Building information modelling also plays a key role in better utility manufacturing center and meeting customer requirements. As BIM is really all about electronic guidance-based displays and trading content, a company has to proactively employ BIM all over the company in

order to benefit from boosting productivity and pursuing cost containment opportunities (F. Varouqa and A. Alnsour, 2024).

Cost savings

The primary factor contributing to the success is primarily the implementation of the implementation of BIM during the early stages of O&M has shown that it significantly reduces expenses. Previously, the main goal of cost-cutting measures related to BIM was focused on O&M assignments in intricate structures. This research now highlights these structures as intricately assembled buildings, with a specific emphasis on utilizing BIM of personal dimensions in Theatre Style Buildings for Atria, Atriums, and Lobbies during operations. This showcases that the use of BIM in the initial phases of O&M greatly reduces overall costs. As of now, the primary effort to cut costs using BIM has been centered around O&M tasks in complex buildings. The present study identifies these buildings as sophisticatedly collected buildings, specifically highlighting the use of individual-sized BIM in Theatre Style Buildings for Atria, Atriums, and Lobbies.in Operation. This illustrates that the implementation of BIM during the early phases of O&M significantly lowers the overall expenses incurred. Up to now, the primary emphasis of cost-cutting measures related to BIM has been on O&M assignments in intricate structures. The current research denotes these structures as intricately assembled buildings, with particular emphasis on utilizing BIM of personal dimensions in Theatre Style Buildings for Atria, Atriums, and Lobbies.in Operations. This demonstrates that utilizing BIM in the initial stages of O&M greatly decreases the overall costs involved. Thus far, the main focus of cost reduction activities involving BIM has been on O&M tasks in complex buildings. The present study refers to these buildings as sophisticatedly collected buildings, specifically highlighting the use of individual-sized BIM in Theatre Style Buildings for Atria, Atrium's, and Lobbies (Sompolgrunk and Banihashemi, 2023).

Material Quantity Take-off has a large task within the Indian Infrastructure market when it is seen in terms of man-hours and the labor hours needed. The average size of the major infrastructures in India is around US\$ 3 Million (Ravikiran, 2017) (Mohammed Abdullah Abkar et al., 2024). The average cost of man-hours in India equivalent to the US region is roughly about 1/6 as per the international and national statistical reports. This indicates that at the world level, the cost savings due to

increased productivity in terms of labor per project is massive from India and the Indian projects. Material quantity take-offs reduce human errors and thus a significant reduction in the number of errors (Hellman et al. 2014) (Nikologianni et al., 2022). Market reports 2017 showed that about 91-97% of the Indian infrastructure start-ups do not complete on time due to late activity commencement and overruns due to changes/notices. Any error made in the quantity take-off in one activity may either result in the reproduction of the whole activity or the direct increase in time by the same percentage. Avoiding the errors leads to a significant reduction in time. Out of all the problems encountered by the Indian (small and medium contractors) where the complete quantity take-off was required, it stood as the second most likely problem due to Lack/Distance of infrastructure technology centers. A small project amounting to 20% of the average infrastructure size therefore will have an approximate saving of \$18,000 which may more be equated to the recent grand charges for the renovation of the Rugby Stadium changing rooms (A reminder of the Government Change Problem of 2000's).

BIM models have the ability to generate automatic BOQs by means of connecting it with modular excel etc, (Anand 2015) (Pouryaghoubi and Mohammadi, 2023). There are significant time savings; cost savings and reduced human errors. The automatic quantities are driven from the objects inserted and linking with the data within those objects. It is therefore impossible to miss out on quantity take-off when the BIM model is generated.

Challenges in embracing BIM

Other challenges include the absence of flexibility in the management of organizational change processes during the implementation stage; inefficiency in procurement and contractual approaches, EII systems not supporting BIM, limitations in data sharing and the operation of prevailing data silos, privacy concerns over shared data and fear of litigation; construction culture of antagonistic competition, lack of leadership in enforcing change, shortsighted and unrealistic company visions of implementing BIM, and absence of active clients wanting BIM, pronounced with little or no incentives and limited clients' participation and immediacy. Lastly, there is a deficiency in BIM implementation benchmarks to gauge progress, lack of open BIM

standards that can be followed, apprehension in deciding on the best technology company or to integrate divergent interoperable solutions (Siebelink et al.2021).

Various challenges and barriers have been identified in previous studies that hinder the adoption, implementation, and use of BIM across the globe. The propagation of BIM is influenced by many factors. In the context of this study, the probable challenges likely impeding the adoption and implementation of BIM technologies are those that concern limitations and a myopic culture. Drawing from previous studies, the following challenges are identified imperatively facing companies within the AEC industry. They include: limited capital, expense, evaluation of returns on investments, lack of understanding and awareness of BIM; users being conservative and hesitant to change; availability of resources to train and recruit suitable employees skilled in BIM; reluctance to cooperate, share, and be involved in collaborative relationships with others due to a low level of trust; resistance to change and support from higher management viewing BIM implementation as an additional expense rather than a strategic tool of competitive advantage (Babatunde et al.2021).

Resistance to change

Impacts and changes will be vast when embracing BIM. While organizations that adapt more quickly will have the opportunity to take great benefits from the advancements of BIM, organizations that adapt slowly can only take advantage of the remainder. Although the AEC industry is rough to changes, we are faced with a new maximum disruptive change known as Building Information Modeling or management at the moment. This research is based on the prep work for implementing BIM. Most crucially, the intent of this study is to clear the obstacles that will emerge during the proliferation of BIM, particularly when embedded in small and medium enterprises, and to try to find partners in the AEC sector that share the same issues and problems (Siebelink et al.2021).

The current architecture, engineering, and construction (AEC) industry faces a great deal of global challenges due to the remnant traditional practices. The traditional practices in the AEC industry limit the maximum efficiency with the resources involved in the process. Nonetheless, the high resistance to change has made the industry a slow adaptive system towards a new technology known as BIM. To

understand the determinants that hinder the BIM adoption, we have reviewed the literature through conference articles, journal articles, review articles, and reports (Gharouni Jafari et al., 2021).

Lack of BIM expertise

Throughout the Aegean Region of Turkey, 54.2% of the practitioners accepted that they encounter difficulties in improving their professional CAD (Computer-Aided Design) knowledge and technical capabilities, and thus, the majority of the practitioners are not sophisticated enough to develop themselves about the new approaches such as BIM. A recent study conducted by consulting services of UBM points out that having difficulties in the educational infrastructure of universities and the number of qualified human resources, lack of qualified planning experiences, and lack of solving real-life problems through practice exercises in the colleges' departments are some other factors that hinder the acceptance of BIM (Building Information Modeling). Assistant Prof. Sibel Sezer Yitmen, in-depth interviews she conducted to gather quantitative research results on BIM, also supported that the majority of the SMEs and their employees accept that they are not proficient enough to cope with the technical knowledge about BIM. This study also voiced that by failing to organize local work out agreements, carried out by the national-governor approved according to the Regulation of the Convener Engineers and Architects, many of the middle-small scale firms work without offering other BIM uses the possibilities to preserve and the packet abroad, and with a low workload and long period applications, many of the enterprises cannot get the requisite BIM practices to use at the. To sum up, it is important to reflect on the fact that BIM applications are crucial in every part of the object or construction, interior space, and also every scale of architectural design practices.

Correctly modeling the project is a heavy time and resource-consuming activity. It requires expertise, knowledge, and a variety of skills. Not only architects, engineers, constructors, and subcontractors, but also the manufacturer companies of materials, systems, and products have to be integrated into the project through exchanging their information with others. As the point made by Autodesk, lack of BIM (Building Information Modeling) expertise is one of the primary and major problem factors that obstructs firms from increasing their efficiency through BIM. Especially in small and

medium-sized firms, the majority of practicing professionals accept that they are not ready to meet the requirements of BIM processes. PhD dissertation research conducted by the researcher showed that within the Aegean Region of Turkey, the percentage of SMEs that had BIM expertise is very low. Whereas 64.5% of the participants accepted that they don't have enough technical and software knowledge, 63% of the participants also accepted that they don't have enough experience about assigning BIM-ready personnel and hiring BIM-supportive staff (Babatunde et al.2021).

Integration with existing systems

This is significant because other processes are based on design aspects, and these design aspects support each other and move forward in the best possible form to operations. The building information model must consider such a context. The information model must be able to manage not only design information but also various other factors in the same environment. Many experts have recognized that a building information model can conveniently support many other application processes if the information model is kept managed under one environment. Such convenience cannot be controversial. Operations are the most important stage in construction and, in many cases, the largest portion of the total construction cost. Also, once a building is erected, it is normally managed for more than 20 years. It is significant from the viewpoint of its sustainability. Clearly, the requirement of an information model at operations is a key point that has an effect on shaping the problem (Lu et al., 2020).

Research indicates that integrating building information models with existing construction processes and tools pioneers a new type of design thinking or "Cybrid thinking" that integrates high-level interaction, collaboration, and reasoning. Lack of design principles causes problems with current BIM design methods since they are based on traditional IT development models that have been transferred to the construction industry. It is paramount to claim that the building information model cannot be completely regarded as the consultant's or architect's responsibility. Often, it is controlled by the owner and built from 2D drawings prepared by consultants. It can correctly assert that it is beyond any consultant's control. Moreover, in the past, design aspects have been treated as completely separate from other aspects, namely,

construction and operations. Architects treated their design objects and the model offered exclusive application for architects only.

Data management

Data management is important since the data in construction projects are often managed manually and written on study. The types of the data are also not consistent within the AEC/FM. This condition affects BIM data exchanges, particularly for collaboration among the AEC/FM stakeholders. However, BIM data management standardization is available through the BIM interoperability process evolution methodology (BIPOE). The methodology standardizes BIM data, as required by the computer data exchange, using the XML schema. The objectives of this methodology are cost reduction, an increase in the quality of the work, speed, interdisciplinary working, flexibility, better collaboration, and improved logistics. It is designed to integrate many technical disciplines, such as architecture, structural engineering, MEP (Mechanical, Electrical, and Plumbing); environmental design and analysis, energy, fire simulation, and daylight modeling; construction, facility management, prefabrication, and logistics into a single model (VAUGHAN et al.2020).

2.6.2.2 Strategies for successful BIM adoption

Building Information Modelling (BIM) started to be used in the construction industry for the purpose of three-dimensional (3D) visualizations and its archival capacity in 2000 and has begun to rapidly develop its widespread use up to now. BIM is not only a model, but it allows characters to reach a common dialogue between different actors, who conform the model. Activities centered upon IoT (Internet of Things) such as logistic, price comparison via interaction with the database and digital documentation effectively accelerate lifelong processes. The concept of a ‘smart city’ is one of these concepts and represents the combination of ideas like city-resource conservation, efficient place usage, and competitive environment developed by industries and institutions. These implications have been resulted from interaction of cities with city-embedded BIM models often called as smart buildings (A. Adebisi et al., 2024).

As a strategic management approach, companies increasingly use BIM technology that presents fundamental changes to the firms at organizational level. However, firms

confront with hurdles in transition to full BIM utilization. These changes involve a spectrum from technological innovation to change management such as BIM offers increased productivity and quality, but also it requires new processes and additional integration which are necessary to be managed effectively. (F. Varouqa and A. Alnsour, 2024). Since BIM spread rapidly, there is a possibility that firms choose incorrect managerial strategies and consequently result in over-expenditures and lost opportunities. Therefore, this research investigated the Key Success Factors (KSFs) for the firms in adopting BIM technology. In conclusions the study introduced the general scheme entitled “Transition Period of Model-based Planning”. In the scheme, it is suggested to be cautious in the early phase of transition. In later phases, the other tools and diversified BIM-modeling’s must be integrated into the main model in the firm establishment. The uncovering of other factors such as self-induced disturbance and extrinsic disturbance allows the firms to build robust strategies. Besides the scheme and general KSFs, some additional strategies also were in the range of present research.

Leadership commitment

Leaders have an important role in embracing the BIM adoption by leading its staff members to establish the foundation, the strategic perspective, the project strategy, and ensure that the entire organization is transparently assimilating BIM, with staff and business partners. Also, because top management plays a significant role in promoting BIM integration and enforcing software policy, BIM applications should be mandated by top management, and educational programs should be organized in order to accommodate the anticipated strategic shift. For this purpose, the top management has to delegate powers and disburse all available resources. Finally, the top leader has to make a flexible environment where the anticipated consequence of BIM implementation can be experienced effectively and give positive result (Anton Kivits and Furneaux, 2013).

When it comes to the organizational level, BIM application strategy, directive and perspectives are actively directed and commanded from the top. On the other hand, soft aspect of BIM adoption like change adaption, process management, data sharing and collaboration are activated and managed by leaders (F. Varouqa and A. Alnsour, 2024). It requires ceasable time, determinism and involvement level from the leaders

for this purpose. With their own culture, the top management has to visualize a transparent outline of its organization's future and importance, outline a strategy for its application, and monitor technological and cultural changes to drive the BIM adoption effectively.

Since, the top management of organizations plays a significant role in the adoption of new technology and advancing their project management delivery mechanism. The adoption of the concept of Building Information Modelling (BIM) being unavoidable for scaling the global market and make the construction industry aligned, reached an inflexion point lately (Dhopte and Daga, 2022). It was visibly enabled and influenced when the leaders of the organizations started understanding the potential of BIM in improving and updating the project management mechanism. They quickly started understanding the benefits and started leading the new development for physical innovation at a global scale including factors like networking, research exploration and finally, an organized adoption. When the adoption touch to its peak, they started playing significant role in improving and understanding economic benefits of BIM.

Strategic planning

Fourth, it is crucial to support the change inside the architectural firm. The transformation of a business model toward a BIM-based organization is possible through a complicated equation of dynamic capabilities and architecture practice agility, proper selection of change management, a coherent learning approach, aligned company processes and opportunities for BIM capability advancement of external consultants for the architectural practice. Changes are strong prescriptions for change leadership in terms of change model that suits architectural practice and the change agent responsible for leading the innovative behavior and organization around the firm. This study is original because it brings forward a complex view from a small-scale BIM micro level based on architectural practice cases. Case studies under investigation aimed at improving company management and performance by integrating technical knowledge for BIM implementation. The social value of that can convey timely responses to architectural business needs for a new market condition driven by mass customization exceeding the original project.

Second, educational efforts must be a part of BIM implementation efforts. According to the literature, the knowledge gap between employees might cause a high resistance to the implementation of BIM in architecture firms (A. Adebiyi et al., 2024). Hence, it is important to make an educational plan for the BIM implementation process. Also, training of a company's professionals has been cited as one of the crucial success factors for the BIM implementation in all of the literature. Team training on BIM has been reported to be effective in reducing the conflicts that occur among firms during the BIM implementation process. Also, educational budgeting for training programs on BIM has been found to provide a competitive advantage for a company during the implementation of BIM. Communication and organization of the firm regarding changes, advances in technology, and new experiences are among the factors obtained for the architectural practice scenarios, which are shown that impact the reluctance to BIM usage, have been identified as the learning approach.

Third, process and organizational deployment of BIM are critical. BIM must be introduced and assimilated gently in some progressive phases, the company's processes must be aligned with its adoption, and the organizational structure must be prepared, taking into account collaborative working methods. The main problem with this approach is, in the light of the evidence from the literature, the lack of a strategic view over the BIM implementation in the architectural firm business model. The transformation of the business model of an architectural practice into a data-driven [(syn: BIM-guided)] knowledge-rich organization requires attention to a combination of "business process facilitators" and "software tools" for the different buildings delivered over the years and lessons learned, positively impacting performance. Thus, sharing learning points has developed a company-based Business Process Reengineering methodology, specifically tailored to micro-scale practice needs, by setting out the Critical Reasoning Algorithm, involving data-driven modelling, to validate the steps involved in a BIM, through a unit of analysis focused on a small practice perspective with its rather typical, and sometimes intense, focus on maintaining a steady workflow approach, essential to maintaining long-term financial stability while simultaneously pursuing growth and scaling according to the BCG growth/share matrix. Business processing facilitators are considered to enhance the speed of shared knowledge for competitive advantage, incorporating model data standards for client feedback, and acquiring professional Knowledge Management

certification to harness technical human capital to share exponentially within the firm, increasing business. Modeling challenged community designs have witnessed a 50% improvement in development with almost no delay, compared to traditional approaches. Coordination and data precision have been cited as the main purpose of the BIM introduction in documents and model platforms, accelerated by software tools.

A range of efforts is critical for an organization's BIM implementation. The first efforts are associated with strategic planning, which is vital for ensuring the success of BIM (Pouryaghoubi and Mohammadi, 2023). Strategic planning involves setting objectives, defining processes and roles, and establishing strategic goals and metrics.

(F. Varouqa and A. Alnsour, 2024). The lack of strategic planning in BIM adoption has been found to be a factor that leads to firms' failure during their implementation. The decision makers must be informed about the long-term outcomes of BIM adoption, and they must be involved in the strategic planning for BIM in all of their projects. Also, the involvement of the firm leader has been reported to be a highly crucial success factor for the firms that have adopted BIM.

Employee training and development

In-company workshop is effective for developing and maintaining discipline and teamwork among the staff. Training should involve a gradually phased shift from established working methods to BIM production. It is important to stress employee transferring scenarios, motivational factors, and presentation of rewards indicative of the capabilities and time invested in BIM. The necessity for technological updates (hardware) is strongly connected with each of the researched capabilities.

In this context, the level of BIM utilization requires a staff with both mandatory hard skills and supplementary soft skills. Topping the list of skills required is the ability to develop, work with, and integrate digital models. Also needed are practical skills for coordinating and consulting, understanding that the ideal workflow will have BIM implementation throughout the firm. There should be mechanisms in place for staff training at all career and skill levels, incentives and rewards for using the new system, clear briefings, and role-specific training (Damek et al., 2022).

The degree of BIM software utilization will depend on three major factors: experience, position, and professional duties. The research showed that professional advancement and experience in BIM utilization is associated with higher software usage. On a typical workday, the position and level of professional duty performed determines the type of BIM software used (Wang et al., 2023).

In recent years, the construction industry has faced a transformation due to the gradual and continuous implementation of BIM processes and principles. For such implementation, the engineering firms should integrate six major dimensions into the organizational strategy. They are process, employee training, developing new skills, improving cooperation among involved parties, policy and regulations modification, and hardware and software development (F. Varouqa and A. Alnsour, 2024).

Investment in technology and infrastructure

The action plan of each construction company as well as engineering and consulting companies considering BIM implementation as part of building smartness should include the organizational changes. Collaboration within projects with BIM requires the effective organization and boundary management, which consist of the allocation of responsibilities and rights between organizational entities. Companies implementing BIM are required to divide the responsibilities at different levels of management, including professional and administrative personnel at each level of organizational management structure. Building companies must revise internal and external communication channels, the effectiveness and regular checking of the tool supports the planning and execution of tasks and checks of the maintenance condition. organization which effectively and consciously start to change degree of smartness will gain the flexibility in the portfolio management and the ability to adapt to the changing environment through appropriate organizational structure and tested, effective processes.

To develop smart buildings and optimize the performance of building services system (e.g. HVAC, water management system), there is a need to leverage machine learning and big data technique. Use of the technique initially could be for the detection of failures, predictive model development, data analytics application for process reengineering and operation system redesigning. These technologies once penetrated

into the non- residential building services installations, the smart buildings will become operation in true sense. BIM is not just advance digital technology, it is associated process and needs to effectively manage and control the complete building cycle process, including roles, specifications of works, complementary bodied equipment and materials for further processing, digital binders, database updates and other improvements due to development in the processes and procedures applied and/or due to the requirements or other constraints on the course of the object lifecycle. Due to the complexity and multidimensionality of BIM, its implementation requires the preparation of appropriate conditions at the various levels of the organization, including knowledge competence related to the reengineering of business processes, along with digitalization (Anton Kivits and Furneaux, 2013).

The industry partners have to invest in technology and infrastructure to embrace BIM efficiently (Pouryaghoubi and Mohammadi, 2023). BIM models have always been considered as an effective technology for planning, coordination, and control of the construction activities. BIM is a multidimensional technology, and the effective implementation of BIM models keep the promises related to its use in the operations and maintenance of the facilities also. Hence, the effectiveness of implementation totally depends on the quality of models that were created. Additionally, the effectiveness of maintenance operations is also depend on the task level information extracted from the models in more effective manner. At several places we see that the high investment in advanced technology development related to BIM models have potential which can enhance the effectiveness and quality of the as built models, while the basic or minimum investment in technology in the initial phase of BIM development is creating an environment where user with minimum investment could set a benchmark in the industry (Yeon Park et al., 2022).

Collaborative culture

So, in practice, the core organisation interest to realise the productivity tailwinds discovered normally distantly from any construction project design or in construction execution but in ‘later’ stages – relatively speaking – at construction operation by the owner and/or end user.

Multidisciplinary team members lacking a single culture with civil servants' further ingredients to underpin collaboration around BIM is that a building project by its nature is a temporary endeavour. The real customer behind the purchase of a road or building is a company or institution operating in the public or private sector. Thus, the 'customer's group' in principle has a strong, shared interest to cooperate and align their work around the BIM related to a project in order to deliver this as efficiently and effectively as possible. The deviation between government and private sector business organization procurement, however, is stark as a government lays down explicitly in clear terms and how to procure a project. The private sector client is far less clear as they largely delegate the decision on how to procure a project to the employer's agent. Therefore, it is different in some ways in their attitude to BIM. Within both private and public sectors, the corporate client group is found consisting of diverse sections.

Refocusing on the topic of regenerating contextual and structural barriers to innovation in the Construction Industry, several challenges hinder progress. One obstacle is the reluctance to openly share information within the supply chain due to the fear of revealing potential errors and losses. This lack of trust leads to strong competition, fostering harmful behavior such as mistreatment of intermediaries and suppliers. However, existing research suggests that trust and cooperation are crucial for maximizing the benefits of BIM and other Contemporary Business Models (CBMs) in the construction industry.

For construction firms, who are the primary users of BIM technology, the key to success lies in working closely together and providing guidance throughout the process. Therefore, the use and exchange of information becomes crucial for achieving better collaboration and advice. Consequently, improving collaboration within the AECO (Architecture, Engineering, Construction, and Operations) sector is essential, considering their role in project management knowledge and design input to enhance outcomes.

Collaboration has long been recognized as an important concept in the AECO community. However, the nature of collaboration between firms, including information sharing, teamwork, and interaction, should be digitized and real-time rather than relying on current methods such as file sharing and infrequent teleconferencing. Therefore, to fully harness the potential of BIM and ensure success,

its adoption must be embraced, and opportunities for collaboration with AECO suppliers should be welcomed and embraced (Wang et al., 2023).

