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A blueprint for successful innovation of a maintenance companies' business model using digitalization

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Preface

After nearly one and a halve years of studying at the University of Twente, my student days are coming to an end. During the master, I learned a lot in the field of Entrepreneurship, Strategy, and Innovation. The report in front of you is the final product for completing the master Business Administration. While writing this report, I had help from several people at different organisations. I would like to thank all who contributed in any way whatsoever in the completion of this study.

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Abstract

The real estate maintenance industry is in its maturity stage, i.e. [1] the market has many competitors, competition is fierce, and margins are low. [2] Cost management key practices are more mature than those of quality measurement, sustainability practices and technological developments. Recently, subject to external influences, a trend has started whereby the focus shifted from cost to quality. As a result, prevailing small margins become irrelevant as maintenance partners look for ways to increase quality. Therefore, the purpose of this research is to investigate how digitalization can support the innovation of maintenance parties' business models. To this end, the following research question was formulated: *How can a maintenance company innovate its business model using digitalization?*

In order to answer the main question, a number of sub-questions have been formulated. Literature research, expertinterviews and observations were conducted to answer these questions. Both the literature and interviews with various experts have shown that, in the current situation, there are no digitalization techniques available that can support maintenance activities during the operational phase of a building.

This study describes in detail how the implementation of BIM with a wireless sensor network integrated in it, facilitates the innovation of a maintenance parties' current businessmodel. Application of BIM integrated NSW offers real-time insight into the current quality level of all kinds of properties. The maintenance partner can then use this insight to [1] develop maintenance plans that excel in quality compared to those of competitors and [2] smartly schedule maintenance activities such that the costs on the long run will be minimized.

From the customer's perspective, the following benefits arise as a result of applying the aforementioned digital techniques. The customer places the maintenance risk entirely with the maintenance partner. The customer knows exactly in advance what the maintenance costs will be. As such, they can also be transparent about this to their tenants.

Also, the implementation of BIM facilitates the possibility of further digitalization of the organization. For example, there is the possibility of linking simulation software to BIM. In this way, the maintenance partner is able to see in advance where defects may arise. The input for these simulations can be measured by the environmental sensors.

Table of contents

List of Figures

List of tables

1. Introduction

This chapter describes the lenses through which this research should be read. The reader is introduced to the scope with which this study was conducted. First, there is a brief description of the client company, its activities, and its position within the market in which it operates. From this stem the research questions that are answered through this study.

1.1 Company Introduction

Uw onderhoudspartner Lenferink (henceforth referred to as UOL) takes care of the maintenance of houses, VvE's, farms and estates. She is responsible for the entire maintenance process, i.e., from receiving the order up to implementation of the maintenance plan. Its key activities consist of carrying out maintenance in the form of painting, glazing, carpentry and wood rot repair. UOL currently switches from carrying out one-time projects to result-oriented long-term partnerships. By doing so they obtain the following benefits:

- 15% cost savings over the operating period.
- Resident satisfaction > 8.
- Quality demonstrably as agreed.
- Budget equals maintenance costs.
- Greater pleasure.

The following vision is central within the company: *"We make more of your property"*. To achieve this, they aim to work according to a step-by-step plan. Below is a schematic view of what this process looks like at the company level.

Phase	Action
1. Initiative	Contracting the client company
2. Plan development	Maintenance plan development
3. Plan optimisation	Refining maintenance plan
4. Order	Checking and signing the order
5. Implementation	Execution as ordered
6. Evaluation	Analysing the result
7. Asset management	managing the complexes between maintenance cycles

Table 1: UOL core business processes

The step-by-step plan covers seven phases. Step one and two of this process are focused on jointly determining the required performance requirements. Step three requires converting functional requirements into measurable quality requirements according to the NEN method. In this step, the standards with which the building must comply are determined. The next step, step four, requires translating the quality requirements into various maintenance scenarios. The client is then free to choose which maintenance scenario should be carried out. Usually, the scenario that is cheapest in the long term, often 30 years, is chosen. This scenario enables the

maintenance partner to reduce the number of maintenance visits through several smart investments. The traditional maintenance interval shifts from five to six or seven years. The maintenance partner is responsible for the quality of the property throughout the entire operating period. This comes with additional risks. After all, additional years between successive maintenance cycles, may result in additional damages. In order to ensure that these additional risks do not result in unforeseen costs, the maintenance partner must have insight into the condition of the complexes at all times. To be able to achieve this, UOL believes that it is important to differentiate itself from its competitors. By adopting a differentiation strategy UOL aims at offering premium quality. By differentiating itself from its competitors, UOL strives to facilitate increased customer demand and thereby increase revenue. In summary, UOL is a maintenance partner that aims at offering premium quality by means of differentiation. The market in which UOL operates will be briefly discussed below.