The BIM development in the UK construction industry is considered a strategic advantage that will bring about improvements in current work practices as well as new ways of working [40]. It is through innovation that a more joined-up process can be achieved where collaborative working across the supply chain becomes new norm. There is evidence that use of BIM can improve the situation compared to current state. There is also consensus about such improvement as building information becomes more accessible and consequently there is a reduction in the need to recreate lost or unavailable information. Therefore, the importance of collaboration and new ways of working cannot be underestimated, and this leads to push towards development of new business models (Yeon Park et al., 2022).

Digital transformations have never been an easy process for firms, as it involves strong organisational change and requires profound transformation to company's culture and operating model. The AEC industry is not unique in this regard. Architects, engineers and constructors need to adapt during the thick class of BIM technology as well as constructing and operating practices around for BIM, which require close integration of supply chain members, sharing of knowledge between different team members, and breaking down of vertical silos. The efficient and effective use of BIM is only possible if firms' culture becomes collaborative and across disciplines.

Partnering with experienced BIM consultants

The skillsets required to produce and read BIM models and fully participate in BIM workflows are limiting the pace at which the market can adopt BIM and digital twins. Exposing the wider engineering and consulting community to accurate simulation data and analysis findings can only increase the demand for the BIM model and pave the way for improved model content and a new surge in BIM use (Dhopte and Daga, 2022). This creates a catch-22 where potential users are reduced to trial-and-error tests and comparisons to understand which of the few and rarely executed workflows available today actually could lead to desired outcomes. Critical to both manufacturer and engineering workflows is that they show true integration with full reliability and

resilience. Firms will welcome staff and supply chain solutions which can demonstrate the necessary levels of reliability and business impact.

Implementing BIM in a project will need the professional help of experienced BIM consultants to ensure the desired project outcomes and solutions are met within schedule and budget constraints. Using market leading BIM collaboration solutions known for their innovative approach and investment over the last years in solutions and integrations which are not even close on behalf of others in this industry (A. Adebiyi et al., 2024). The consultants will ensure, that team members and stakeholders use the final BIM model for the daily design/execution of the project. Trained BIM-designers can work together in 3D BIM environments and embedded workflows are already enabled on IT infrastructures of their designing company and the industry (Anton Kivits and Furneaux, 2013). Adoption of these aspects is necessary to be ready for the BIM and digital twin era and get prepared to differentiate their market advantages from others. More market competitive advantages will be delivered when a truly open IFC-compliant BIM collaboration platform addresses all disciplines and their very large model size project needs for the industry leading BIM collaborative solution.

The implementation of the right BIM tools and platforms is key in BIM projects' real success, and in order to achieve that partnering with experienced BIM consultants will be one of the most important decisions.

Establishing BIM standards

Early adopters of BIM were architectural firms due to a shift in design practices and the reduced effort on non-value-added activities. Contractors also started demanding BIM for efficiency gains and better project coordination. Owners and developers embraced BIM for project coordination benefits like project transparency and for benefits like cost estimation, procurement planning, and construction schedule tracking. Contractors see BIM's integration with cloud data, cost estimation, quantity takeoff requirement in pre-tendering stages and construction schedules as the considerable business benefits of BIM. Increasing climate change concerns and strict carbon emission norms from Governments are pushing architecture, engineering, and construction professionals to adopt BIM-enabled energy-efficient or carbon negative

construction practices. Governments have taken steps for policy changes to encourage BIM adoption including the construction of a BIM library for resource availability and BIM use policies for the public building projects (Yeon Park et al., 2022).

The success of BIM (Building Information Modelling) in a company depends on the approach of setting BIM standards (Dhopte and Daga, 2022). Once an organization understands the potential for BIM, the next step is to define global strategies, standards, and workflows to manage the complexity of BIM processes more transparently. There are several detailed guides that articulate a company's global approaches and strategies for BIM. BIM standards combine the critical processes that a company follows to ensure the scope and quality of the project and address company-oriented items with globally accepted BIM standards such as IFCs, IDM-A, IDM-T, etc. Implementing BIM's critical success factors (CSFs) includes improving cooperation among stakeholders, using a shared data context, and reducing errors in project documentation. BIM also enhances the construction administration lifecycle and facilitates coordination of layout and operational activities. 4D modeling allows stakeholders to visualize constructability and scheduling (F. Varouqa and A. Alnsour, 2024).

Change management

According to Zmud and Co-opted (1982), change management is seen as a set of processes or activities that try to move the organization from one state to another, improving how the organization operates. It has to help individuals to deal with changes that are being driven (e.g., project realization) and their implications. Kotter (1996) suggests a dual way of management: by applying coercive mechanics to ensure that desired change happens, and normative mechanics to manage responses to the change that is occurring. The FH can, in fact, be also seen as a combined approach investing at the same time social and technological aspects. BIM implementation can be classified into three main areas: technology driven, process driven, and people driven. Based on the type of change the implementation will cause, Kotter (1996) prescribe different strategies for change. The FH validation process showed that this implementation of BIM can be considered process driven and that a tailored answer for the problems the change will cause should be developed (Kim et al., 2005).

It is necessary to emphasize that BIM implementation is not an information system implementation, but a true business transformation (De Vries et al. (F. Varouqa and A. Alnsour, 2024)). As such, it should be carefully aligned with the company's core values, products, and services. BIM should also change an organization's interior core physics – affecting how, when, and where things are done (Ismail et al. (Yeon Park et al., 2022)). Clearly, the greater the change a BIM implementation brings into the company, the more likely there are to be problems. Thus, the success of any BIM implementation largely depends on how people within a company are handling these changes. This includes management i.e. how they communicate changes, and sponsors, as well as all members of the organization. FH1 was created to help BIM implementation stakeholders through the transition process (Ciais et al. (Wang et al., 2023)).

Continuous improvement and evaluation

Companies need to pay particular attention to better understanding the company's constraints, needs, targets, and market circumstances. Besides, they should gather all information after using BIM, as well as that information that is valuable from BIM, evaluate the data obtained, and profit instructions from elaborate data analysis (Anton Kivits and Furneaux, 2013). It is known that the company's ambitions are defined when appropriate measurement and monitoring processes are introduced to assess progress formally against those objectives.

To overcome those challenges, the importance of the access to externally accredited resources could make a substantial variation. There are certain organizations or groups that need to promote the implementation and joint activities and developments. They also need to generate the data, achieve specific research fields, and create dissent. Additionally, the completion of the construction industry should also be supported (F. Varouqa and A. Alnsour, 2024). The aim of this research is to help both businesses that perform significant building machinery design and production and companies that integrate a tendered contract with irregular duties for complicated designs and manufacturing capabilities.

It should be noted that after satisfying the need and implementing BIM, organizations must adapt the application as a continuous learning process. They need to adapt and

conduct numerous training programs and support knowledge transfer across the organization (Yeon Park et al., 2022). This should be done to avoid any resistance to change that may be encountered by the users in the organization. Moreover, allocation of sufficient trainings is essential as the competence is considered one of the key determiners in helping the stakeholders to achieve the targeted objectives and advantages. This advocates that constant training, as well as advancement in the technical skills must be encouraged and regularly checked for the competent use of the applications.

2.7 BIM Objects

BIM objects are foundational components within the BIM framework, crucial for digitally representing buildings and facilities (Eastman et al., 2011). These objects are essentially data structures encapsulating attributes, relationships, and geometric information that define different elements within a construction project (Succar, 2009).

In essence, BIM objects serve as digital counterparts to real-world building components, offering a detailed representation of elements such as walls, windows, doors, columns, pipes, and electrical equipment (Kensek & Noble, 2014). They encapsulate key properties and parameters, including material types, dimensions, insulation values, and fire resistance, among others.

Moreover, BIM objects facilitate seamless data exchange and interoperability among stakeholders involved in the project lifecycle (Autodesk). By defining relationships and interactions with other components, they ensure consistency and accuracy throughout various project stages, promoting collaboration and information sharing among architects, engineers, contractors, and suppliers.

2.7.1 Creating BIM objects

Building Information Modelling (BIM) objects play a crucial role in the digital representation of buildings and infrastructure projects (Eastman et al., 2011). Their accurate creation is essential for ensuring compatibility, functionality, and usefulness across various stages of the construction project lifecycle (Succar, 2009). The key steps involved in creating BIM objects, to industry standards and best practices:

- **Requirement gathering:** BIM objects begin with a thorough understanding of project requirements and standards. Architects, engineers, contractors, and other stakeholders should provide input to define the object's functionality, purpose, and parameters effectively (Eastman et al., 2011; Autodesk, n.d.).
- **Geometry design:** Specialized software tools like Autodesk Revit, ArchiCAD, or Bentley MicroStation are used to develop the geometric representation of the object. Adherence to industry standards for BIM compatibility and accuracy is paramount during this phase (Eastman et al., 2011).
- **Parameter addition:** The definition of an object's properties, parameters, and metadata using BIM authoring tools is a critical aspect of the creation process (Smith et al., 2018). This step entails specifying material specifications, dimensions, performance data, and other relevant information essential for seamless integration into the BIM environment (Jones & Brown, 2019).
- **Metadata inclusion:** Additional metadata, such as manufacturer information, product codes, URLs, and maintenance requirements, is incorporated to enhance the usability of the object and support lifecycle management processes (Smith et al., 2018).
- **Classification application:** Appropriate classification codes and categories are assigned to the BIM object based on industry standards such as UniFormat, Omniclass, or MasterFormat. This ensures consistency and facilitates efficient data exchange across platforms (Jones & Brown, 2019).
- **Testing and validation:** Comprehensive testing of the BIM object is conducted to verify its functionality, accuracy, and compatibility with various BIM software applications. The object is validated against project requirements and standards, with necessary adjustments made as required (Smith et al., 2020).
- **Documentation and publication:** The creation process of the BIM object is documented, encompassing design decisions, parameters, and metadata definitions. The BIM object is then published in standardized formats such as

IFC or Revit Family files for distribution to project teams and stakeholders (Smith et al., 2020).

- **Maintenance and updates:** BIM objects are regularly reviewed and updated to reflect changes in product specifications, standards, or project requirements. A library of standardized BIM objects is maintained for reuse across multiple projects, ensuring consistency and efficiency in design and construction workflows (Smith et al., 2020).

By adhering to industry standards and best practices, designers and manufacturers can create high-quality BIM objects that promote interoperability, collaboration, and informed decision-making throughout the construction project lifecycle (Smith et al., 2020). Ensuring the accuracy, compatibility, and usefulness of BIM objects in digital construction projects is essential (Johnson & Lee, 2019).

2.7.2 Implementing BIM objects

When a company decides to start using BIM, it will initially face a large set of challenges that need to be dealt with at its early stages (Zhou et al., 2017). After the initial Radio Frequency Identification (RFID) tags and geographic information system (GIS) equipment are collected during the construction phase and the BIM model is integrated, when the operation phase begins, a plethora of various ETFE membrane materials, coatings, and reassessment and exclusion of CAD and BIM objects will quickly appear. Objects and materials are mainly divided into static and dynamic properties. BIM objects are elements or building parts that have both physical and digital properties (Pouryaghoubi and Mohammadi, 2023). For instance, a digitally depicted inventory of all building components and products that have different characteristics (materials, dimensions, fire classifications, suppliers, etc.) and which can be described by numerous properties is a BIM object. BIM is much more than just a unique CAD system: it is a complex digital infrastructure that allows digital representations of construction and can challenge traditional approaches in the construction sector.

When considering which BIM objects to implement, it is important to consider the initial cost and potential return on investment, including both tangible and intangible benefits (Anton Kivits and Furneaux, 2013). This process is conducted by performing

a cost-benefit analysis. The intangible benefits can be the improvements in performance, workflow efficiencies and asset management activities. The objects that are to be implemented as BIM objects should be determined based on the company's need and the expected ROI from implementing the BIM objects.

2.7.2.1 Integration with BIM software

After a stable performance of interconnection can be achieved, both the generative design solutions through DashBoard or alternatively, a plug-in tool directly integrated into the design environment, and the BIM may result in an effective connectivity, resulting in a direct exchange of model data. Optionally, information exchange can be achieved through a shared repository like glTF file format. BIM data may also be pushed and pulled to and from the generative design solutions for workflow compatibility. Integration with BIM software may also include features that exports geometry volumes and relationships, data on individual elements, and additional structural simulation results (A. Adebisi et al., 2024).

The integration with BIM software enables automatic energy modelling and assessment (e.g., hourly EnergyPlus for HVAC and Radiance for natural light simulation) as different design iterations are generated and analysed (Hui Teo et al., 2022). For design assessment and checking in the BIM, Automation Generative Design can also connect with source control on a Revit model to calculate automated zoning. However, a direct interface between the generative software and other BIM can be very challenging. Access to computational geometry and design scripting capabilities (i.e., plug-in for Rhino, Rhino Compute, Dynamo for Revit), or different programming environments e.g., Python for better interoperability and problem solving perhaps involved depending on vendor's API.

The integration of Building Information Modelling (BIM) with generative design software is required to be conducted through application programming interfaces (APIs), as these solutions are being run by different vendors and developed using different software systems (Ma et al., 2021). ABAQUS and Revit are the examples of software that provide APIs for input/output capabilities between the two systems. Interoperability also involves exporting results from the generative software to BIM software such as Rhino and BIM Vision as BIM objects. Some commercial generative

software or BIM platforms is now well compatible and integrates with others, like Autodesk Forge which can be used as a platform, this allows generative design to be performed in an authoring environment or viewed in any web-based viewer like A360, Autodesk Viewer and BIM 360.

2.7.2.2 Managing object libraries

As reliance on building digital data increases, BIM has become an integral part of the construction industry and a major technology trend in this industry. BIM is defined as a model-based concept that creates data and digital representations of physical and functional characteristics of a built structure. Despite the advantages that BIM offers in the construction industry, broadly used cross-platform data exchange is a work in progress and challenges related to BIM integration due to the lack of standard specifications and data formats exist. A unified data model is necessary to facilitate the development of IoT-based operational analytics applications. The study defines a conceptual IoT data model that employs manufacturing data, product data, and facility management integrated with a digital twin, using open standards. The integrated data model caters to a wide range of IoT applications.

On the second area, some general concepts are presented that should be carried out while searching for an object within the model. The solution is to use the class names from object-oriented programming. An attempt was made for BIMserver to customize the view on the collection of classes in the IFC model by adapting the Entity object to the classes we want to present to the user. An additional function was introduced, which is to present using a flat list, for example, all the columns in the model regardless of the type of entity in which it was placed, or create classes based on object type or attribute (F. Varouqa and A. Alnsour, 2024).

2.7.2.3 Utilizing BIM objects in projects

During, initiation, strategic planning, and contractor's project execution, the concept, and principles of utilizing BIM objects in projects show important interdisciplinary ties that confirm the flexibility of BIM objects for future alterations. Upon transitioning from design to construction, BIM objects facilitate automatic planning of construction works and form the basis for cross-disciplinary collaboration at the stage of procurement and management. The crucial support role that BIM objects plays for

calculation, computational analysis, and construction sphere of a digital twin is illustrated and their contribution to the execution phase in creating a digital avatar is apparent. The use of BIM objects is a necessity in the phases of operation and dismantling as prime elements of extremely important promotional steps within the new products. They are indispensable for the volumes of digital infrastructure data and close the cycle from the cradle to the grave of the construction product (Martin et al., 2016).

Given the importance of interoperability in the construction design sector, current BIM users are demanding for more efficient sharing of digital objects “BIM objects” across various software and hardware platforms. In this context, development and utilization of BIM objects enable efficient and secure data management within a project, it enables accurate visual representation of building components and systems under varying operating conditions. Literature shows a potential and relevance of BIM objects to serve as a centralized component repository contributing to collaborative BIM teamwork among stakeholders. Literature also demonstrates the benefits of BIM object in the virtual mockup and digital prototype environments during different phases of delivery projects (A. Adebisi et al., 2024).

Modern construction projects are characterized by their complexity and time constraints which necessitate innovations in design collaboration. Collaborative Building Information Modelling (BIM) technology has therefore emerged and is vital to serving as an integrative engine which is capable of assembling, sharing, and managing building data among different stakeholders in the complex division of labour. Excelling as a multidimensional repository, BIM enables seamless translation between building design and construction phases and facilitates timely project revisions more efficient than traditional drawing-based documentation (Antunes and Poshdar, 2018).

2.7.3 BIM object library platforms

BIM object library platforms are online platforms that contain digital versions of various building components used in construction projects. These platforms enable architects, engineers, contractors, and other project stakeholders to easily find and use the objects they need. Additionally, these platforms ensure the compliance and

accuracy of the objects used in projects, thereby making projects more consistent and reliable. The benefits offered by BIM object library platforms include:

- **Diversity and standards:** These platforms offer a wide range of objects, typically created in accordance with industry standards. This allows users to easily find objects that meet their needs.
- **User-friendly interfaces:** The platforms provide user-friendly interfaces that allow users to navigate easily and find the objects they need. Search and filtering features enable users to work quickly and efficiently.
- **Timeliness and accuracy:** BIM object library platforms provide regularly updated and verified content. This enables users to use reliable and up-to-date objects in their projects.
- **Collaboration and efficiency:** These platforms enhance collaboration among project stakeholders and increase efficiency. Objects available on a shared platform facilitate information sharing and enable projects to be managed more efficiently.

Some examples of BIM object library platforms include:

- **BIMobject:** One of the largest and most popular BIM object library platforms worldwide, BIMobject offers a variety of objects that architects and engineers need.
- **NBS National BIM Library:** Created by the NBS, this platform provides a wide range of objects for architects and engineers in the UK.
- **ARCHICAD BIMcomponents:** Specifically designed for ARCHICAD users, this platform offers various objects compatible with ARCHICAD and provides ready-made solutions for users' projects.

2.8 Survey Studies in Construction Industry about BIM

To investigate the trends of BIM in the construction sector, survey studies are conducted to assess the prevalence of BIM usage, adoption rates, challenges, and

opportunities encountered (Smith & Johnson, 2020). These studies are typically conducted among construction professionals, engineers, architects, project managers, and other industry stakeholders. Surveys may focus on a specific geographical region or sector segment, or they may provide a general overview.

Such survey studies are important for determining the levels of BIM adoption, evaluating the increasing trends of BIM usage in the industry, and understanding the challenges faced in transitioning to BIM within the sector (Wong et al., 2019). Surveys are also used to understand professionals' experiences, needs, and expectations regarding BIM.

For example, a study may conduct a comprehensive survey to determine the prevalence of BIM usage in the construction sector and professionals' attitudes towards BIM (Rahman & Rahman, 2020). This survey could provide insights into participants' use of BIM software, their training needs, the benefits they expect from BIM, and the challenges they face.

Some sample survey studies:

2.8.1 Global BIM adoption study (Nemetschek Group, 2020)

Aimed to assess the adoption and implementation of BIM practices worldwide. The study utilized a comprehensive survey administered to professionals in the architecture, engineering, and construction (AEC) industry across different regions.

The survey gathered data on various aspects of BIM adoption, including the extent of BIM usage, common challenges faced during implementation, perceived benefits, software preferences, training needs, and future trends. Participants were asked to provide insights into their experiences with BIM, ranging from initial adoption to ongoing usage and optimization.

The study analyzed the survey results to identify trends, patterns, and disparities in BIM adoption across different regions and sectors within the AEC industry. Key findings from the survey included:

Adoption Rates: The study examined the prevalence of BIM adoption among AEC professionals globally, including the proportion of firms using BIM in their projects and the maturity level of BIM implementation.

Challenges: Participants were asked to identify the main challenges they encountered during the adoption and implementation of BIM practices. Common challenges included resistance to change, lack of training, interoperability issues, and resource constraints.

Benefits: The survey explored the perceived benefits of BIM usage, such as improved collaboration, enhanced project visualization, better decision-making, cost savings, and reduced errors and rework.

Software preferences: Participants were asked about their preferred BIM software platforms and tools, as well as their satisfaction with the features and functionalities offered by these solutions.

Training needs: The study assessed the training needs of AEC professionals regarding BIM adoption, including the types of training programs required, preferred delivery methods, and perceived barriers to accessing training resources.

Overall, the "Global BIM Adoption Study" provided valuable insights into the current state of BIM adoption worldwide and offered recommendations for addressing challenges and maximizing the benefits of BIM implementation in the AEC industry.

2.8.2 BIM adoption and implementation for architectural practices (Journal of Construction Engineering and Management, 2018)

Examines and analyzes the adoption processes of architectural firms towards BIM. Data was collected through interviews and surveys with several architectural firms. The collected data was analyzed to assess the firms' transition to BIM, the BIM software they use, their training needs, project management processes, and the impact of BIM on their operations.

The findings of the study identified the challenges and success factors encountered by architectural firms in the BIM adoption process. Additionally, it highlighted the strategies and best practices implemented to enhance the effectiveness of BIM in

architectural projects. The results include recommendations such as providing training, resources, and process improvements to facilitate the widespread adoption of BIM in the architectural sector.

This study contributes significantly to better understanding the BIM adoption processes of architectural firms and promoting BIM usage in the industry. The findings offer insights into strategies that can be implemented to enhance the effectiveness of BIM in architectural projects.

2.8.3 BIM adoption survey (Autodesk, 2019)

Aimed to assess the trends in BIM adoption and usage within the industry. Participants included architects, engineers, contractors, and other construction professionals. The survey findings indicate that BIM usage is becoming increasingly prevalent, with many industry professionals preferring to utilize BIM in their projects. However, some participants highlighted challenges encountered during the adoption process, such as software compatibility, training requirements, and costs. Nevertheless, the majority of respondents believe that BIM will see wider adoption in the construction sector in the future.

2.8.4 State of BIM adoption and implementation (Dodge Data & Analytics, 2018)

Provides valuable insights into the current status of BIM adoption across the construction industry. The study surveyed architects, engineers, contractors, and other professionals involved in construction projects. Key findings reveal a growing trend towards BIM adoption, driven by its potential to improve project outcomes and collaboration among stakeholders. However, challenges such as initial costs, training needs, and interoperability issues remain significant barriers to widespread adoption. Despite these challenges, the report indicates a positive outlook for BIM adoption, with many industry professionals recognizing its long-term benefits for project efficiency and cost savings.

2.8.5 BIM in practice: what do the practitioners say? (Construction Industry Council, 2020)

Offers valuable insights into the practical application of BIM within the construction industry. Through surveys and interviews with practitioners including architects, engineers, contractors, and project managers, the report examines the real-world experiences, challenges, and benefits associated with BIM implementation. Key findings shed light on the varying levels of BIM maturity across different sectors of the construction industry, as well as the factors influencing successful BIM adoption. Additionally, the report highlights the importance of collaboration, training, and standardization efforts in maximizing the benefits of BIM. Overall, the insights provided by practitioners offer valuable guidance for industry professionals seeking to enhance their BIM practices and leverage its potential for improving project outcomes.

2.8.6 BIM implementation and adoption strategies for building owners (American Society of Civil Engineers, 2017)

Presents comprehensive strategies for building owners looking to implement and adopt BIM in their projects. The report outlines various approaches and best practices tailored to the specific needs and objectives of building owners, emphasizing the benefits of BIM for facility management, operation, and maintenance. Through case studies, interviews, and expert insights, the publication offers practical guidance on overcoming challenges and maximizing the value of BIM throughout the building lifecycle. Key topics covered include selecting appropriate BIM technologies, integrating BIM into existing workflows, establishing collaboration protocols with project teams, and developing BIM-enabled facility management processes. Overall, the report serves as a valuable resource for building owners seeking to harness the power of BIM to optimize building performance and achieve long-term operational efficiency.

2.8.7 BIM adoption in developing countries: a systematic literature review (International Journal of Construction Management, 2020)

Provides a comprehensive review of the adoption of BIM in developing countries. Through a systematic literature review, the study examines the current state of BIM adoption, challenges, and opportunities in developing countries' construction industries. It synthesizes findings from various scholarly articles, case studies, and

reports to identify common themes, trends, and factors influencing BIM adoption in these contexts. The article sheds light on the unique challenges faced by developing countries in adopting BIM, such as limited infrastructure, resource constraints, and lack of awareness and expertise. Additionally, it highlights the potential benefits of BIM adoption for improving project efficiency, collaboration, and sustainability in developing country settings. The systematic literature review offers valuable insights for policymakers, practitioners, and researchers seeking to promote and support BIM adoption initiatives in developing countries, ultimately contributing to the advancement of the construction industry worldwide.

The literature review shows that BIM Adoption Level within Construction Product Manufacturers is not sufficiently, highlighting a significant gap in current research. This scarcity of existing studies underscores the value and importance of this research. By exploring this under-researched area, our work aims to contribute valuable insights and data, providing a foundational understanding of BIM adoption among construction product manufacturers. This contribution is not only crucial for academic purposes but also offers practical implications for industry stakeholders, helping to guide future implementations and strategies in the transition towards BIM.



3. METHODOLOGY

The study involved a detailed survey conducted using a quantitative research method with construction product manufacturers in Europe to investigate the adoption of BIM.

The survey was distributed via LinkedIn and targeted individuals working in product manufacturing companies who are currently working on or have previously worked on BIM. It was sent across all of Europe and received participation from 71 individuals spanning 17 different countries. Almost 60% of participations have more than five years experience in industry. This participation provided a diverse set of perspectives and experiences from professionals involved in BIM.

In the analysis of our survey (Figure 3.1), the Kruskal-Wallis and Mann-Whitney tests were selected due to their suitability for non-parametric data. The Kruskal-Wallis test is ideal for comparing responses from multiple independent groups, such as different countries, without assuming a normal distribution, which is often not present in survey data. It helps determine if there are statistically significant differences in median responses across these groups. Similarly, the Mann-Whitney U test is used for pairwise comparisons between two independent groups, allowing us to identify specific differences between subgroups within our survey population. These tests are robust to outliers and skewed distributions, making them perfect for handling the ordinal nature of our data and ensuring reliable and meaningful insights into the perceptions and experiences related to BIM.

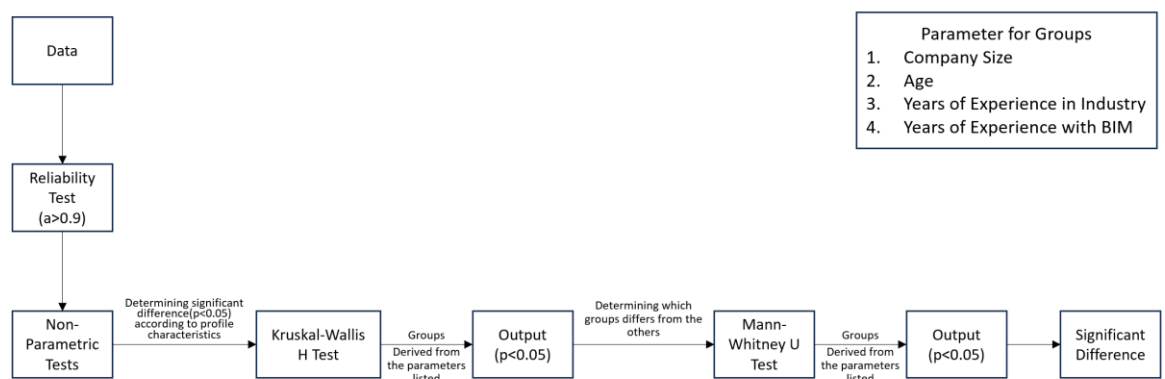


Figure 3.1: Flow chart of analysis.

3.1 Survey Study

The aim of the survey is to examine and assess the adoption processes of construction material manufacturers in Europe regarding BIM.

Through the survey questions, the goal is to measure the extent to which European construction material manufacturers have adopted BIM, their trends in BIM usage, how they manage product information, methods for creating BIM objects, and the standardization of these processes.

The survey results aim to understand the challenges and barriers faced by product manufacturers and to identify strategies for overcoming these barriers, thereby facilitating BIM adoption and increasing sector efficiency.

3.2 Design of survey

The survey used in this study was prepared using the questionnaire developed by Karakoç (2021) to investigate the adoption of design and manufacturing firms in Turkey.

The target audience of the study being construction product manufacturing firms in Europe, the survey questions were tailored specifically for this target group. The survey was structured to examine participants in two different groups based on their BIM investment status.

The questions directed to participants in the first section of the survey were as follows:

1. How many employees does your company employ?
2. Which age group do you belong to?
3. How many years of experience do you personally have in the construction industry?
4. How many years of experience do you personally have with BIM?

5. Which option(s) best describe your responsibilities in your company?
6. Which option(s) best describe your products?
7. Which option best describes your company's production process?
8. How is your company's product data structured?
9. Which of the options best describes the state of current BIM investment within your company?

These questions aimed to understand the general profile of the participants and to be used in the evaluation of the survey results. The 9th question of the survey was used to divide participants into two different groups.

The question directed to participants who have not invested in BIM in the second section of the survey was as follow:

10. Select the option(s) that best describe your company's reason(s) for not investing in BIM?

This question aimed to assess why participants have not invested in the BIM field.

The questions directed to participants who invested in BIM in the second section of the survey were as follows:

11. Select the option(s) that best describe your company's reason(s) for investing in BIM?
12. In your opinion, what degree of impact do these obstacles have in the transition to BIM processes?
13. How many years of experience does your company have with BIM?
14. Do you think your investment in BIM has paid off?
15. Do you use IFC in your projects?
16. What percentage of your products can you present as BIM objects?

17. Who initially creates the BIM objects?
18. Who updates the BIM objects?
19. How are BIM objects shared?
20. With the transition to BIM processes, how has the number of questions about your products changed (from the customer/designer/contractor)?
21. How difficult are the decisions regarding each of the following factors when preparing BIM objects?
22. How do you determine for which products BIM objects will be created?
23. For each of the following options, please select to what extent you agree or disagree with the following statements regarding BIM.
24. In which languages do you present your BIM objects?
25. Which of the following documents are used in the preparation of your BIM objects?
26. Which classification system do you use to categorize your products?
27. Which software(s) packages do you use to prepare your BIM objects?

These questions aimed to understand the challenges and obstacles encountered by participants.

3.2.1 Sampling of survey

The term "sample" refers to a subset of individuals or items taken from a larger population for research purposes (Cochran, 1977). Samples are used in research to gather information about a population by studying a smaller, more manageable group that represents the characteristics of the larger population (Trochim & Donnelly, 2008). Sampling methods vary depending on the research design and objectives, but they are typically chosen to ensure that the sample is representative of the population of interest (Cochran, 1977). Random sampling, for example, involves selecting individuals from the population at random, giving each member an equal chance of

being included in the sample (Cochran, 1977). This method helps to minimize bias and improve the generalizability of the research findings (Trochim & Donnelly, 2008). Other sampling techniques, such as stratified sampling or convenience sampling, may be used depending on the research goals and constraints (Trochim & Donnelly, 2008).

In this study, the random sampling method was employed, and individuals working in the construction product manufacturing sector in Europe who have knowledge about BIM were selected as the sample from the population.

3.2.2 Required sample size

The required sample size for a survey depends on various factors such as the population size, confidence level, margin of error, and expected variability in responses (Aron, Coups, & Aron, 2019). Generally, a larger sample size leads to more reliable results. Researchers often use statistical formulas to determine the appropriate sample size based on these factors. The formula for calculating sample size is:

$$n = \frac{Z^2 p(1-p)}{E^2} \quad (3.1)$$

Where:

- n = required sample size
- Z = Z-score corresponding to the desired confidence level
- p = estimated proportion of the population that possesses the characteristic of interest
- E = margin of error (expressed as a proportion)

By plugging in the appropriate values for Z , p and E researchers can determine the minimum sample size needed for their survey to achieve the desired level of confidence and precision.

The required sample size for this study, aiming for 90% confidence level and a 0.10 standard deviation, corresponds to a Z-score of 1.645 according to the Z-table. To

maximize the estimated proportion, p is set to 0.5. Given these values, the necessary sample size can be calculated as follows:

$$n = \frac{1.645^2 \times 0.5 \times (1-0.5)}{0.1^2} = 67.65 \quad (3.2)$$

Considering that 71 individuals responded to the survey, we can infer that this study has a 90% confidence level with a 0.10 standard deviation.

3.2.3 Survey analysis

In the analysis of the survey results, classification questions were analyzed using circular (pie) and bar charts, while questions assessing the degree of importance were analyzed using a five-point Likert scale.

For classification questions, circular (pie) and bar charts were utilized to visually represent the distribution of responses. These types of questions typically include demographic information or categorical data, such as: Company size.

- Company Size
- Role of the respondent
- Level of experience with BIM

For questions aimed at understanding the importance of various factors, a five-point Likert scale was employed. The Likert scale typically ranges from "Strongly Disagree" to "Strongly Agree" or "Not Important" to "Very Important". Equation of Five-Point Likert Scale (3.3) is:

$$\bar{x} = \sum_{i=1}^5 \frac{X_i}{n} \quad (3.3)$$

Where:

$\bar{x}$: Mean score

X_i : Represents the individual Likert scores (1 to 5).

n : Total number of responses.

In the context of a survey that includes both classification (categorical) questions and Likert scale questions, the Kruskal-Wallis H test can be used to explore the relationship

between these two types of questions. Specifically, it can be used to determine if the distribution of Likert scale responses differs significantly across different groups defined by a categorical variable.

The Kruskal-Wallis H test is a non-parametric method used to determine if there are statistically significant differences between the medians of two or more independent groups. This test is particularly useful when dealing with ordinal data or when the assumptions of ANOVA (such as normality and homogeneity of variances) are not met. Kruskal-Wallis H test (3.4) is:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^k \left[\frac{R_i^2}{n_i} \right] - 3(N+1) \quad (3.4)$$

Where:

N : Total number of observations across all groups.

k : Number of groups.

R_i : Sum of ranks for the i -th group.

n_i : number of observations in the i -th group.

In this study, questions 12, 21, and 23, which are used to understand the importance levels, will be subjected to the Kruskal-Wallis H test to examine their relationship with the responses to the classification questions provided by the survey participants. The results of the test will determine whether there is a significant difference between the classification characteristics of the participants and their responses to the importance level questions.

Once the significant differences in characteristics are identified, the Mann-Whitney U test will be applied to determine which specific characteristics contribute to these significant differences.

The Mann-Whitney U test, also known as the Mann-Whitney-Wilcoxon test, is a nonparametric test used to determine whether two independent groups have different distributions (Mann & Whitney, 1947). It is commonly employed when the assumptions of the independent samples t-test are not met, particularly when the data are ordinal or not normally distributed.

This test works by ranking all the data points from both groups together, then calculating the sum of ranks for each group. The test statistic U represents the probability that a randomly selected observation from one group will have a higher value than a randomly selected observation from the other group.

If the U value is sufficiently small or large, it suggests that the two groups differ significantly in their distributions. The null hypothesis assumes that there is no difference between the groups, while the alternative hypothesis suggests that there is a difference.

The significance of the test statistic is determined by comparing it to critical values from the Mann-Whitney U distribution or by conducting a significance test. If the p -value is below a predetermined significance level (often 0.05), the null hypothesis is rejected, indicating a significant difference between the groups.

The Mann-Whitney U test is widely used in various fields, including psychology, biology, and social sciences, where it allows researchers to compare two groups without making assumptions about the distribution of the data.

4. SURVEY RESULTS

4.1 Review of Survey Responses

4.1.1 Demographic characteristics of the participants

To gain insights into the profile of the participants and understand the influence of participant characteristics on the responses, five different questions related to demographics were asked. These questions aimed to gather information about variables such as number of company employees, age, professional experience, years of experience with BIM and responsibilities. Analyzing participant demographics provides a deeper understanding of how various factors may impact survey responses.

Participants' workplaces were classified based on the number of employees in their companies (Figure 4.1). This classification aimed to understand how the size of the company might influence participants' perceptions, experiences, and responses regarding the survey topics. The categories typically ranged from small-scale enterprises with fewer than 50 employees to large corporations with over 500 employees, providing insights into how organizational size might impact attitudes and behaviors related to the surveyed topics.

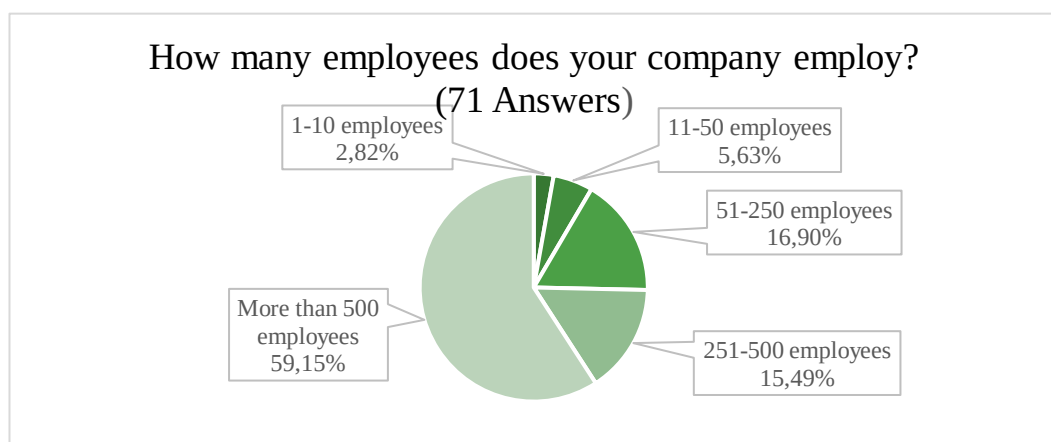


Figure 4.1: Classification of the number of the employees' participants' firms.

Participants' ages were categorized to analyze potential differences or trends based on age groups (Figure 4.2). Age classifications typically ranged from younger participants (e.g., under 25 years old) to older participants (e.g., over 65 years old), with intermediate categories covering different age ranges. This classification aimed to explore how age might influence participants' perspectives, experiences, and responses regarding the survey topics, providing valuable insights into generational differences or similarities in attitudes and behaviors.

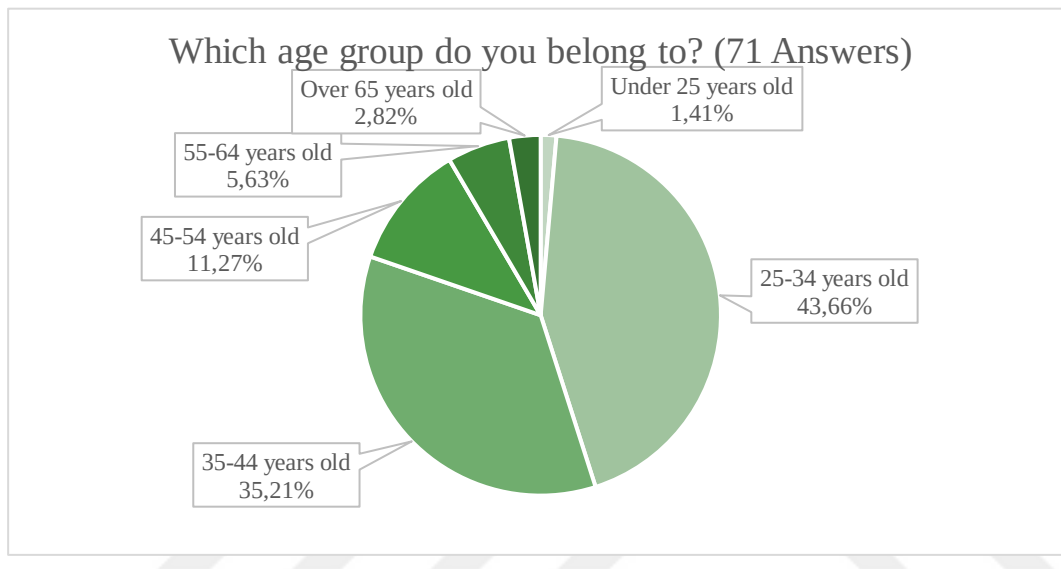


Figure 4.2: Classification of participants according to their ages.

Participants were categorized based on their individual experience in the construction sector to evaluate the potential impact of industry tenure on their responses (Figure 4.3). Classification criteria typically included different experience levels, such as 0-2 years, 3-5 years, 6-10 years, 11-20 years, and more than 20 years. This classification aimed to investigate whether varying levels of experience influenced participants' perceptions, attitudes, and responses regarding the survey topics, providing insights into the role of industry experience in shaping perspectives and decision-making.

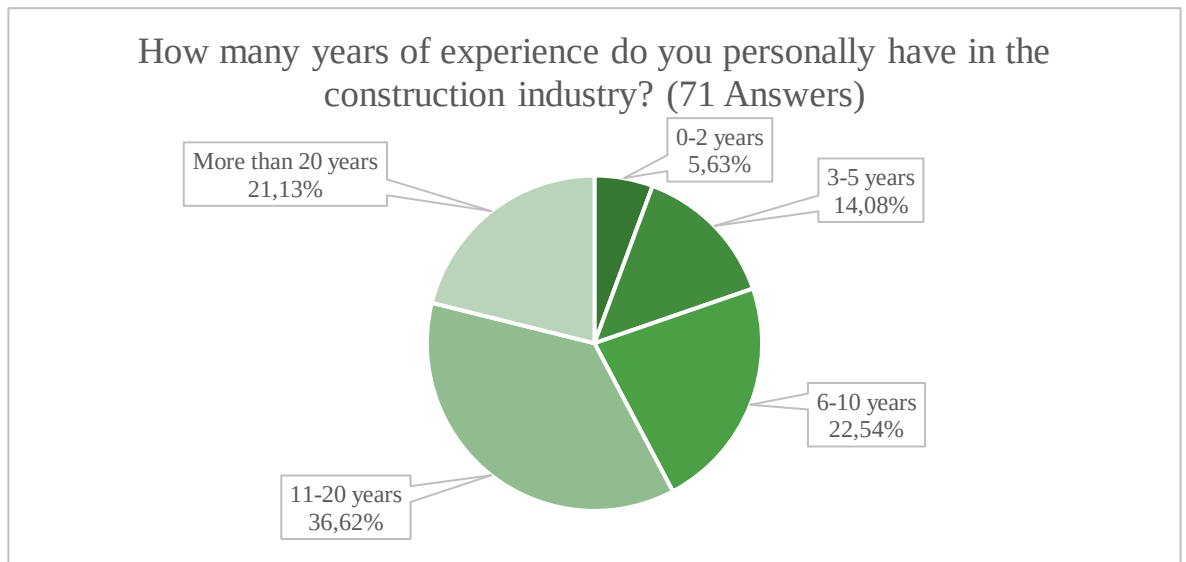


Figure 4.3: Classification of participants' experience in the construction industry.

Participants were classified based on their individual experience with Building Information Modeling (BIM) to assess its potential influence on their responses (Figure 4.4). Classification criteria typically included different levels of BIM experience, such as beginners, intermediate users, and advanced users. This classification aimed to explore whether varying levels of BIM expertise influenced participants' perceptions, attitudes, and responses regarding BIM-related topics, providing insights into the role of BIM experience in shaping perspectives and decision-making.

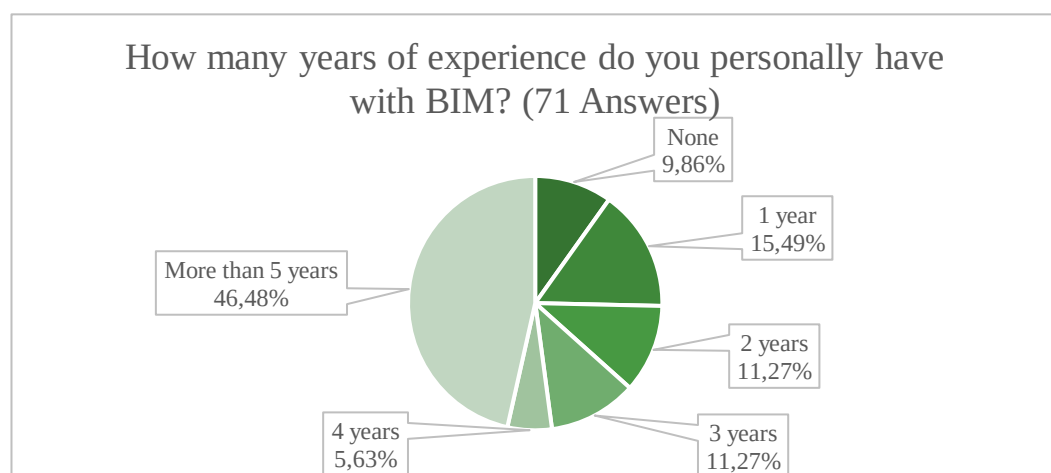


Figure 4.4: Classification of participants according to their experience with BIM.

Participants' distribution of responsibilities within their firms was analyzed to understand the range of roles involved in BIM implementation and usage (Figure 4.5).

Understanding the distribution of responsibilities provided insights into the multidisciplinary nature of BIM adoption and its integration across different organizational functions within firms.