1.2 The property maintenance market

Willis and Rankin (2009) proposed a model with which the maturity of an industry can be measured. The outcome is the classification of an industry into one of the following maturity levels: Mature, Transitional Mature and Immature. Using Willis and Rankin (2009) as a guide, it can be concluded that the industry in which UOL operates is in the maturity stage, i.e. [1] the market has many competitors, competition is fierce, and margins are low. [2] Cost management key practices are more mature than those of quality measurement, sustainability practices and technological developments. Because property maintenance companies tend to compete on price, they have become proficient at managing. This has led to cost management performance having the highest level of realisation compared to quality management performance, sustainability practices and technological developments. However, mainly due to government restrictions the market is subject to change. To meet the climate target in 2050, real estate must become more sustainable. Both existing and new buildings must be equipped with greener energy labels and lower CO2 emissions. This results in a shift from a mere focus on cost to a focus on quality. As a result, prevailing small margins become irrelevant as maintenance partners look for ways to increase quality. The role that UOL plays in this is discussed in the next section.

1.2.1 Uw onderhoudspartner Lenferink – Market position

In traditional property maintenance market, projects are often put out to tender. In general, this means that the cheapest party is allowed to carry out the work. Projects are effort-oriented instead of result-oriented. This means that both client and contractor are focused on achieving

the lowest possible cost. According to Porter (1998) this corresponds to the adoption of the so-called cost leadership strategy. Property maintenance partners focus on a wide range of customers where they try to win projects by offering a lower price compared to its competitors.

However, in recent years property maintenance has increasingly switched from traditional outsourcing of maintenance to result-oriented property maintenance (Langenhof, 2009). In short, result-oriented maintenance is the smart scheduling of long-term maintenance interventions to ensure that maintenance costs are saved on the long-term. In practice, outsourcing of maintenance is often chosen when either the client has little or no experience with result-oriented maintenance or when the strategy of a complex to be maintained shows that it will not be maintained for a long time. By shifting from traditional to result-oriented maintenance the strategy property maintenance partners adopt also changes. Result-oriented maintenance involves large investments in the early years. Maintenance partners that educate themselves in result-based maintenance focus primarily on delivering better quality compared to its competitors. According to Porter (1998) differentiation is one of the ways in which an organization can increase the quality of its offers.

In a traditional market with many maintenance partners with a cost leadership strategy, increasing turnover by lowering cost is virtually impossible. Uw onderhoudspartner Lenferink strives to achieve this business goal by increasing the quality of their service. In doing so UOL already began adjusting its value proposition. Instead of executing procurement projects, UOL is trying to shift to customers who are willing to enter long-term cooperation's. Serving these clients requires a differentiation of the current value proposition. Where former customers primarily steered toward keeping costs low, multi-year customers demand a certain level of quality. In doing so, the maintenance partner must provide insight in advance into the expenses that the customer must incur each year. In summary, it is clear to see that the market focus switches from cost to quality.

1.2.2 Uw onderhoudspartner Lenferink – The organisation

At the operational level, adjusting the value proposition requires several changes to be made within the organisation. On the work floor, workers will have to make different choices in the execution of the work. For example, different types of paint must be used to be able to guarantee the agreed level of quality. The planners will have to plan the maintenance interventions in such a way that the additional investments (i.e., more expensive materials or workers) will not lead to much higher costs in the long run.