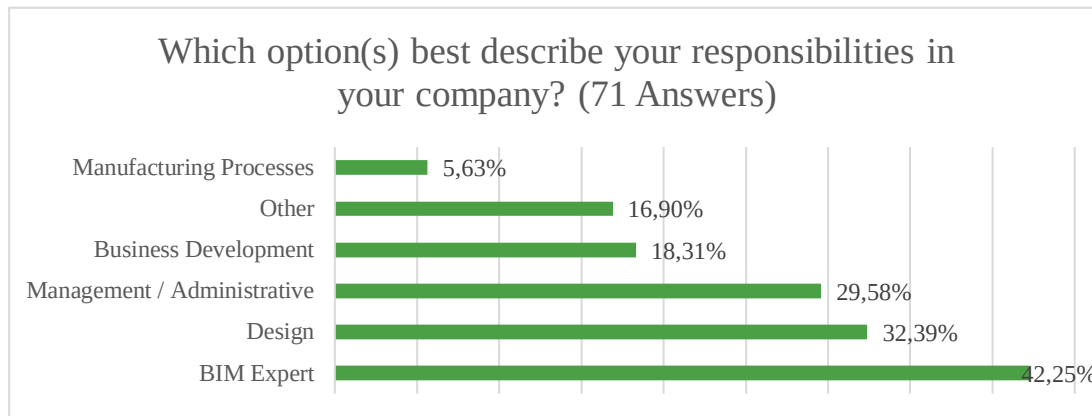


Figure 4.5: Distribution of participants' responsibilities in their companies.

The data presents a comprehensive overview of the demographics, experience levels, and roles within the construction industry, particularly focusing on Building Information Modeling (BIM). The majority of respondents come from larger companies with over 500 employees, indicating a broad scope of operations. The workforce is primarily composed of individuals aged 25 to 44, with a significant portion having over a decade of experience in the industry. Notably, BIM expertise is prevalent among respondents, with nearly half having more than five years of experience in this area. This suggests a strong emphasis on technological proficiency within the sector. In terms of responsibilities, a considerable portion of employees are involved in BIM expertise, followed closely by design and management/administrative roles. The findings highlight a dynamic workforce adept at leveraging advanced technologies for efficient project management and development within the construction domain.

4.1.2 Survey questions about firms

In this section, participants were asked for details about the firms they work for. The questions aimed to gather information on the types of construction products they manufacture, their production processes, how product data is structured, and their status regarding BIM investment. By understanding these aspects, the study sought to

identify the diversity of construction products, the extent of BIM adoption, and how firms manage and utilize BIM-related data.

The survey data indicates the diversity of products offered by the companies surveyed for BIM adoption (Figure 4.6). The largest category, with 46.48% of respondents, consists of products used in finishing works, reflecting a significant portion of the market focused on interior and final phase construction materials. Infrastructure and rough construction products follow closely at 40.85%, highlighting the importance of foundational and structural elements in the industry. Products used in fine work account for 30.99%, indicating a substantial focus on detailed and precision-based construction tasks. Other product categories include electricity and plumbing products, each at 11.27%, air conditioning products at 9.86%, and a small segment (1.41%) dedicated to landscaping products. Additionally, 14.08% of respondents indicated 'other' products, suggesting a variety of niche or specialized construction materials. This data underscores the broad range of products relevant to BIM implementation, with a notable emphasis on finishing and rough construction materials, essential for comprehensive BIM adoption strategies.

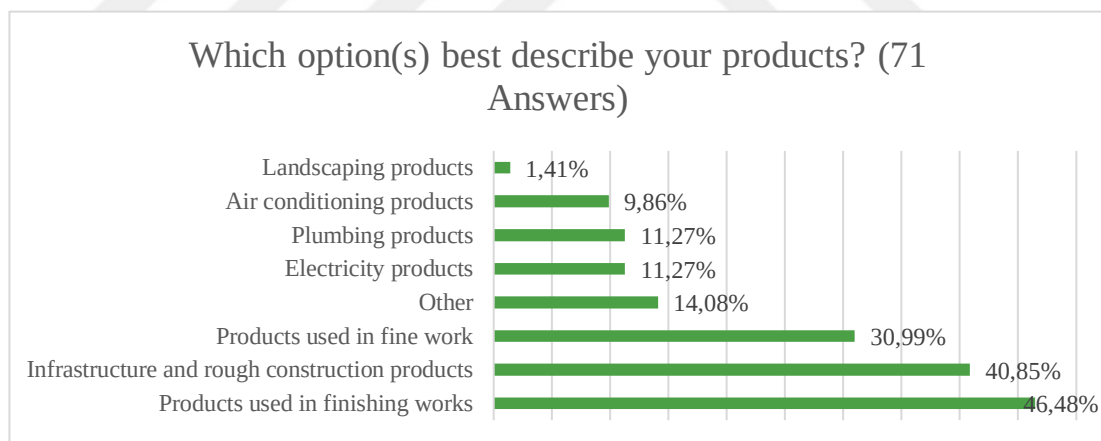


Figure 4.6: Distribution of participants' products.

The survey results on company production processes (Figure 4.7) reveal that the majority of respondents, 54.93%, reported that their production is made to order. Additionally, 49.30% indicated that production is engineered to order, while 33.80% stated that production is made to stock. A smaller percentage, 11.27%, reported that they do not know the details of their company's production process.

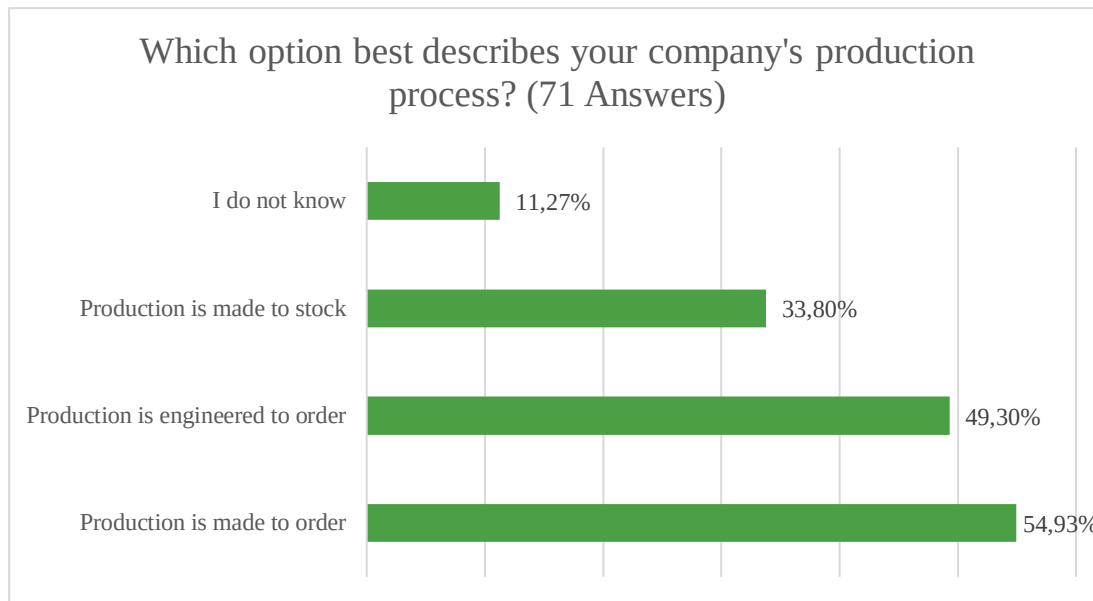


Figure 4.7: Distribution of participants' production process.

The survey results regarding the structure of product data (Figure 4.8) show that 46.48% of companies use a company-specific template to structure their product data. Additionally, 30.99% of respondents reported using an international standard template, while 12.68% stated that their product data is not structured in a template and is stored in multiple files. A smaller portion, 7.04%, were unsure about how their company's product data is structured, and 2.82% indicated other methods of data structuring.

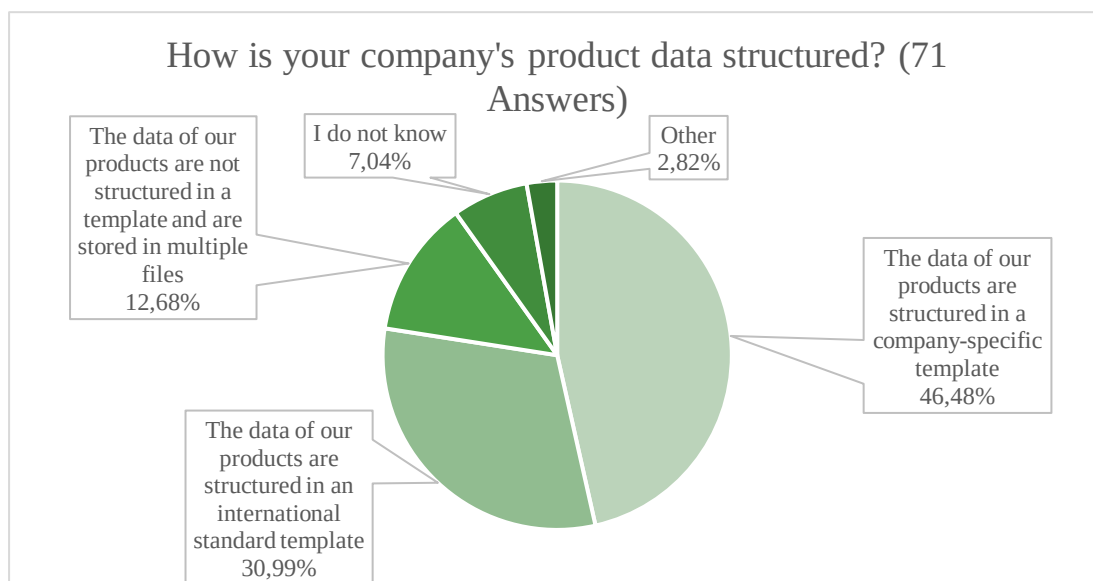


Figure 4.8: Distribution of participants' structure of product data.

The survey results regarding the state of current BIM investment (Figure 4.9) within companies reveal that 83.10% of respondents have invested in BIM and actively use it in their processes. Meanwhile, 9.86% have invested in BIM but have not yet started using it. A smaller proportion of companies, 4.23%, have not invested in BIM but plan to do so in the future, and 2.82% have not invested in BIM and have no plans to invest.

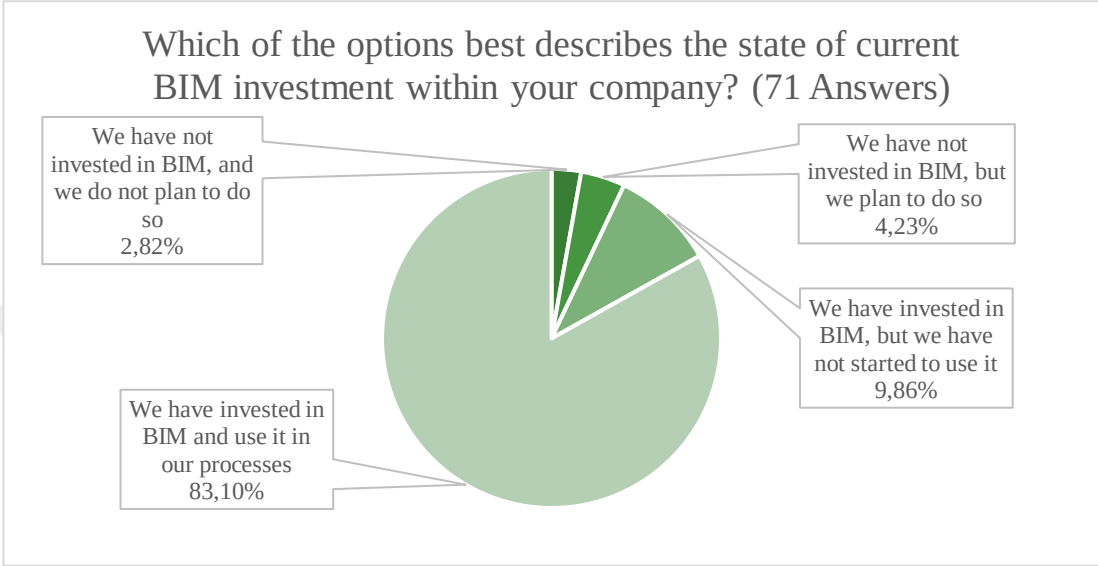


Figure 4.9: Distribution of participants' investment in BIM.

The survey results offer valuable insights into the product description, production processes, data structuring, and BIM investment within companies surveyed. In terms of product description, the majority of companies specialize in finishing works, with infrastructure and rough construction products closely following. Interestingly, a significant portion also deals with fine work, electricity products, plumbing products, and air conditioning products, showcasing a diverse product portfolio within the industry. Concerning production processes, the data suggests a split between made-to-order and engineered-to-order approaches, indicating a degree of customization in manufacturing. However, a notable portion also follows a made-to-stock model. Regarding data structure, a significant number of companies utilize company-specific templates, while others adhere to international standards or lack a standardized template altogether, highlighting varying levels of data organization. Regarding BIM investment, a substantial majority of companies have invested in BIM and actively incorporate it into their processes, demonstrating a strong commitment to leveraging advanced technology for improved project outcomes.

4.1.3 Survey questions asked to not invest in BIM

Only 5 participants among the 71 surveyed have not invested in BIM, and their reasons for not doing so have been queried. However, with such a small sample size, solely the responses from these 5 participants may not sufficiently elucidate why firms opt not to invest. The limited number represents a narrow spectrum of perspectives, making it challenging to draw broad conclusions. Given the diverse circumstances and priorities of different companies, a more comprehensive analysis is required to understand the underlying reasons behind the decision not to invest in BIM (Figure 4.10). Therefore, further examination of the views and rationales of other participants who have not invested in BIM would be crucial for gaining a deeper understanding of the factors influencing these decisions.

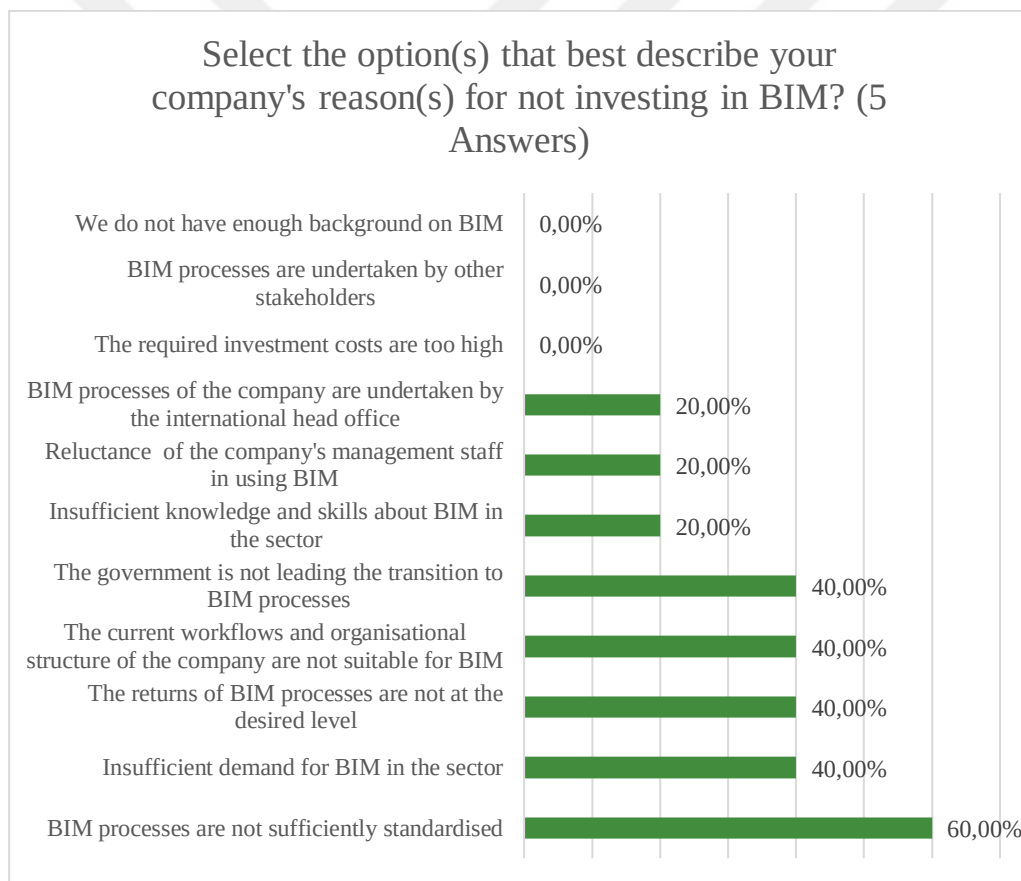


Figure 4.10: Distribution of participants' reason to not investment in BIM.

4.1.4 Survey questions asked to invest in BIM

The survey results reveal a wide array of compelling reasons why stakeholders choose to invest in BIM (Figure 4.11). At the forefront is the desire to increase cooperation

between stakeholders, reflecting the importance of seamless collaboration in modern construction projects. Additionally, the drive to enhance competitiveness underscores the recognition of BIM as a strategic advantage in the industry. Participants also emphasize the value of BIM in providing integrated processes within projects, enabling smoother workflows and improved project outcomes. The capability of BIM to detect design errors and deficiencies easily is seen as a significant benefit, aligning with the industry's pursuit of efficiency and quality assurance. Moreover, the ability of BIM to facilitate the management of project information and provide visualization closer to reality resonates with stakeholders seeking enhanced project transparency and communication. These findings underscore the multifaceted benefits of BIM beyond mere design and construction, extending to project management, compliance, and overall project success.

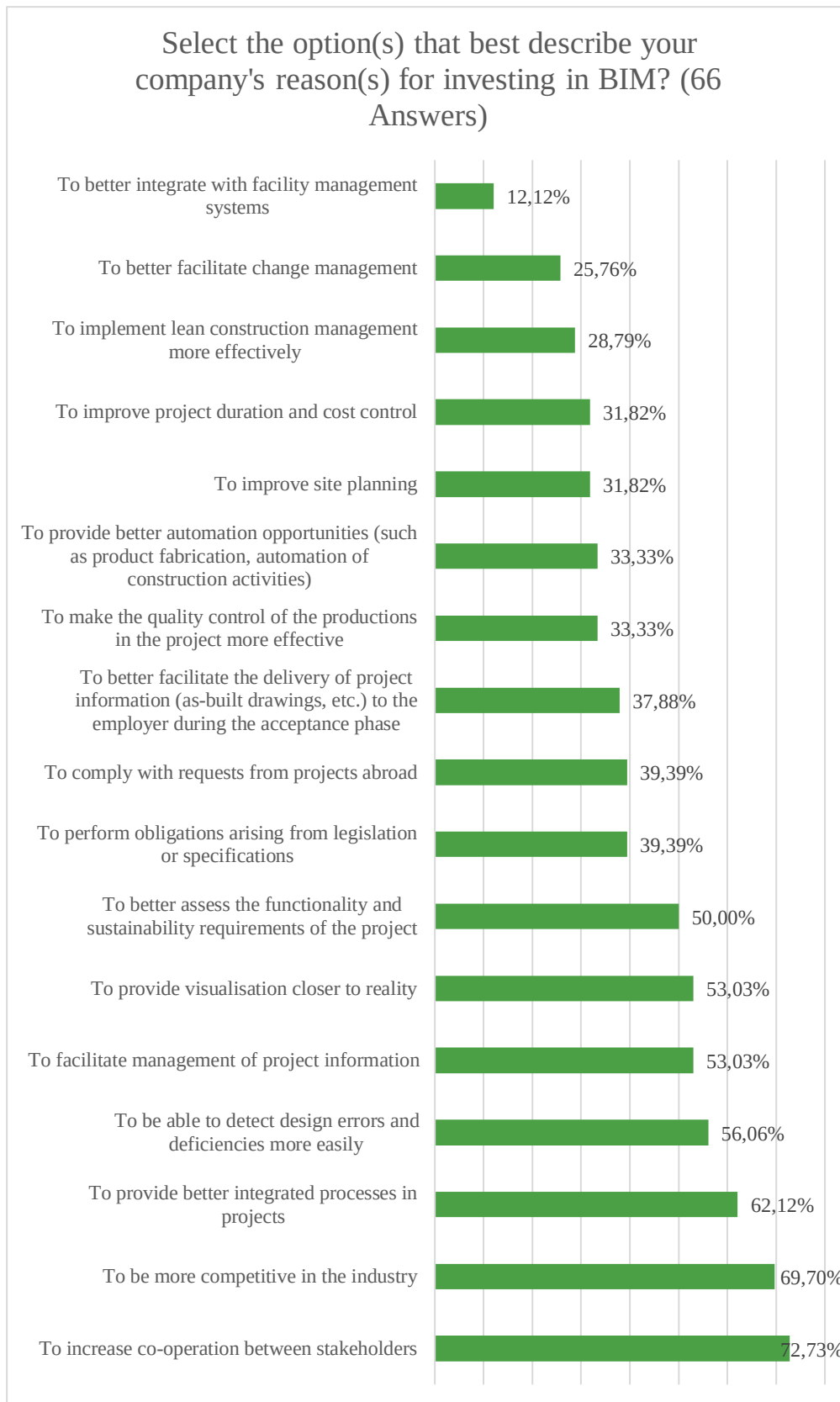


Figure 4.11: Distribution of participants' reason to investment in BIM.

The results from the Likert scale indicate the perceived importance of various factors hindering the adoption of BIM within companies (Figure 4.12). Among these, resistance to change emerges as the highest-ranked obstacle, suggesting a prevalent reluctance among stakeholders to embrace new methodologies and technologies. Following closely are concerns regarding the lack of knowledge and skills about BIM within the company, highlighting a significant barrier to effective implementation. Additionally, the perceived lack of cooperation among stakeholders and the absence of trained personnel are identified as key challenges, underscoring the importance of cohesive teamwork and specialized expertise in BIM adoption. Furthermore, the reluctance or inertia from company management to adopt BIM is noted, emphasizing the critical role of leadership buy-in in driving organizational change. Other notable barriers include the failure to obtain appropriate consultancy services, deficiencies in information management, and the complexity of BIM processes, all of which contribute to the overall resistance to BIM adoption. Addressing these barriers effectively will be essential for facilitating smoother transitions and maximizing the benefits of BIM within companies.