On the organisational level, UOL strives to differentiate from their competitors by offering premium quality compared to competitors. Within their maintenance plans UOL guarantees higher quality standards then competitors can offer. According to Porter (1980), organisations that adopt a differentiation strategy need to actively pursue the following three things:

- Good research, development, and innovation.
- Ability to deliver high quality goods and services.
- Transparency about what benefits customers get from it

Literature mentions several potential benefits of successfully adopting a differentiation strategy. In the event of a successful adoption, UOL enjoys the following benefits. [1] When it no longer participates in tender projects, the need to take a low-cost position is eliminated. This means that the margins will be somewhat higher. [2] Differentiation and thus the conclusion of long-term contracts ensures greater continuity within the organisation. It also creates customer loyalty so that customers will be less sensitive to price.

Following the above differentiation strategy requires a change in the organisation's way of working. The following image prevails within the organisation: Digitalization facilitates innovation and innovation facilitates differentiation. The latter is confirmed by Porter (1980) who indicates that for the successful adoption of a differentiation strategy there must be sufficient innovation within an organisation. This study investigates whether digitalization facilitates innovation.

1.2.3 The challenge

In brief, UOL aims at adopting a differentiation strategy in which they offer premium quality maintenance plans. This research examines how digitalization can support the realisation of premium quality maintenance plans. The challenge described above can be translated into the following research questions.

1.3 Research questions

Achieving the objective described above requires answering the following research questions:

[1] *How can a maintenance company innovate its business model using digitalization?*

To be able to answer the central research question, it has been further broken down into the following sub-research questions:

[1.1] *What is asset management?*

[1.2] *What is digitalization?*

[1.3] *What is business model innovation?*

[1.4] *How can digitalization support new asset management value propositions?*

1.4 Academic relevance

This research contributes to the new research field of digital innovations supporting organisational processes. Both innovation and digitalization receive a considerable deal of attention in the existing literature. Literature on innovation describes, for example, how an organisation can achieve innovation and how it can successfully manage this innovation (Porter & Ketels, 2003). Digitalization is often referred to in the literature as a method for realising innovations (Yoo, 2010). However, there is only a limited volume of literature available that links innovation and digitalization within the construction industry. This research fills this gap in the literature by analysing how digitalization can be used as a tool for process innovation.

1.5 Practical relevance

The practical implications of this research have enormous potential. Implementing digital solutions within the property maintenance sector offers numerous potential benefits to its user. Property maintenance companies can use this research as a blueprint for improving the quality of their offerings. Premium quality can increase company turnover either by increasing the number of sales or the prices at which the offerings are sold.

1.6 Thesis outline

The outline of the thesis is as follows. Chapter two [2], describes the theoretical framework underlying this research. The first part of the framework [2.1] is used to discusses literature about asset management. Subsections [2.2] and [2.3] describe innovation within the construction industry and digitalization within the same industry respectively. Section [2.4] elaborates on the significant role played by BIM and the supportive technologies that may be appropriate here. Chapter three [3] describes the design and elaboration of the empirical research. Chapter [4] elaborates on the daily activities of the client company based on two completed projects. Chapter [5] provides insight into the results obtained in this study. Subsection [5.1] discusses the BIM set-up, [5.2] describes how BIM can successfully be implemented, [5.3] outlines the costs and benefits involved with this implementation and [5.4] explains the corresponding organisational consequences. Chapter six [6] concludes this study by answering the research questions. It also discusses limitations [6.1], future research [6.2] and practical implications [6.3].

2. Theoretical framework

In this chapter, the theory relevant to the research will be discussed. First theories that explain the concept of Asset Management will be discussed. These theories are necessary since they provide understanding in how property maintenance company manage their assets. Hereafter, the theoretical framework pays attention to how managing assets can be digitalised. Next, six key examples of digitization initiatives in the property maintenance industry that may be of interest to maintenance partners are provided.