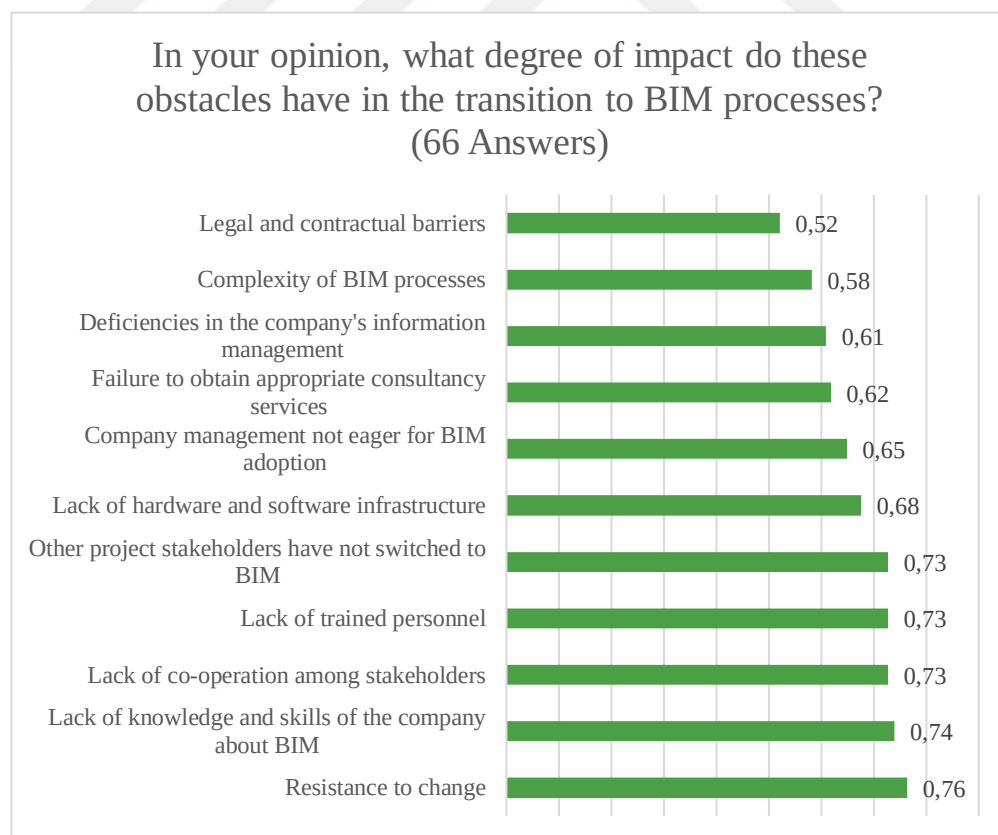


Figure 4.12: Likert scale distribution of obstacles to transition to BIM.

The data illustrates the varying levels of experience that the company possesses in utilizing BIM (Figure 4.13). While a small percentage of participants have less than a year of experience or are relatively new to BIM (less than 3 years), the majority demonstrate a substantial level of proficiency, with over 59% reporting more than 5 years of experience. This distribution suggests a significant investment of time and resources into integrating BIM into the company's workflow over the years. The substantial number of participants with extensive experience indicates a mature understanding and utilization of BIM within the company, likely contributing to enhanced efficiency, collaboration, and project outcomes.

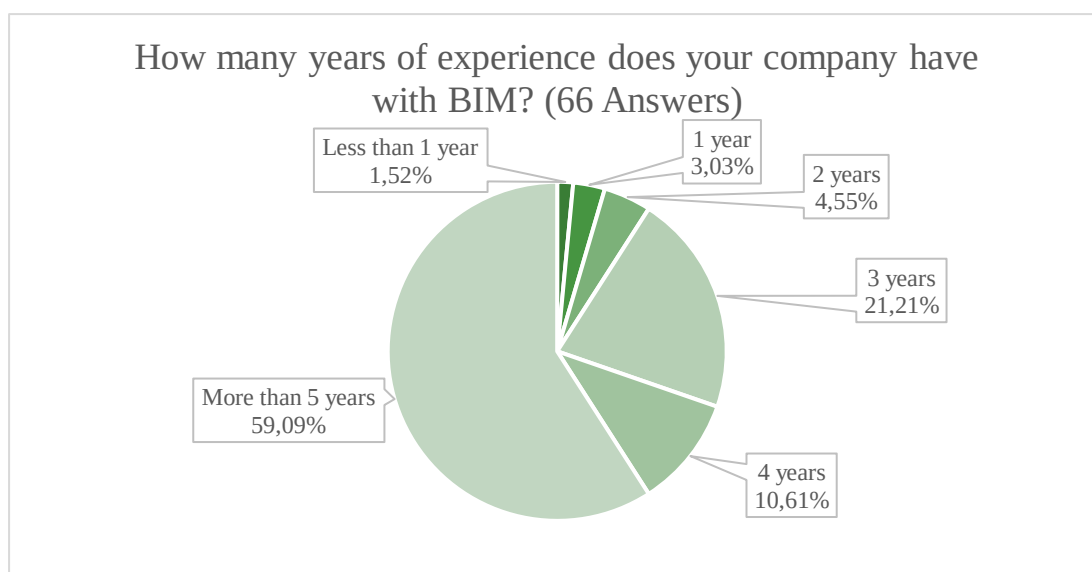


Figure 4.13: Distribution of participants' firms' experience with BIM.

The responses indicate a mixed sentiment regarding the payoff of the company's investment in BIM (Figure 4.14). While a substantial proportion of participants express confidence in the benefits of their investment, with 36.36% stating that it has definitely paid off, a comparable number (31.82%) believe that it has partly paid off. Conversely, a smaller percentage (7.58%) express dissatisfaction, with 3.03% stating that it has absolutely not paid off and 4.55% indicating that it has partly not paid off. Additionally, 24.24% remain undecided about the extent to which their investment in BIM has yielded favorable outcomes. These responses reflect a nuanced evaluation of the effectiveness and impact of BIM within the company, suggesting a need for further assessment and possibly optimization of BIM utilization to maximize its benefits.

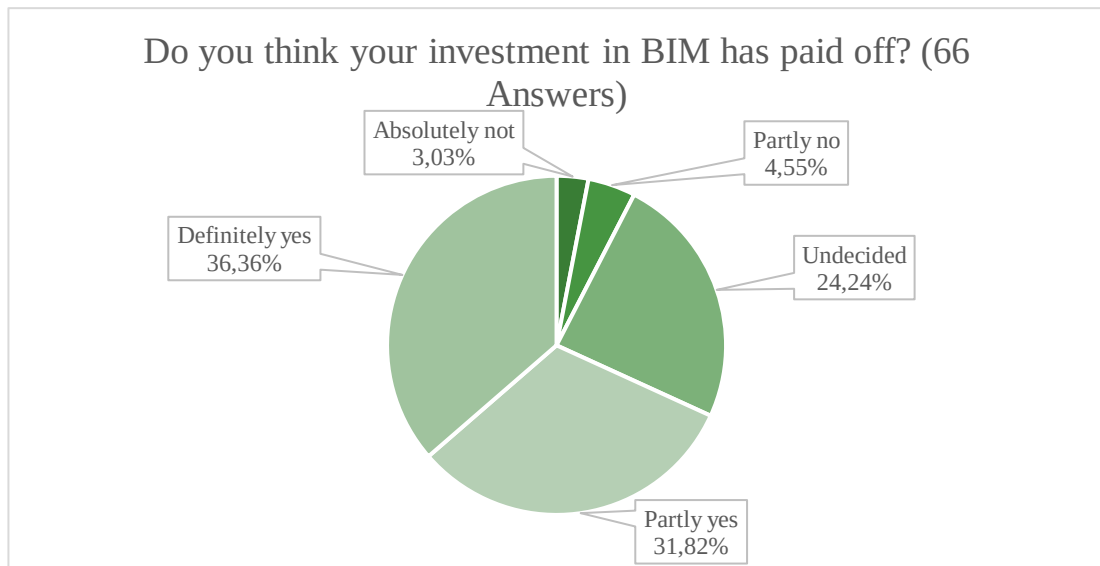


Figure 4.14: Distribution of participants' firms' experience with BIM.

The survey results indicate that a majority of participants, comprising 63.64%, use Industry Foundation Classes (IFC) in their projects (Figure 4.15), while 36.36% do not. This suggests a widespread adoption of IFC, a standardized file format commonly used for exchanging and sharing BIM among different software platforms. The high usage rate of IFC underscores its importance as a key interoperability solution within the construction industry, enabling seamless collaboration and integration across various stakeholders and software applications.

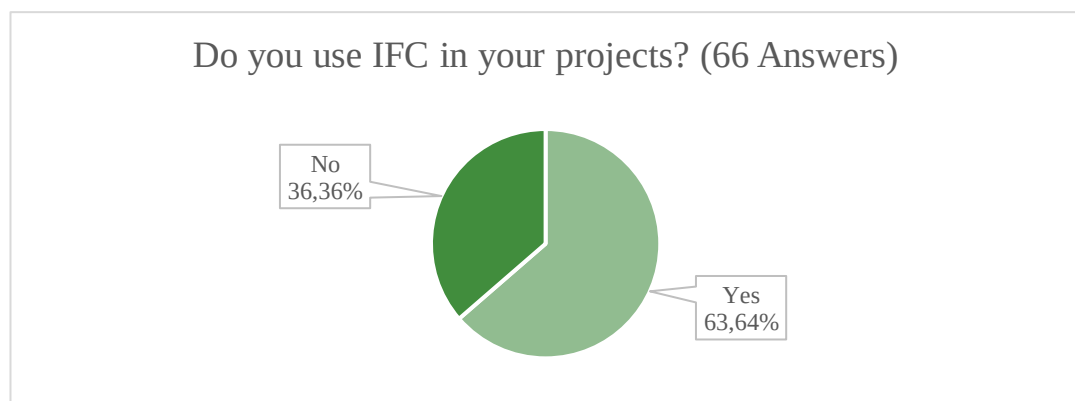


Figure 4.15: Distribution of participants' IFC usage in projects.

The survey data reveals the varying extent to which participants can present their products as BIM objects (Figure 4.16), reflecting the degree of BIM integration within their organizations. A notable proportion of respondents, comprising 27.27%, indicate that they can present 80-100% of their products as BIM objects, showcasing a high

level of digitalization and alignment with BIM standards. Additionally, a considerable number of participants, representing 22.73%, report being able to present 20-40% of their products as BIM objects, suggesting ongoing efforts towards enhancing BIM capabilities and product digitalization initiatives. However, it is noteworthy that a small percentage of respondents (3.03%) have not yet converted any of their products into BIM objects, indicating potential areas for improvement in BIM adoption and implementation strategies within these organizations.

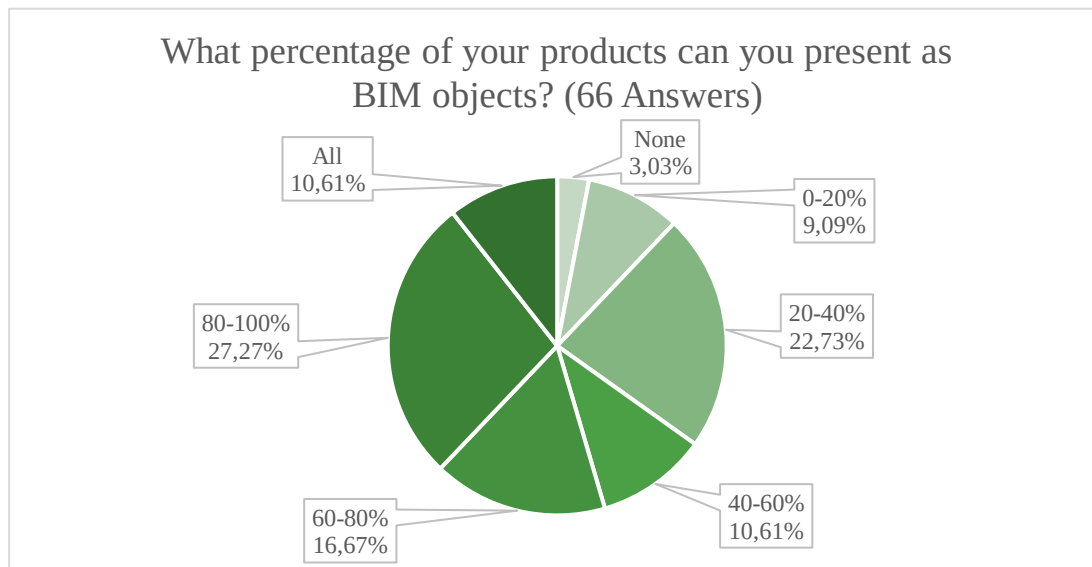


Figure 4.16: Distribution of participants' BIM object percentage.

According to the survey results, the majority of participants, accounting for 63.64%, initially create BIM objects in-house (Figure 4.17). This indicates that these companies have internal capabilities and resources dedicated to the creation of BIM objects, reflecting a hands-on approach to BIM implementation and digitalization efforts. Additionally, 15.15% of respondents indicate that BIM objects are created by the head office abroad, particularly for representatives of international companies operating in the country. This suggests a centralized approach to BIM object creation within multinational corporations, potentially leveraging expertise and resources available at the headquarters. Moreover, a smaller percentage of participants, comprising 13.64%, rely on external companies providing consultancy services for the creation of BIM objects, highlighting the role of external expertise in supporting BIM initiatives. Finally, 7.58% of respondents mention external platforms hosting BIM objects,

indicating the utilization of third-party resources for accessing or acquiring BIM content.

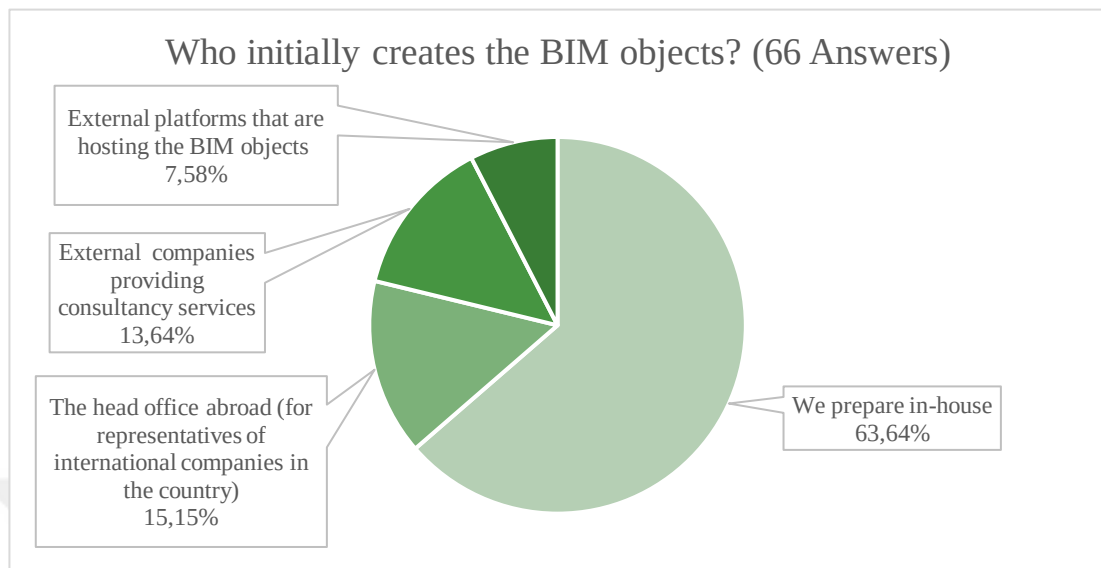


Figure 4.17: Distribution of participants' BIM object creation.

The survey data unveils interesting dynamics regarding the updating of BIM objects (Figure 4.18) compared to their initial creation. While a majority of participants (72.73%) take on the responsibility of updating BIM objects themselves within their organizations, a slightly smaller percentage (63.64%) initially create these objects in-house. This indicates a significant level of self-reliance and internal capacity for ongoing maintenance and updating of BIM content among respondents. Conversely, a smaller proportion of participants delegate the task of updating BIM objects to external entities, with 12.12% relying on the head office abroad and 13.64% engaging external consultancy firms for this purpose. Additionally, only 1.52% mention external platforms hosting BIM objects as responsible for updates. This comparison suggests that while there is a preference for in-house control and management of BIM objects, organizations may seek external support or leverage centralized resources for certain aspects of the updating process, particularly in the case of international companies or when specialized expertise is required.

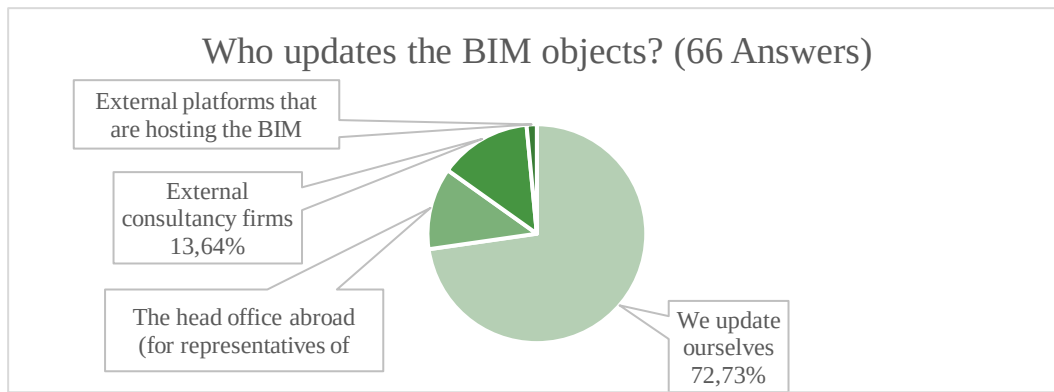


Figure 4.18: Distribution of participants' BIM object updates.

The survey reveals a multifaceted landscape regarding the sharing of BIM objects (Figure 4.19) within the construction industry. A majority of participants, comprising 53.03%, opt to share BIM objects through the manufacturer's own platform, such as their official website. This approach allows manufacturers to maintain direct control over the distribution process, potentially ensuring accuracy and consistency in the BIM content provided. Additionally, 34.85% of respondents utilize plug-ins developed by BIM software manufacturers on BIM object library platforms, indicating a reliance on specialized tools to streamline integration with BIM software and enhance accessibility for users. Furthermore, 27.27% share BIM objects through dedicated library platforms like bimobject.com, leveraging centralized repositories to facilitate widespread access and standardization of BIM content. Notably, 13.64% mention distributors as a channel for BIM object distribution, highlighting the involvement of intermediaries in expanding the reach of BIM content. The survey also identifies various other methods, accounting for 10.61%, indicating a diverse range of approaches tailored to specific needs or preferences.

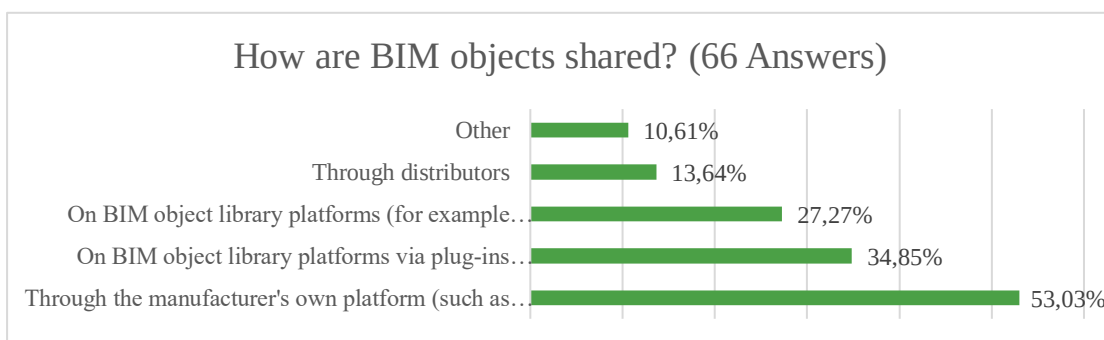


Figure 4.19: Distribution of participants' BIM object sharing.

According to the survey responses, the transition to BIM processes has had varying effects on the number of questions about products from customers, designers, and contractors (Figure 4.20). The majority of participants, accounting for 77.27%, report no change or very little change in the number of inquiries. This suggests that for most respondents, the adoption of BIM has not significantly impacted the frequency of questions regarding their products. However, 13.64% of participants note a noticeable increase in inquiries, indicating that the implementation of BIM processes has led to heightened interest or scrutiny regarding product specifications and compatibility within BIM workflows. Conversely, a smaller percentage of respondents, comprising 9.09%, report a noticeable decrease in questions, suggesting that BIM adoption may have streamlined communication or provided more readily available product information, reducing the need for inquiries.

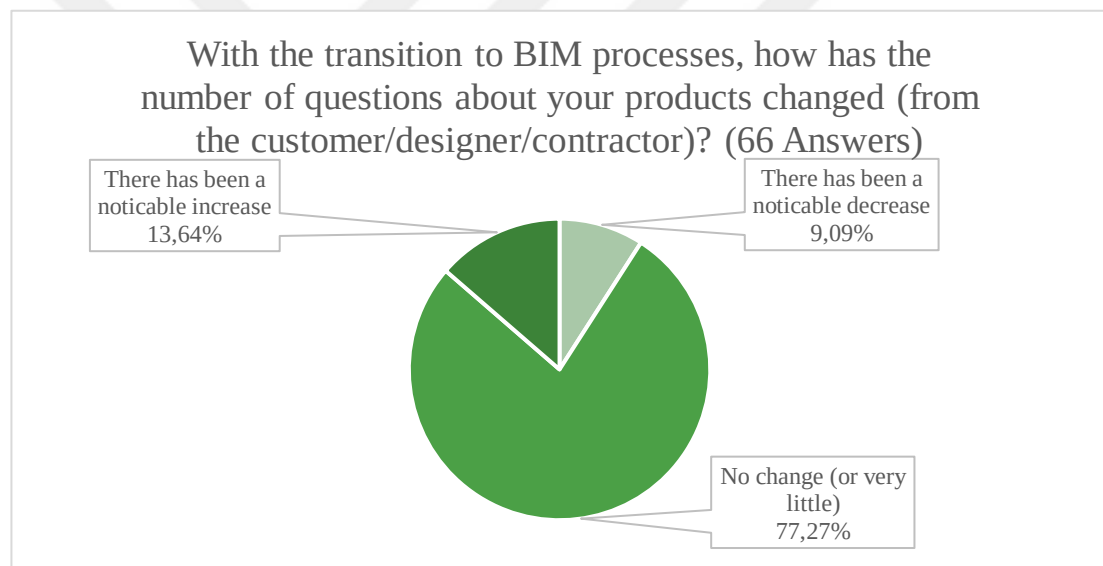


Figure 4.20: Distribution of changing the questions about product asked.

The survey results provide valuable insights into the perceived difficulty of decisions regarding various factors when preparing BIM objects (Figure 4.21). Participants rate the decision-making process regarding how requirements will change for each project phase as the most challenging, with an importance index of 0.5818. This underscores the complexity of anticipating and accommodating evolving project needs and specifications throughout different stages of development. Additionally, respondents highlight the significance of considering the expectations and needs of BIM object users, as well as determining the non-visual data and visual information to be included

in BIM objects, with importance indices of 0.5636 and 0.5606, respectively. These findings emphasize the critical role of user-centric design and comprehensive data integration in the development of effective BIM objects. Furthermore, decisions regarding whether to represent intervention and service areas, select levels of detail (LOD/LOI), manage file size, and establish naming conventions also rank high in perceived difficulty, indicating the multifaceted nature of BIM object preparation and the importance of thoughtful decision-making in this process.

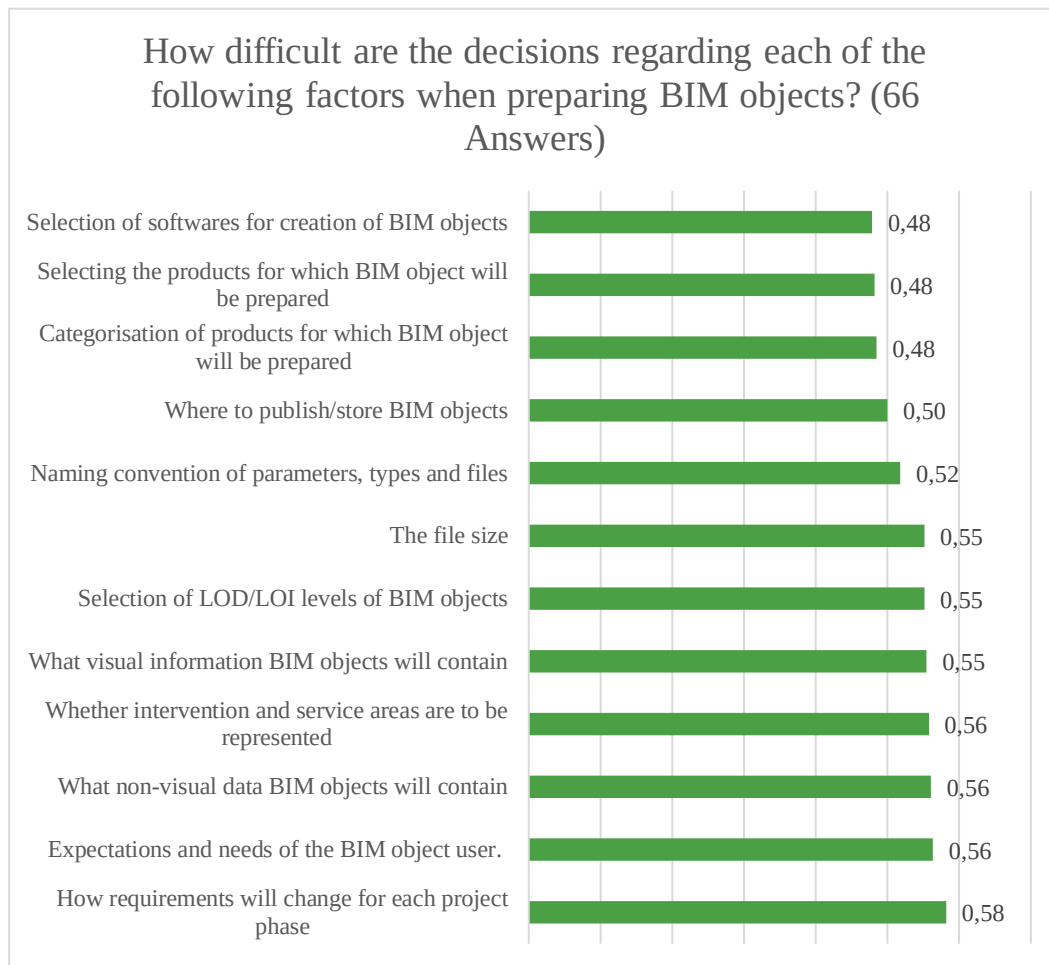


Figure 4.21: Likert scale distribution of difficulties to preparing BIM objects.

The survey results provide insights into how companies determine which products to create BIM objects for (Figure 4.22). The most common approach, indicated by 40.91% of participants, is to create BIM objects for products used in projects where BIM utilization is high. This suggests a strategic focus on aligning BIM object creation with the needs of projects that heavily rely on BIM, thereby maximizing relevance and utility. Additionally, 39.39% of respondents create BIM objects for all their products,

reflecting a comprehensive approach aimed at ensuring all offerings are available in BIM format, potentially enhancing accessibility and versatility.

Furthermore, 28.79% of participants create BIM objects for products specifically demanded by users, highlighting a responsive strategy that prioritizes customer and stakeholder requests. Lastly, 18.18% of respondents focus on creating BIM objects for their best-selling products, indicating a pragmatic approach that prioritizes high-demand items to maximize the impact and return on investment of their BIM efforts.

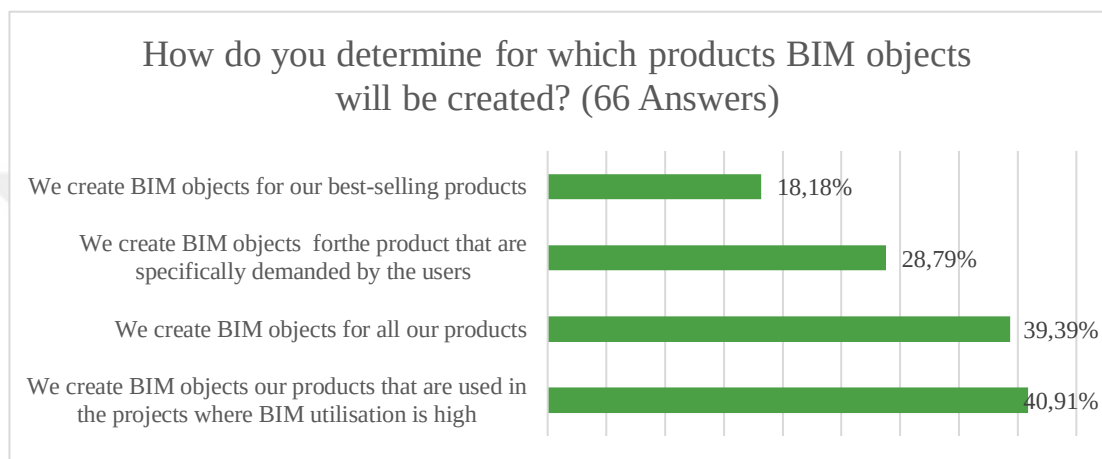


Figure 4.22: Distribution of BIM object creation.

The survey responses reflect participants' varying degrees of agreement with statements regarding BIM and its impact on product information and design processes (Figure 4.23), using a Likert scale where responses range from strongly disagree (-2) to absolutely agree (2). Participants express moderate agreement (0.38) with the statement that Product Information Templates (PDTs) are not yet sufficiently standardized, indicating some concern about the consistency of these templates. There is stronger agreement (0.62) that the information contained in BIM objects is not sufficiently standardized and that a lot of information is required when preparing BIM objects, highlighting challenges related to information overload and standardization.

Conversely, participants slightly disagree (-0.12) with the notion that they are asked to present BIM objects in too many formats, suggesting that format requirements are not seen as a major issue. Positive sentiment is strong regarding the benefits of BIM, with participants agreeing that BIM makes it easier to manage the technical information of products (0.80) and enables improvements in product designs (0.62). These results

underscore the dual aspects of BIM adoption, where standardization and information demands pose challenges, yet significant advantages are recognized in terms of information management and design enhancement.

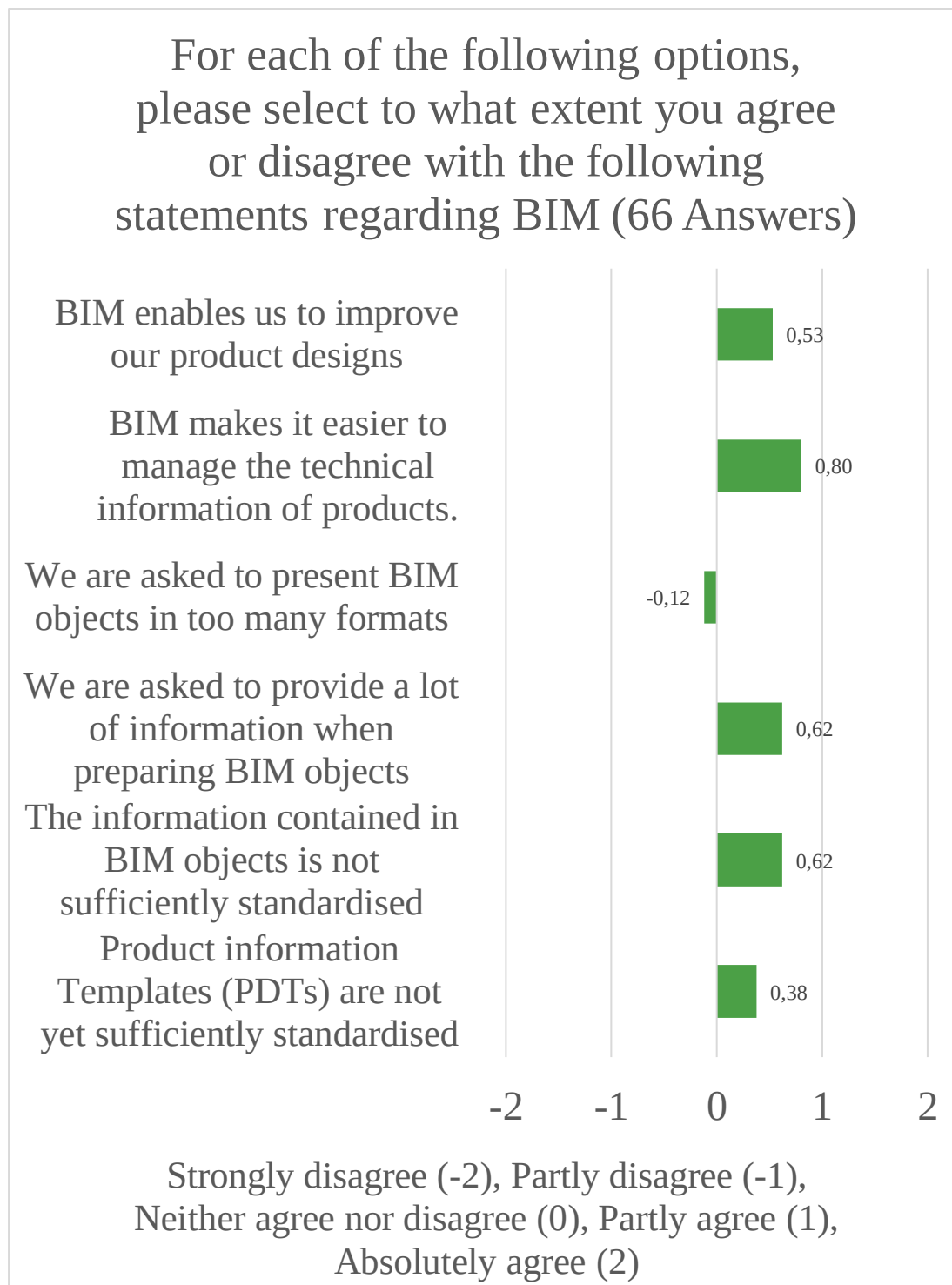


Figure 4.23: Distribution of participants' thoughts about BIM.

English is the predominant language, used by 89.39% of respondents (Figure 4.24), reflecting its status as the primary language for international business and technical communication. German is the next most common language, used by 30.30% of participants, followed by Turkish, utilized by 22.73%. Dutch and French are also represented, with 13.64% and 12.12% of respondents respectively offering BIM objects in these languages. Italian is used by 9.09% of participants, and 6.06% indicate the use of other languages. This multilingual approach demonstrates the need to cater to diverse markets and users, facilitating better accessibility and usability of BIM objects across different regions and linguistic groups.

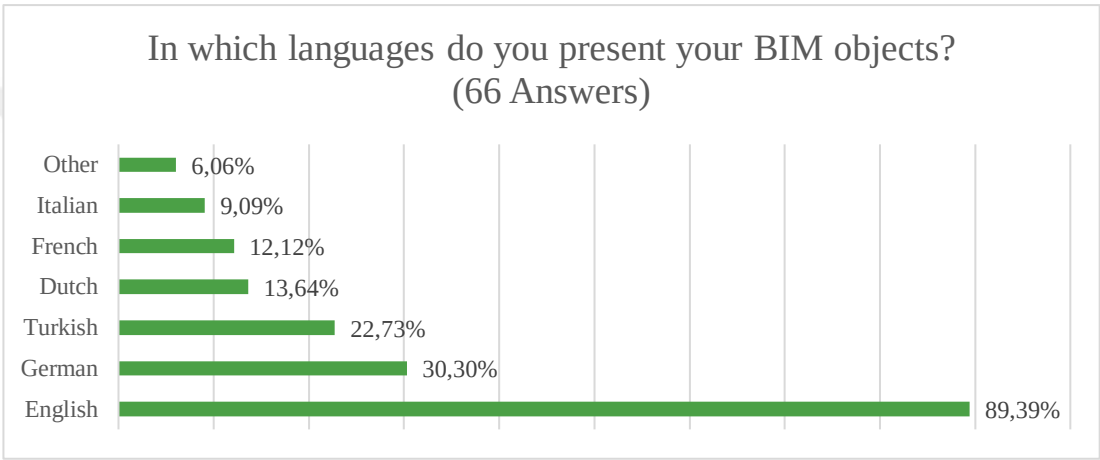


Figure 4.24: Distribution of BIM object languages.

The survey results reveal the diverse range of documents used in the preparation of BIM objects (Figure 4.25). A majority of participants (53.03%) rely on information from the company's current catalogues, reflecting the importance of leveraging existing product data. Information requirements of the customer on a project basis are also crucial, cited by 50% of respondents, indicating the need to meet specific project demands and client specifications.

Standards such as ISO 19650 are used by 36.36% of participants, underscoring the significance of adhering to international guidelines for managing information over the lifecycle of a built asset using BIM. ISO 16739, which deals with IFC, is referenced by 18.18% of respondents. Other standards and guides, such as BS 1192 (10.61%), BIM Object Style Guide (7.58%), BS 8541 (6.06%), NBS BIM Object Standard (6.06%), and NATSPEC Open BIM Object Standard (4.55%), are used by smaller

percentages of participants, highlighting the variety of frameworks available to support BIM object preparation.

Additionally, 13.64% of respondents are unsure of the specific documents used, and 3.03% indicate that none of the listed documents are utilized in their processes. The BIM Store Bible and the CIC HK BIM Object Guide are the least used, each cited by only 3.03% and none of the respondents, respectively. This diversity in document usage illustrates the varying practices and standards adopted by organizations to ensure the accuracy and quality of their BIM objects.

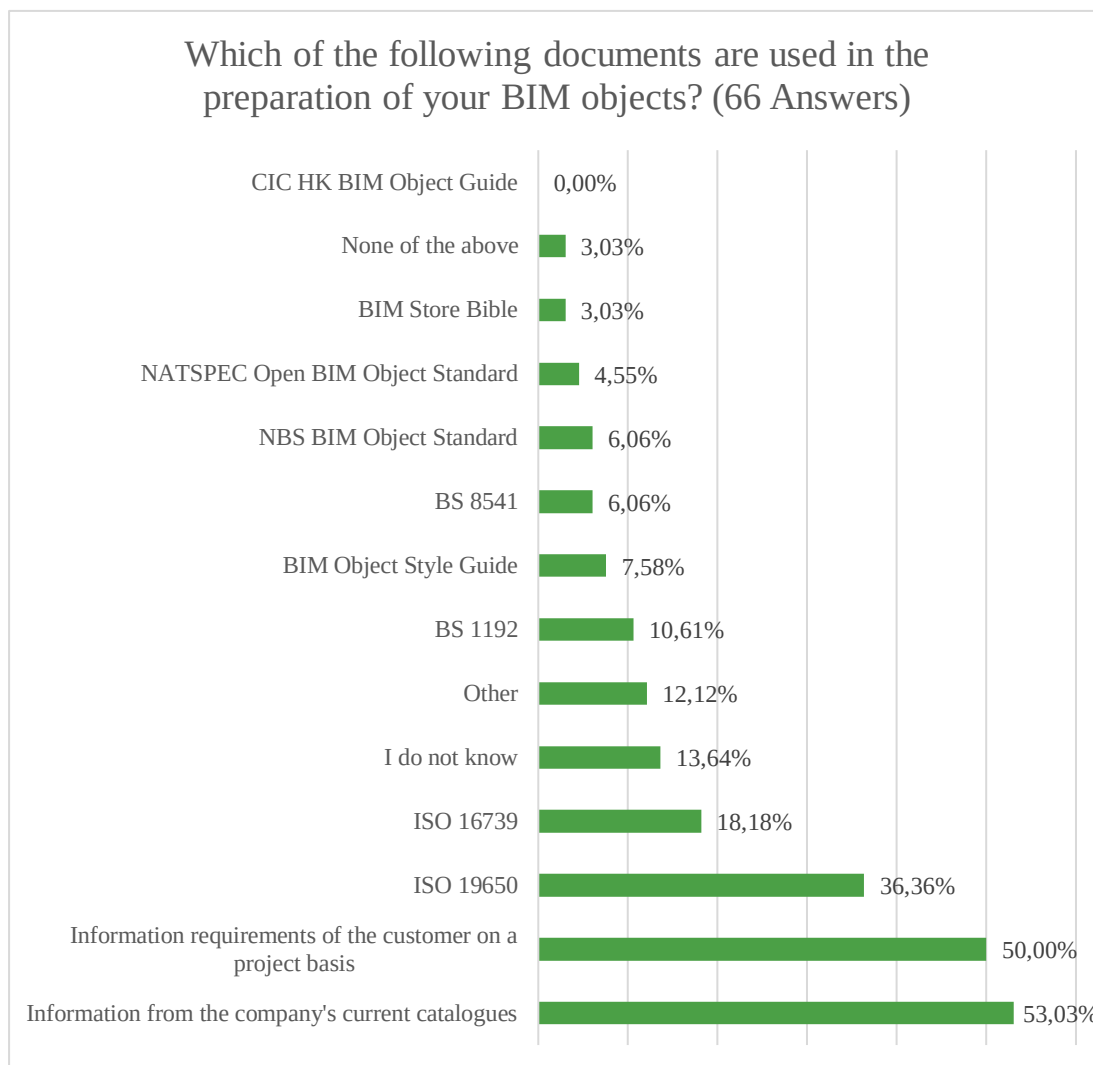


Figure 4.25: Distribution of document using in preparation of BIM objects.

The survey results indicate a variety of classification systems used by participants to categorize their products (Figure 4.26). OmniClass is the most commonly used system, with 28.79% of respondents utilizing it. Close behind, 27.27% of participants report

not using any classification system. Uniclass and the buildingSMART Data Dictionary are both used by 25.76% of respondents, reflecting their importance in standardizing BIM data.

A notable 22.73% of participants are unsure of the classification system used, suggesting a need for better awareness or training in this area. UniFormat and MasterFormat are used by 16.67% and 12.12% of respondents, respectively, indicating their continued relevance in certain regions or project types. TALO2000, ETIM, and other systems are each used by 4.55% of participants, showing their niche applications. CCS and NS 3451 & TFM are the least used, cited by 3.03% and 1.52% of respondents, respectively, while CoClass is not used by any of the participants.

These findings illustrate the diverse landscape of classification systems in use, highlighting the need for flexibility and adaptability in categorizing BIM products across different projects and regions.

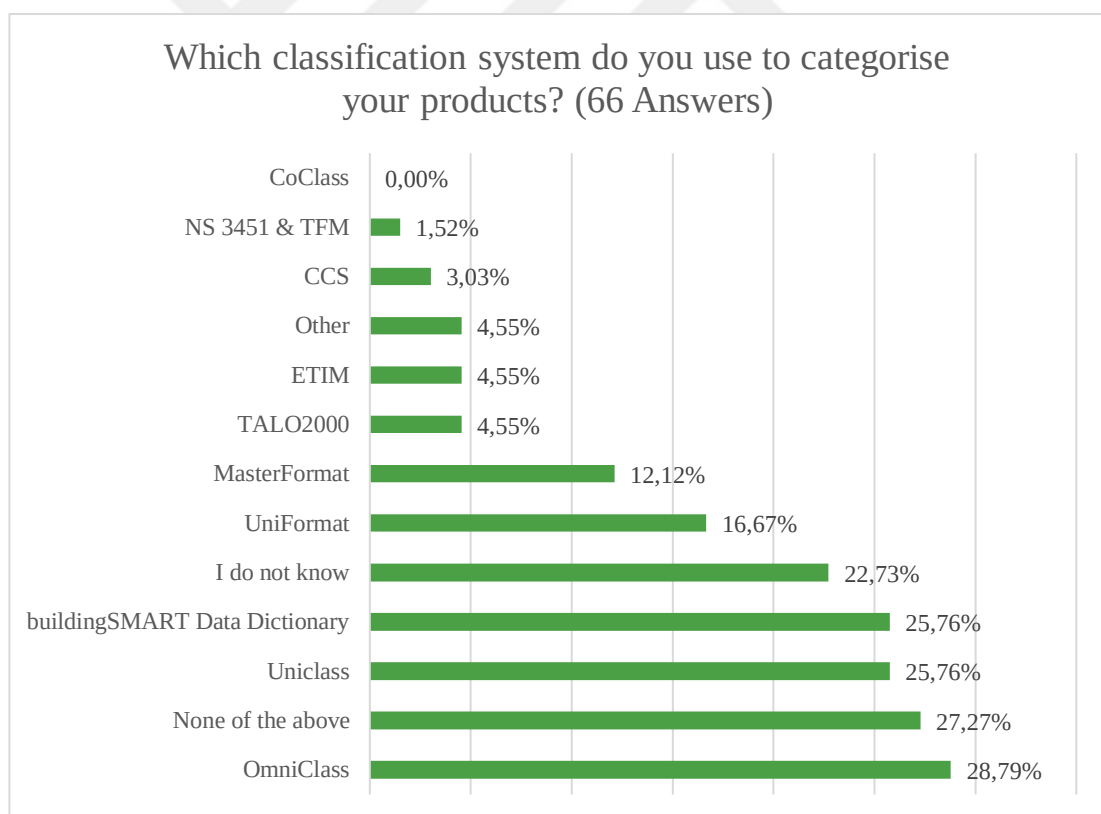


Figure 4.26: Distribution of classification using to categorizing products.