2.1 Asset management

Traditionally, maintenance is described as ensuring that an asset continuously does what the user wants it to do, within a given operating environment. Asset management (AM) is the concept of balancing performance, risks, and costs to achieve an optimal maintenance plan. Asset management has a wide range of definitions. Some cover financial and human capital assets where others are more specified towards the operations and production areas. In this study, AM is defined as *"the total management of physical assets"* (Amadi-Echendu *et al.*, 2010). Traditionally, the owner of the physical object is responsible for its maintenance. They therefore determine when and how often this maintenance is carried out. Recently, a change took place in which the responsibility for maintenance during the entire operational period of a physical asset lies with the maintenance partner. This means that the maintenance company has an interest in creating value through smart asset management. Lu *et al.*, (2019) argue that the efficiency of AM processes can be increased by using digital support technology. Pan and Zhang (2021) illustrate this by proposing a smart construction project management tool which integrates Internet of Things (IoT) and Data mining (DM) techniques to be able to capture, model and analyse real-time data. Khuntia, Rueda and van der Meijden (2018) argue that IoT together with big data analytics will play an important role in the future of smart asset management. It is Schneider *et al.* (2006) who distinguish between the different types of asset management strategies. They state that every maintenance company adapts to one of the following four maintenance strategies.

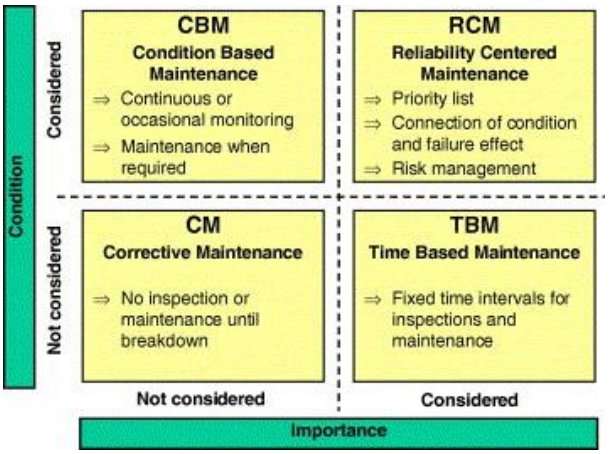

Figure 1: Maintenance strategies (Schneider et al., 2006)

Most of all property maintenance companies uses Time Based Maintenance (TBM). This means that maintenance is carried out at pre-set intervals. The major risk here is that maintenance is carried out when, based on the condition of the component, it is not necessary. From this, the urge to switch to Condition Based Maintenance arose. Continuous or occasional monitoring of the component indicates when this component is required to be maintained. In practice, a component often proves to last longer than the maintenance intervals planned. For example, a paint system, if applied correctly, has a life of seven years, while in practice it is often replaced after five years. Monitoring of the component is done through digital support technologies. In subsection [2.4], the use of supportive technology in the construction sector is discussed in detail.

Recently, asset management has improved greatly due to advances in IT (Kivits & Furneaux, 2013). These advances in IT enabled easy transfer of knowledge which facilitated improvements in asset management. Roberts *et al.* (2018) support this statement by arguing that advancements in digital technologies have led to greater sector performance. Superior data management and streamlined processes are based on these performances. However, the improvements resulting from the application of digital technologies have yet to be realised in the operational phase of a building (Roberts *et al.*, 2018; Liu & Issa, 2013). This research therefore attempts to complement existing literature on the use of digital technologies in the operational phase. Before looking at the different types of supportive technologies in more detail, I will first discuss how an innovation within the construction industry comes about in the following section.

2.2 Construction industry innovation

Innovation can be described as follows: *"a pervasive attitude that allows businesses to see beyond the present and create a future vision"* (Kuszmarski, 1996). He argues that innovations can only be applied if all organisational business actively participates in the process. Where, in the past, limiting production- and labour cost was enough to achieve a competitive advantage, today this requires innovative thinking. Kuszmarski argues that innovative thinking leads to one of the following situations in most cases. [1] Improved versions of existing products are developed. [2] Trend-of-the-moment products are developed. Both situations are undesirable as the products offer low financial return and enjoy only a short lifespan. Radically new and innovative products or services are ones that side-line competitors. These innovations can provide organisations with sustainable competitive advantages and profit-making stamina. Therefore, innovation is viewed upon as an important source of competitive advantage and thus indispensable for the survival of an organisation (Egbu *et al.*, 2001). Hardie *et al.*, (2006) add that the importance of fostering innovative practices in the construction industry has been widely acknowledged. Gambatese and Hallowell (2011) describe innovation as vital for companies within the construction industry. They identified several factors of which the presence has a positive influence on the innovation outcomes of a company. Some examples are 'the presence of an innovation champion', 'organizational climate' and 'upper management support'. Rothwell (1974) complements that the capacity of organisations to innovate is dependent on both the internal organisational structure and the market the organisation operates in. He argues that innovation results in projects that exceed expectations in terms of cost, quality, and safety. Thus, it can be concluded that innovations can be very beneficial for organisations. Yet, as far as the construction sector is concerned, most processes have been the same for the past 20 years (Lenferink, 2020).