The survey results indicate a variety of software packages used by participants to prepare their BIM objects (Figure 4.27). Revit is the most widely used, with 96.97%

of respondents utilizing it, underscoring its dominance in the BIM field. AutoCAD follows, used by 46.97% of participants, reflecting its continued relevance for certain tasks and workflows.

Rhino is used by 21.21% of respondents, indicating its popularity for complex geometry and design flexibility. Tekla (13.64%), Inventor (12.12%), and Archicad (12.12%) are also employed, showing their importance in specific sectors or for particular tasks within the BIM process. Solidworks and other unspecified software are used by 10.61% of participants, demonstrating the diverse range of tools available for BIM object creation.

Less commonly used software includes Allplan (4.55%) and Microstation (3.03%), which cater to niche markets or specialized requirements. These findings highlight the prevalence of Revit and AutoCAD while also showcasing the varied software landscape that supports the creation of BIM objects, reflecting the diverse needs and preferences of industry professionals.

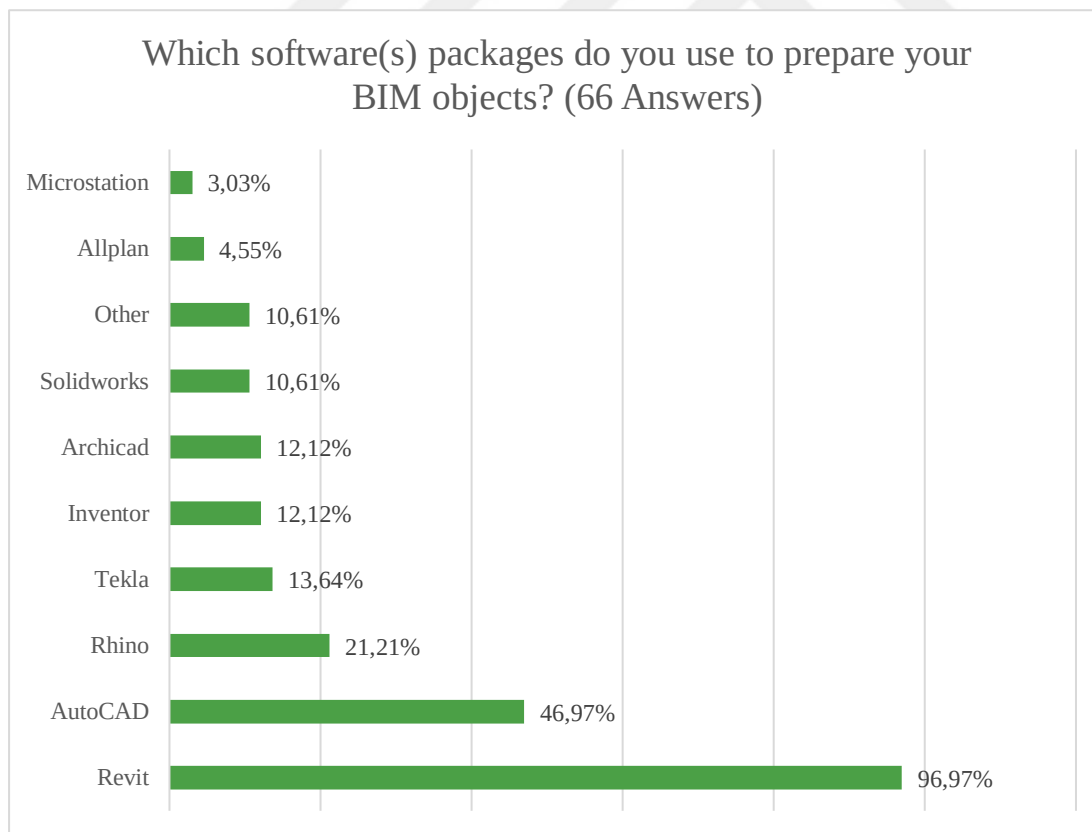


Figure 4.27: Distribution of software usage in preparation of BIM objects.

4.1.5 Survey result analysis

This section presents the results of statistical analyses conducted to determine whether the participants' qualifications significantly influenced their responses (Figure 4.28). These analyses aim to explore how various attributes of the participants, such as their experience, role, or the size of their company, affect their perspectives and practices regarding BIM adoption and usage.

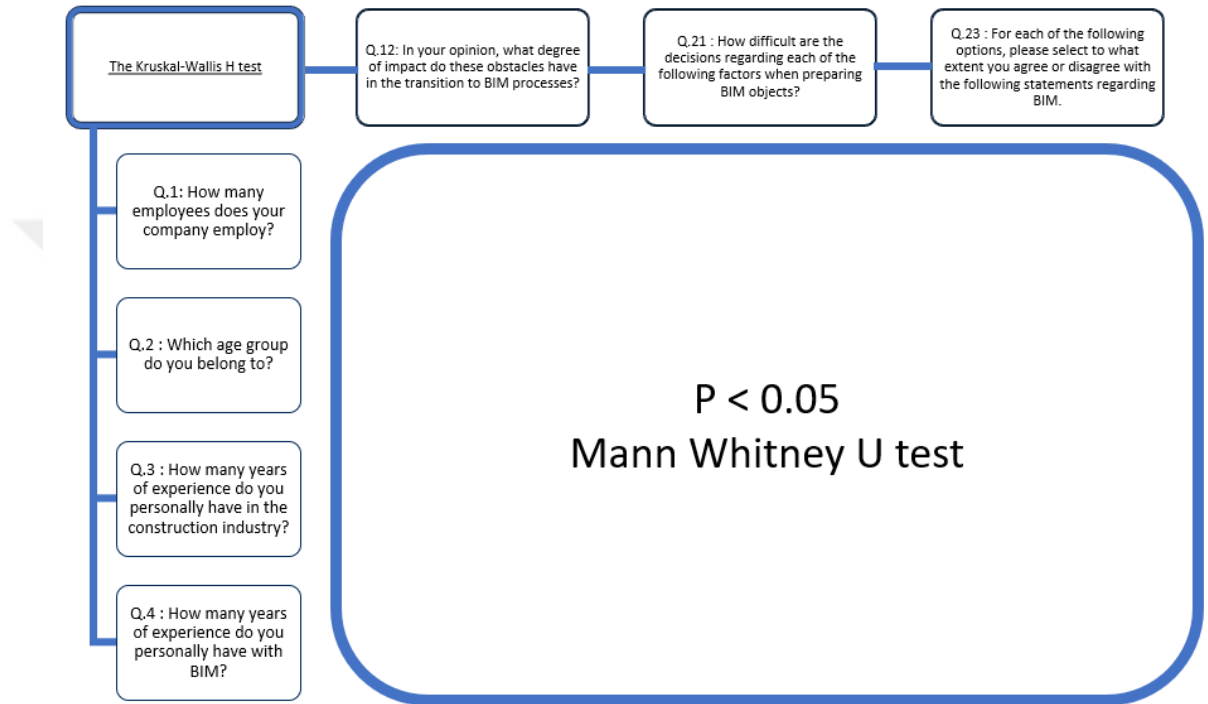


Figure 4.28: Survey result analysis.

4.1.5.1 Kruskal-Wallis H test

The Kruskal-Wallis H test was used to examine whether there is a significant relationship between participants' firm size, age group, industry experience, and BIM experience, and their responses regarding barriers to BIM adoption, difficulties in preparing BIM objects, and agreement with statements about BIM.

According to Kruskal Wallis H Test results, p-values below 0.05 indicate that there are significant differences in these responses.

Table 4.1: Kruskal-Wallis H test p-values.

Question	Q1	Q2	Q3	Q4
Q12.1	0,070	0,942	0,873	0,562
Q12.2	0,074	0,190	0,173	0,246
Q12.3	0,622	0,177	0,290	0,887
Q12.4	0,101	0,464	0,492	0,605
Q12.5	0,007	0,142	0,551	0,865
Q12.6	0,043	0,831	0,812	0,537
Q12.7	0,052	0,393	0,184	0,981
Q12.8	0,140	0,577	0,828	0,208
Q12.9	0,955	0,305	0,347	0,373
Q12.10	0,065	0,717	0,534	0,853
Q12.11	0,418	0,338	0,445	0,950
Q21.1	0,239	0,975	0,994	0,062
Q21.2	0,676	0,083	0,146	0,301
Q21.3	0,791	0,188	0,305	0,681
Q21.4	0,310	0,187	0,280	0,595
Q21.5	0,041	0,122	0,210	0,184
Q21.6	0,152	0,087	0,120	0,731
Q21.7	0,948	0,383	0,314	0,400
Q21.8	0,599	0,172	0,408	0,076
Q21.9	0,262	0,575	0,635	0,032
Q21,10	0,215	0,372	0,611	0,433
Q21,11	0,702	0,237	0,660	0,912
Q21,12	0,081	0,248	0,251	0,027
Q23,1	0,008	0,368	0,383	0,146
Q23,2	0,050	0,777	0,597	0,775
Q23,3	0,602	0,462	0,460	0,574
Q23,4	0,415	0,809	0,912	0,873
Q23,5	0,473	0,326	0,185	0,329
Q23,6	0,728	0,239	0,546	0,059

Accordingly, there is a significant difference between the number of firm employees and items 5 and 6 of question 12. These items are:

- Q12.5: Lack of trained personnel
- Q12.6: Failure to obtain appropriate consultancy services

Also, there is a significant difference between the number of firm employees and item 5 of question 21. This item is:

- Q21.5: What non-visual data BIM objects will contain

Also, there is a significant difference between the number of firm employees and items 1 and 2 of question 23. These items are:

- Q23.1: PDTs are not yet sufficiently standardised
- Q23.2: The information contained in BIM objects is not sufficiently standardised

Also, there is a significant difference between the years of experience with BIM and items 9 and 12 of question 21. These items are:

- Q21.9: The file size
- Q21.12: Where to publish/store BIM objects

4.1.5.2 Mann-Whitney U test

To understand why there are significant differences among the attributes identified by the Kruskal-Wallis H Test, pairwise comparisons of these groups were conducted using the Mann-Whitney U Test.

The table 4.2 presents the Mann-Whitney U Test results for the variable "Lack of trained personnel" (Q12.5), showing comparisons between different employee size groups within firms. The U Value and p Value columns indicate the significance of the differences between pairs.

Table 4.2: Mann-Whitney U test results for Q12.5.

Item	Group	N	Mean Rank	U Value	p Value
Q1.1	1-10 employees	1	1,500	0,500	0,480
Q1.2	11-50 employees	2	2,250		
Q1.1	1-10 employees	1	6,000	5,000	0,777
Q1.3	51-250 employees	12	7,080		
Q1.1	1-10 employees	1	5,000	4,000	0,713
Q1.4	251-500 employees	10	6,100		
Q1.1	1-10 employees	1	5,500	4,500	0,128
Q1.5	More than 500 employees	41	21,890		
Q1.2	11-50 employees	2	8,750	9,500	0,626
Q1.3	51-250 employees	12	7,290		
Q1.2	11-50 employees	2	7,500	8,000	0,629
Q1.4	251-500 employees	10	6,300		

Table 4.2 (continued): Mann-Whitney U test results for Q12.5.

Item	Group	N	Mean Rank	U Value	p Value
Q1.2	11-50 employees	2	13,750	24,500	0,270
Q1.5	More than 500 employees	41	22,400		
Q1.3	51-250 employees	12	11,330	58,000	0,888
Q1.4	251-500 employees	10	11,700		
Q1.3	51-250 employees	12	16,540	120,500	0,003
Q1.5	More than 500 employees	41	30,060		
Q1.4	251-500 employees	10	15,950	104,500	0,008
Q1.5	More than 500 employees	41	28,450		

Significant differences were found in the following comparisons:

- Firms with 51-250 employees compared to those with more than 500 employees (p = 0.003)
- Firms with 251-500 employees compared to those with more than 500 employees (p = 0.008)

These results suggest that larger firms (those with more than 500 employees) perceive a lack of trained personnel differently compared to medium-sized firms (51-250 and 251-500 employees). For other pairwise comparisons, the p-values are above 0.05, indicating no significant differences in their perceptions of the lack of trained personnel.

According to Table 4.3, the Kruskal-Wallis H Test results indicate a statistically significant difference in responses to Q12.6 (failure to obtain appropriate consultancy services) among different company sizes (p-value = 0.043). This suggests that experiences with obtaining consultancy services vary significantly depending on the size of the company.

Table 4.3: Mann-Whitney U test results for Q12.6.

Item	Group	N	Mean Rank	U Value	p Value
Q1.1	1-10 employees	1	1,000	0,000	0,157
Q1.2	11-50 employees	2	2,500		
Q1.1	1-10 employees	1	2,000	1,000	0,164
Q1.3	51-250 employees	12	7,420		
Q1.1	1-10 employees	1	1,500	0,500	0,134
Q1.4	251-500 employees	10	6,450		
Q1.1	1-10 employees	1	1,500	0,500	0,076

Table 4.3 (continued): Mann-Whitney U test results for Q12.6.

Item	Group	N	Mean Rank	U Value	p Value
Q1.5	More than 500 employees	41	21,990		
Q1.2	11-50 employees	2	9,000	9,000	0,556
Q1.3	51-250 employees	12	7,250		
Q1.2	11-50 employees	2	5,000	7,000	0,500
Q1.4	251-500 employees	10	6,800		
Q1.2	11-50 employees	2	17,000	31,000	0,532
Q1.5	More than 500 employees	41	22,240		
Q1.3	51-250 employees	12	9,880	40,500	0,186
Q1.4	251-500 employees	10	13,450		
Q1.3	51-250 employees	12	20,170	164,000	0,064
Q1.5	More than 500 employees	41	29,000		
Q1.4	251-500 employees	10	28,250	182,500	0,568
Q1.5	More than 500 employees	41	25,450		

When examining the Mann-Whitney U Test results in Table 4.3, notable differences between specific company sizes emerge. For instance, the comparison between small companies (1-10 employees) and large companies (more than 500 employees) shows a p-value of 0.076. Although this value is slightly above the 0.05 threshold, it is close to being significant, indicating that there might be substantial differences in consultancy service experiences between small and large companies. Similarly, the comparison between mid-sized companies (51-250 employees) and large companies (more than 500 employees) yields a p-value of 0.064, which is also near the significance threshold.

These results suggest that large companies (more than 500 employees) have distinctly different experiences in accessing and benefiting from consultancy services compared to smaller and mid-sized companies. This could imply that larger companies face unique challenges or have different needs when it comes to consultancy services, possibly resulting in lower satisfaction or greater difficulties in obtaining appropriate consultancy services.

In conclusion, there are significant differences in experiences with consultancy services based on company size. These findings indicate that consultancy services might need to be tailored according to company size to better address the specific needs and challenges of different-sized companies.

According to the Table 4.4, the most notable result is between companies with 251-500 employees and those with more than 500 employees, where the p-value is 0.003. For companies with 251-500 employees, the mean rank is 13.800, while for those with more than 500 employees, the mean rank is 28.980. This statistically significant difference suggests that larger companies (more than 500 employees) have different views on what non-visual data BIM objects should contain compared to mid-sized companies (251-500 employees).

Table 4.4: Mann-Whitney U test results for Q21.5.

Item	Group	N	Mean Rank	U Value	p Value
Q1.1	1-10 employees	1	1,500	0,500	0,480
Q1.2	11-50 employees	2	2,250		
Q1.1	1-10 employees	1	6,500	5,500	0,886
Q1.3	51-250 employees	12	7,040		
Q1.1	1-10 employees	1	9,500	1,500	0,240
Q1.4	251-500 employees	10	5,650		
Q1.1	1-10 employees	1	21,000	20,000	0,965
Q1.5	More than 500 employees	41	21,510		
Q1.2	11-50 employees	2	9,250	8,500	0,493
Q1.3	51-250 employees	12	7,210		
Q1.2	11-50 employees	2	10,500	2,000	0,071
Q1.4	251-500 employees	10	5,700		
Q1.2	11-50 employees	2	27,750	29,500	0,486
Q1.5	More than 500 employees	41	21,720		
Q1.3	51-250 employees	12	13,830	32,000	0,054
Q1.4	251-500 employees	10	8,700		
Q1.3	51-250 employees	12	25,920	233,000	0,773
Q1.5	More than 500 employees	41	27,320		
Q1.4	251-500 employees	10	13,800	83,000	0,003
Q1.5	More than 500 employees	41	28,980		

The larger companies may have more complex and larger-scale projects, requiring more detailed and varied non-visual data in BIM objects. They also likely have greater resources to invest in advanced BIM technologies, which might lead them to demand more comprehensive non-visual data. Additionally, bigger companies often face specific requirements due to regulatory standards, internal policies, or client demands, which are not as prevalent in smaller firms.

These findings imply that BIM service providers should offer customized data solutions that cater to the specific needs of large companies. This includes developing

advanced features and more extensive data sets in BIM objects to meet the expectations of larger firms, as well as providing specialized training and support to help them leverage the full potential of non-visual data in BIM.

There are also trends towards significance in other comparisons. The p-value of 0.071 between small companies (11-50 employees) and mid-sized companies (251-500 employees), and the p-value of 0.054 between mid-sized companies (51-250 employees) and larger mid-sized companies (251-500 employees) suggest potential differences in their views on non-visual BIM data. These near-significant results further emphasize that company size plays a crucial role in shaping expectations for BIM data, highlighting the importance of a tailored approach in BIM development and support.

The analysis of the Mann-Whitney U Test results for Q23.1 (Table 4.5) reveals several significant differences in opinions on the standardization of PDTs among different company sizes. Notably, there is a statistically significant difference between small companies (11-50 employees) and mid-sized companies (51-250 employees), with a p-value of 0.035. Small companies, with a mean rank of 13.000, perceive PDT standardization differently compared to mid-sized companies, which have a mean rank of 6.580. This suggests that smaller firms may find PDTs less standardized or have different expectations for their standardization.

Table 4.5: Mann-Whitney U test results for Q23.1.

Item	Group	N	Mean Rank	U Value	p Value
Q1.1	1-10 employees	1	1,000	0,000	0,221
Q1.2	11-50 employees	2	2,500		
Q1.1	1-10 employees	1	3,500	2,500	0,317
Q1.3	51-250 employees	12	7,290		
Q1.1	1-10 employees	1	5,000	4,000	0,711
Q1.4	251-500 employees	10	6,100		
Q1.1	1-10 employees	1	2,500	1,500	0,102
Q1.5	More than 500 employees	41	21,960		
Q1.2	11-50 employees	2	13,000	1,000	0,035
Q1.3	51-250 employees	12	6,580		
Q1.2	11-50 employees	2	2,000	0,000	0,021
Q1.4	251-500 employees	10	10,000		
Q1.2	11-50 employees	2	30,250	24,500	0,319
Q1.5	More than 500 employees	41	21,600		
Q1.3	51-250 employees	12	13,460	36,500	0,095

Table 4.5 (continued): Mann-Whitney U test results for Q23.1.

Item	Group	N	Mean Rank	U Value	p Value
Q1.4	251-500 employees	10	9,150	106,500	0,002
Q1.3	51-250 employees	12	15,380		
Q1.5	More than 500 employees	41	30,400		
Q1.4	251-500 employees	10	9,250	37,500	0,001
Q1.5	More than 500 employees	41	30,090		

Another significant difference is observed between small companies (11-50 employees) and larger mid-sized companies (251-500 employees), with a p-value of 0.021. Here, small companies (mean rank of 2.000) differ significantly from larger mid-sized companies (mean rank of 10.000) in their views on PDT standardization, indicating lower satisfaction or differing expectations among smaller firms.

Furthermore, mid-sized companies (51-250 employees) show a significant difference in perspective compared to large companies (more than 500 employees), with a p-value of 0.002. Mid-sized companies have a mean rank of 15.380, whereas large companies have a higher mean rank of 30.400. This significant difference implies that larger companies may have higher expectations or face more challenges related to PDT standardization due to their more complex needs and stringent requirements.

Lastly, the most pronounced difference is between companies with 251-500 employees and those with more than 500 employees, with a p-value of 0.001. The mean rank for the 251-500 employees group is 9.250, while it is 30.090 for the more than 500 employees group. This indicates that larger companies have significantly different perceptions and possibly higher expectations for the standardization of PDTs compared to their slightly smaller counterparts.

In summary, these significant findings underscore the varying expectations and challenges related to PDT standardization across different company sizes. Small companies, mid-sized firms, and large enterprises each have unique perspectives and needs, suggesting that a one-size-fits-all approach to PDT standardization may not be effective. Tailored strategies are essential to meet the specific requirements of companies based on their size.

Table 4.6 presents the Mann-Whitney U Test results for the statement "The information contained in BIM objects is not sufficiently standardized" across different employee size groups (Q1.1 to Q1.5).

Table 4.6: Mann-Whitney U test results for Q23.2.

Item	Group	N	Mean Rank	U Value	p Value
Q1.1	1-10 employees	1	1,000	0,000	0,221
Q1.2	11-50 employees	2	2,500		
Q1.1	1-10 employees	1	3,500	0,500	0,107
Q1.3	51-250 employees	12	7,290		
Q1.1	1-10 employees	1	5,000	3,500	0,622
Q1.4	251-500 employees	10	6,100		
Q1.1	1-10 employees	1	2,500	4,000	0,151
Q1.5	More than 500 employees	41	21,960		
Q1.2	11-50 employees	2	13,000	3,000	0,075
Q1.3	51-250 employees	12	6,580		
Q1.2	11-50 employees	2	2,000	1,500	0,060
Q1.4	251-500 employees	10	10,000		
Q1.2	11-50 employees	2	30,250	32,500	0,603
Q1.5	More than 500 employees	41	21,600		
Q1.3	51-250 employees	12	13,460	39,000	0,146
Q1.4	251-500 employees	10	9,150		
Q1.3	51-250 employees	12	15,380	151,500	0,036
Q1.5	More than 500 employees	41	30,400		
Q1.4	251-500 employees	10	9,250	84,500	0,003
Q1.5	More than 500 employees	41	30,090		

The test results indicate significant differences in perceptions among certain groups. Notably, the comparison between companies with 51-250 employees and those with 251-500 employees (Q1.3 and Q1.4) shows a p-value of 0.036, indicating a statistically significant difference. This suggests a significant disparity in the perceptions of BIM standardization between these two mid-sized company groups.

Similarly, the comparison between companies with 251-500 employees and those with more than 500 employees (Q1.4 and Q1.5) yields a p-value of 0.003, indicating a highly significant difference. This result highlights a substantial difference in perceptions of BIM standardization between larger companies and mid-sized companies. Other comparisons, particularly those involving smaller employee groups (e.g., 1-10 and 11-50 employees), did not show significant differences, with p-values generally above 0.05. These comparisons suggest that perceptions of standardization

are more consistent among smaller companies, or the sample sizes might be too small to detect differences.

In summary, the data indicate significant differences in the perceptions of BIM object standardization primarily between mid-sized and larger companies. Smaller companies' perceptions do not show significant variation, possibly due to smaller sample sizes or more homogeneous views. This analysis underscores the importance of company size in influencing perceptions of BIM standardization, with larger companies (particularly those with more than 500 employees) showing distinct views compared to mid-sized companies (251-500 employees).

Table 4.7 presents the Mann-Whitney U Test results for the statement "The file size" (Q21.9), which examines responses across different experience groups (Q4.1 to Q4.6). The Kruskal-Wallis H Test yielded a p-value of 0.032 for this question, indicating statistically significant differences among the groups. However, the individual Mann-Whitney U Test comparisons between specific pairs of groups do not show statistically significant differences, as all p-values are greater than 0.05.

Table 4.7: Mann-Whitney U test results for Q21.9.

Item	Group	N	Mean Rank	U Value	p Value
Q4.1	None	5	9,000	15,000	0,290
Q4.2	1 year	9	6,670		
Q4.1	None	5	7,000	20,000	1,000
Q4.3	2 years	8	7,000		
Q4.1	None	5	5,800	14,000	0,561
Q4.4	3 years	7	7,000		
Q4.1	None	5	4,700	8,500	0,700
Q4.5	4 years	4	5,380		
Q4.1	None	5	17,600	73,000	0,675
Q4.6	More than 5 years	33	19,790		
Q4.2	1 year	9	7,830	25,500	0,285
Q4.3	2 years	8	10,310		
Q4.2	1 year	9	7,000	18,000	0,139
Q4.4	3 years	7	10,430		
Q4.2	1 year	9	6,330	12,000	0,337
Q4.5	4 years	4	8,500		
Q4.2	1 year	9	15,830	97,500	0,109
Q4.6	More than 5 years	33	23,050		
Q4.3	2 years	8	7,130	21,000	0,396

Table 4.7 (continued): Mann-Whitney U test results for Q21.9.

Item	Group	N	Mean Rank	U Value	p Value
Q4.4	3 years	7	9,000		
Q4.3	2 years	8	6,060	12,500	0,541
Q4.5	4 years	4	7,380		
Q4.3	2 years	8	18,000	108,000	0,417
Q4.6	More than 5 years	33	21,730		
Q4.4	3 years	7	5,710	12,000	0,699
Q4.5	4 years	4	6,500		
Q4.4	3 years	7	20,640	114,5	0,971
Q4.6	More than 5 years	33	20,470		
Q4.5	4 years	4	21,380	56,5	0,633
Q4.6	More than 5 years	33	18,710		

Further comparisons among the 2-year, 3-year, and 4-year groups with each other and with the group having more than 5 years of experience yield p-values ranging from 0.285 to 0.971, indicating no statistically significant differences. Specifically, the comparisons between 3 years and 4 years, as well as between 4 years and more than 5 years, also show no significant differences with p-values of 0.699 and 0.633, respectively.

In summary, while the Kruskal-Wallis H Test indicates overall significant differences among the groups regarding the file size question, the pairwise Mann-Whitney U Tests do not reveal any specific significant differences between individual pairs of experience groups. This suggests that the overall difference is spread across multiple group comparisons rather than being concentrated between any specific pairs.

Table 4.8 presents the Mann-Whitney U Test results for the statement "Where to publish/store BIM objects" (Q21.12), comparing responses across different experience groups (Q4.1 to Q4.6). The Kruskal-Wallis H Test p-value for this question is 0.027, indicating significant differences among the groups. However, the individual Mann-Whitney U Test comparisons between specific pairs of groups do not show statistically significant differences, as all p-values are greater than 0.05.

Table 4.8: Mann-Whitney U test results for Q21.12.

Item	Group	N	Mean Rank	U Value	p Value
Q4.1	None	5	6,200	16,000	0,370
Q4.2	1 year	9	8,220		
Q4.1	None	5	6,600	18,000	0,754

Table 4.8 (continued): Mann-Whitney U test results for Q21.12.

Item	Group	N	Mean Rank	U Value	p Value
Q4.3	2 years	8	7,250		
Q4.1	None	5	5,300	11,500	0,308
Q4.4	3 years	7	7,360		
Q4.1	None	5	4,500	7,500	0,524
Q4.5	4 years	4	5,630		
Q4.1	None	5	14,600	58,000	0,268
Q4.6	More than 5 years	33	20,240		
Q4.2	1 year	9	10,110	26,000	0,311
Q4.3	2 years	8	7,750		
Q4.2	1 year	9	8,390	30,500	0,913
Q4.4	3 years	7	8,640		
Q4.2	1 year	9	7,000	18,000	1,000
Q4.5	4 years	4	7,000		
Q4.2	1 year	9	18,890	134,000	0,639
Q4.6	More than 5 years	33	21,940		
Q4.3	2 years	8	7,000	20,000	0,325
Q4.4	3 years	7	9,140		
Q4.3	2 years	8	6,000	12,000	0,474
Q4.5	4 years	4	7,500		
Q4.3	2 years	8	15,130	85,000	0,105
Q4.6	More than 5 years	33	22,420		
Q4.4	3 years	7	6,140	13,000	0,846
Q4.5	4 years	4	5,750		
Q4.4	3 years	7	20,360	114,5	0,97
Q4.6	More than 5 years	33	20,530		
Q4.5	4 years	4	17,880	61,5	0,816
Q4.6	More than 5 years	33	19,140		

When comparing the group with no experience (None) to those with varying years of experience (1 year, 2 years, 3 years, 4 years, and more than 5 years), the p-values range from 0.268 to 0.754, none of which indicate significant differences. Similarly, comparisons between the 1-year group and other experience groups, including 2 years, 3 years, 4 years, and more than 5 years, also do not show significant differences, with p-values ranging from 0.311 to 1.000.

Further comparisons among the 2-year, 3-year, and 4-year groups with each other and with the group having more than 5 years of experience yield p-values ranging from 0.105 to 0.970, indicating no statistically significant differences. Specifically, the comparisons between 3 years and 4 years, as well as between 4 years and more than 5

years, also show no significant differences with p-values of 0.846 and 0.816, respectively.

In summary, while the Kruskal-Wallis H Test indicates overall significant differences among the groups regarding where to publish/store BIM objects, the pairwise Mann-Whitney U Tests do not reveal any specific significant differences between individual pairs of experience groups. This suggests that the overall difference is spread across multiple group comparisons rather than being concentrated between any specific pairs.





5. DISCUSSION

The analysis of the survey results using the Kruskal-Wallis H Test and subsequent pairwise comparisons with the Mann-Whitney U Test has revealed several significant insights into how various attributes of participants influence their perspectives on BIM adoption and usage. The Kruskal-Wallis H Test identified significant differences based on company size and BIM experience, particularly in responses related to barriers to BIM adoption, difficulties in preparing BIM objects, and agreement with specific statements about BIM.

Key findings from the Kruskal-Wallis H Test include:

- Significant differences in responses were found between the number of firm employees and specific items related to the lack of trained personnel, the failure to obtain appropriate consultancy services, non-visual data in BIM objects, and the standardization of PDTs and BIM object information.
- Significant differences based on BIM experience were identified in responses related to the file size and the publication/storage of BIM objects.

The Mann-Whitney U Test further detailed these findings, highlighting:

- Larger firms (those with more than 500 employees) perceive a lack of trained personnel and difficulties in obtaining consultancy services differently compared to medium-sized firms (51-500 employees). This indicates that larger firms might face unique challenges in these areas, possibly due to their more complex operational requirements and higher expectations.
- Significant differences in perceptions of non-visual data requirements in BIM objects were found between companies with 251-500 employees and those with more than 500 employees. Larger firms may require more detailed and varied non-visual data due to their larger-scale projects and stringent regulatory standards.

- Perceptions of the standardization of PDTs and the information contained in BIM objects varied significantly between different company sizes, with larger companies showing higher expectations and facing more challenges in these areas.

Lack of trained personnel (Q12.5): The results suggest that the perception of a lack of trained personnel varies significantly between medium-sized firms and larger firms:

- Larger firms (more than 500 employees) may have more resources and capacity to hire and train personnel, thereby reducing the perceived shortage.
- Medium-sized firms (51-500 employees), on the other hand, might struggle more with attracting and retaining trained personnel, leading to a higher perceived shortage.

These results highlight a potential issue for medium-sized construction product manufacturers, who may need more support or strategies to effectively manage their workforce and training programs. Addressing this disparity could involve targeted training programs, incentives to attract skilled workers, or collaborative efforts with educational institutions to ensure a steady pipeline of trained personnel.

For other pairwise comparisons, the p-values are above 0.05, indicating no significant differences in their perceptions of the lack of trained personnel.

Consultancy services (Q12.6): Kruskal-Wallis H test results suggests that experiences with obtaining consultancy services vary significantly depending on the size of the company.

According to Mann-Whitney U test results, the comparison between small companies (1-10 employees) and large companies (more than 500 employees) shows a p-value of 0.076.

Although this value is slightly above the 0.05 threshold, it is close to being significant, indicating that there might be substantial differences in consultancy service experiences between small and large companies.

Similarly, the comparison between mid-sized companies (51-250 employees) and large companies (more than 500 employees) yields a p-value of 0.064, which is also near the significance threshold.

The findings indicate that experiences with obtaining consultancy services vary significantly by company size, with both very small and mid-sized companies facing different challenges compared to very large companies. This suggests a need for tailoring consultancy services to better address the specific needs and challenges faced by companies of different sizes.

Enhancing the accessibility and relevance of consultancy services for smaller and mid-sized firms could significantly improve their experiences and outcomes in the construction product manufacturing sector. This could involve developing consultancy offerings that are more affordable, flexible, and specifically tailored to the size and scope of the projects these companies handle. For larger firms, consultancy services might need to be more sophisticated and capable of addressing complex, large-scale challenges.

Overall, these findings highlight the importance of a differentiated approach in providing consultancy services, ensuring that firms of all sizes receive the support they need to thrive in the construction product manufacturing sector.

Non-visual data in BIM objects (Q21.5): According to results, the most notable result is between companies with 251-500 employees and those with more than 500 employees, where the p-value is 0.003.

The statistically significant difference in perceptions about non-visual data requirements between mid-sized and large companies highlights the necessity for BIM service providers to offer differentiated and tailored solutions.

The larger companies may have more complex and larger-scale projects, requiring more detailed and varied non-visual data in BIM objects.

By focusing on the specific needs of larger firms, BIM service providers can not only improve the immediate experiences of these clients but also contribute to long-term improvements in the construction product manufacturing sector. Tailored BIM solutions will lead to more efficient project execution, better compliance with

regulations, and enhanced overall productivity. This, in turn, can drive innovation and competitiveness within the industry, fostering a more robust and capable construction sector equipped to meet the challenges of the future.

Standardization of PDTs (Q23.1): Notably, there is a statistically significant difference between small companies and mid-sized companies, with a p-value of 0.035.

Small companies, with a mean rank of 13.000, perceive PDT standardization differently compared to mid-sized companies, which have a mean rank of 6.580.

This suggests that smaller firms may find PDTs less standardized or have different expectations for their standardization.

Another significant difference is observed between small companies and larger mid-sized companies, with a p-value of 0.021.

Here, small companies (mean rank of 2.000) differ significantly from larger mid-sized companies (mean rank of 10.000) in their views on PDT standardization, indicating lower satisfaction or differing expectations among smaller firms.

Furthermore, mid-sized companies show a significant difference in perspective compared to large companies, with a p-value of 0.002.

Mid-sized companies have a mean rank of 15.380, whereas large companies have a higher mean rank of 30.400.

This significant difference implies that larger companies may have higher expectations or face more challenges related to PDT standardization due to their more complex needs and stringent requirements.

Lastly, the most pronounced difference is between companies with 251-500 employees and those with more than 500 employees, with a p-value of 0.001.

The mean rank for the 251-500 employees group is 9.250, while it is 30.090 for the more than 500 employees group.

This indicates that larger companies have significantly different perceptions and possibly higher expectations for the standardization of PDTs compared to their slightly smaller counterparts.

These findings shows, small companies, mid-sized firms, and large enterprises each have unique perspectives and needs, suggesting that a one-size-fits-all approach to PDT standardization may not be effective.

Tailored strategies are essential to meet the specific requirements of companies based on their size.

Information in BIM objects (Q23.2): Notably, the comparison between companies with 51-250 employees and those with 251-500 employees shows a p-value of 0.036, indicating a statistically significant difference.

This suggests a significant disparity in the perceptions of BIM standardization between these two mid-sized company groups.

Similarly, the comparison between companies with 251-500 employees and those with more than 500 employees yields a p-value of 0.003, indicating a highly significant difference.

This result highlights a substantial difference in perceptions of BIM standardization between larger companies and mid-sized companies.

Other comparisons, particularly those involving smaller employee groups (e.g., 1-10 and 11-50 employees), did not show significant differences, with p-values generally above 0.05.

These comparisons suggest that perceptions of standardization are more consistent among smaller companies, or the sample sizes might be too small to detect differences.

These finding shows, smaller companies' perceptions do not show significant variation, possibly due to smaller sample sizes or more homogeneous views.

This analysis underscores the importance of company size in influencing perceptions of BIM standardization, with larger companies (particularly those with more than 500

employees) showing distinct views compared to mid-sized companies (251-500 employees).

File size (Q21.9) publication/storage of BIM objects (Q21.12): The differences in responses based on BIM experience suggest that more experienced individuals have different expectations and practices regarding file size and the publication/storage of BIM objects. Experienced BIM users may prefer more optimized file sizes and advanced storage solutions due to their familiarity with best practices and performance considerations. This implies that training programs should emphasize best practices for file management and storage solutions tailored to varying levels of BIM experience.

These findings suggest that BIM adoption and usage experiences are significantly influenced by company size and BIM experience. Larger firms often have different, more complex needs and face distinct challenges compared to smaller and mid-sized companies. Therefore, BIM service providers and policymakers should consider these differences and tailor their strategies and support mechanisms accordingly. Customized training programs, consultancy services, and standardized data solutions that address the specific needs of companies based on their size and experience with BIM will be crucial in facilitating more effective BIM adoption and utilization across the industry.

By addressing the unique challenges identified in this analysis, stakeholders can improve BIM adoption rates and effectiveness, ultimately leading to more efficient and successful construction projects. Enhanced training, better consultancy services, and improved standardization efforts are key areas that need attention to support the diverse needs of firms within the construction industry.

6. FUTURE DIRECTIONS AND UTILIZATION OF RESEARCH FINDINGS

The findings from this master's thesis offer critical insights that various stakeholders in the construction product manufacturing industry can leverage to enhance the adoption and effectiveness of Building Information Modeling. Here are keyways in which different groups can utilize these findings and recommendations for future actions:

6.1 Product Manufacturers

Understanding BIM Integration: Product manufacturers can use the insights to better understand the current landscape of BIM adoption. Recognizing that a significant percentage of companies are in the early stages of BIM integration, manufacturers can develop more comprehensive BIM strategies and training programs.

Addressing training needs: Medium-sized firms, in particular, struggle with a lack of trained personnel. Manufacturers can invest in targeted training initiatives and partnerships with educational institutions to create a steady pipeline of skilled workers. Tailoring training programs to the specific needs of different company sizes can bridge the skills gap and improve overall BIM competency.

Customizing consultancy services: By understanding the distinct challenges faced by different company sizes, manufacturers can seek consultancy services that are tailored to their unique requirements. Smaller firms might benefit from more affordable and flexible consultancy offerings, while larger firms might require more sophisticated solutions to address complex project needs.

6.2 BIM Service Providers

Developing tailored solutions: BIM service providers can use the findings to create customized solutions that cater to the varied needs of companies based on their size and experience with BIM. For instance, larger firms might need more detailed non-visual data in BIM objects and more advanced features in their BIM tools.

Improving standardization: The study highlights differing expectations and satisfaction levels regarding the standardization of Product Data Templates (PDTs). BIM service providers can work towards developing more standardized and universally accepted PDTs that can be easily adopted by companies of all sizes, improving efficiency and interoperability.

Enhancing training programs: Training programs can be refined to focus on best practices for file management and the publication/storage of BIM objects, especially for users with varying levels of BIM experience. This can help ensure that all users, regardless of their experience, can utilize BIM tools effectively.

6.3 Industry Associations and Policymakers

Supporting medium-sized firms: Industry associations can develop initiatives aimed at supporting medium-sized firms that struggle with attracting and retaining trained personnel. This could include advocacy for more funding towards vocational training programs and creating incentives for skilled workers to join the construction product manufacturing sector.

Facilitating collaboration: Policymakers can encourage collaboration between large firms, medium-sized firms, and educational institutions to develop comprehensive training and certification programs that meet the industry's needs. This can help create a more uniform level of BIM competency across the sector.

Regulatory frameworks: Policymakers can use the findings to create regulatory frameworks that promote the standardization of PDTs and ensure that all firms, regardless of size, can benefit from a more structured approach to BIM adoption.

6.4 Researchers

Exploring barriers to adoption: Future research can delve deeper into the specific barriers identified in this study, such as the initial cost of software and training, and the complexity of integrating BIM with existing systems. Understanding these barriers in more detail can help develop more targeted strategies to overcome them.

Longitudinal studies: Researchers can conduct longitudinal studies to track the progress of BIM adoption over time. This can provide valuable insights into the effectiveness of different strategies and interventions aimed at promoting BIM adoption.

Comparative studies: Comparative studies across different regions or sectors within the construction industry can help identify best practices and successful strategies that can be replicated or adapted for use in other contexts.

6.5 Construction Industry at Large

Promoting best practices: The industry as a whole can benefit from promoting and sharing best practices identified through this research. By highlighting successful case studies and strategies, companies can learn from each other and accelerate the overall adoption of BIM.

Innovation and competitiveness: Embracing the tailored recommendations from this study can drive innovation and competitiveness within the industry. As companies adopt more efficient and effective BIM practices, they can improve project outcomes, reduce costs, and enhance profitability.



7. CONCLUSION

This master's thesis aims to investigate the adoption of Building Information Modeling among construction product manufacturers. Specifically, it seeks to evaluate the extent of BIM adoption in the industry, understand the differences in adoption levels, and identify the barriers to its implementation. A survey method was employed to collect data from product manufacturers across Europe. This geographical focus on Europe allowed the study to capture a diverse range of BIM adoption practices influenced by different regulatory and economic environments.

The study involved 71 participants, with 80% having more than five years of experience in the industry, although only 46% have over five years of experience with BIM. The overwhelming majority of companies have already invested in BIM and integrated it into their processes. The collected data were analyzed using quantitative methods to determine the scope of BIM adoption. This analysis detailed not only the percentage of companies using BIM but also the depth of its integration into business processes. The findings provided insights into the main reasons for both the adoption and avoidance of BIM.

The study also explored the specific challenges and benefits of BIM adoption. Common challenges include the initial cost of software and training, the complexity of integrating BIM with existing systems, and resistance to change from traditional practices. Conversely, the benefits reported by manufacturers include improved collaboration among project teams, increased precision in the design stages, and better control over resource management, leading to reduced waste and increased profitability. Moreover, the study identified the main tools, standards, and platforms used by manufacturers, providing a snapshot of the current technological landscape supporting BIM in the manufacturing sector. One of the most notable findings is that despite BIM usage, many material manufacturers in Europe often lack their own standards.

The analysis revealed significant differences in the perceptions of large and medium-sized firms regarding the lack of trained personnel, indicating unique challenges or expectations in larger organizations. Experiences with consultancy services also varied significantly with company size. Larger firms, likely due to more complex projects and greater resources, tend to demand more detailed and varied non-visual data in BIM objects. This suggests that BIM service providers need to tailor their offerings to meet the specific needs of larger companies, including advanced features and comprehensive data sets.

The study highlighted differing views on the standardization of Product Data Templates (PDTs), noting that smaller firms have different expectations and potentially lower satisfaction levels compared to larger firms. This indicates that a one-size-fits-all approach to PDT standardization may not be effective. While general differences in perceptions of BIM object file sizes and publishing/storage locations were recorded across different experience groups, no specific significant differences were found among individual groups.

Despite these insights, several obstacles in the transition to BIM processes were identified by participants, showing that all challenges have at least a medium or higher impact on the transition. Competition and cooperation were found to have the biggest impact on the transition to BIM, while facility management had almost no impact. Most participants use Industry Foundation Classes (IFC) in their projects and believe that investment in BIM has paid off. More than half of the participants present at least 60% of their products as BIM objects, but only 10% present all their products as such. Interestingly, despite presenting their products as BIM objects, many participants felt that the number of questions they faced did not change.

We have stated that because of the lack of literature, we have identified challenges ourselves. The results show that there are still many challenges in adoption. Especially, CPMs need proper guidance. Although most CPMs claimed to have adopted BIM, the results we collected indicate that the adoption is still in the early stages. Only 10% present all their products as BIM objects, and many still rely on their head offices. These findings show that the expected benefits from BIM are not fully realized, and CPMs have not fully adopted BIM.

In conclusion, these findings underscore the need for customized solutions based on company size and specific needs. Tailoring consultancy services, BIM data solutions, and PDT standardization strategies to the varied requirements of companies of different sizes can help bridge perception gaps and enhance overall efficiency and satisfaction in business processes. Future work should focus on how the identified challenges can be improved for product manufacturers. The findings from this research can be utilized by product manufacturers planning to adopt BIM, providing them with a clearer understanding of potential impacts and considerations. Additionally, the results can aid researchers in further exploring the factors influencing BIM adoption and how these can be addressed to increase uptake and effectiveness. This study not only fills a significant gap by providing detailed data on BIM adoption among product manufacturers but also contributes to the broader context of improving technological integration in the construction industry.



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CURRICULUM VITAE

Name Surname : Kübra Bayrak

EDUCATION

- **B.Sc.** : 2016, Namik Kemal University, Civil Engineering
Faculty, Civil Engineering

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2024- Royal HaskoningDHV | Senior Civil Engineer
- 2022-2024 Arup Germany | BIM Coordinator
- 2019-2022 Arup Istanbul | BIM Coordinator
- 2018-2019 Kalyon Construction | BIM Engineer
- 2015-2018 Ülker Engineering | Structural Engineer

PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

OTHER PUBLICATIONS, PRESENTATIONS AND PATENTS:

- **Keser A. E., Temur O., Koloğlu B., Bayrak K., Öngen B., Gürcanlı G. E.,** 2022. A Simulation of Tunnel Operation Model Using Stroboscope, *7th International Project and Construction Management Conference (IPCMC2022)*, 890-899.