However, there is a limited amount of literature available that describes how innovation occurs within the construction industry. Abd El Halim and Haas (2004) describe construction innovation. They state that every innovation in the construction industry follows the same pattern. First, the need for innovation arises because of a shortcoming and/or risk in the current methodology. This study illustrates this. It owes its existence to a shortcoming in one of the key processes of maintenance companies: an inaccurate wood rot inspection leads to unwanted high failure costs. Stage two involves the development of a fundamental model. Identification of the main causes provides the basis for alternative solutions. Stage three focusses on the further development of these solutions. Stage four and five are concerned with testing the validity and

reliability of the solution found in the previous stages. This study attempts to walk through all the above-mentioned steps. If this is done successfully, sustainable competitive advantage can be gained.

The organisation wishing to innovate has its own influence on the capacity in which the above five steps are completed. However, there are also determinants that the organisation cannot directly influence. These external factors are best described by Pries and Janszen (1995). They argue that the environment of companies within the construction sector plays a dominant role in their innovative and strategic behaviour. They view upon specialisation and diversification as the most important strategic choices. In addition, Blayze and Manley (2004) identified six factors influencing construction industry innovation, namely [1] clients and manufacturers, [2] the structure of the production, [3] relationships between individual firms within the industry and between the industry and external parties, [4] procurement systems, [5] regulations/standards and [6] the nature and quality of organisational resources. Bossink (2004) proposes a classification of the above-mentioned construction innovation drivers into the four following categories: [1] environmental pressure, [2] technological capability, [3] knowledge exchange and [4] boundary spanning. Within the construction industry, three management levels can be distinguished among companies that co-innovate within this industry (Bossink, 2004). The intrafirm level represents the influences that are important for an individual firm. The interfirm level represents those projects that companies work on cooperatively. The trans firm level transcends the companies and reflects the influences as they apply to the entire industry. The above literature has clarified what factors must be present for a company to be innovative. The theoretical review continues with a description of how substance can be given to the concept of innovation within the construction industry.

2.3 Construction industry digitalization

Tronvoll *et al.* (2019) argue that digitalization enables firms to offer new product and service solutions to their customers. Barrett, Davidson and Prabhu (2015) clarify the potential of service innovation in the digital age. They state that, as firm modularity and granularity increase, opportunities for service innovations increase. Modularity is interpreted as the decomposition of a firm into smaller autonomous organisation units, while granularity refers to the extent to which a firm is composed of distinguishable pieces. In other words, less complex firms allow for easier service innovations. Lusch and Nambisan (2015) argue that innovations evolve from

joint action in a network of actors. Furthermore, the focus has shifted from innovation features and attributes to the value that is created by innovations.

Back in 1934, Schumpeter already identified the role of innovation in economic value creation (Ferreira, Reis & Pinto, 2016). Innovation is fundamental for creating economic value (Feldman, 2004). Value is defined as "*comparative appreciation of reciprocal skills or services that are exchanged to obtain utility"* (Vargo & Lusch, 2004).

Besides the economic value that digitalization creates, digital innovations also create value seen from a strategic perspective. Oks, Fritzsche and Lehman (2016) propose that managers are questionable as it comes to adopting a technology that has the potential to disrupt their operations. However, Oks *et al.* (2016) argue that the strategy chosen to implement digitalization lays the groundwork for the future development of digitalization. In other words, the reason for implementing digitalization has a great effect on the value it can bring forth. Cusumano & Gawer (2012) argue that a digital infrastructure allows for the creation of value through platforms. Extant literature mentions numerous digital infrastructures that allow for value creation; Azhar (2019) describes Building Information Modelling (BIM) as the most promising digitalization platform within the construction sector. The theoretical framework continues below with a description of what is already known about Building Information Modelling within the construction industry.

2.4 Construction industry digitalization - BIM

Boulton and lamb (2019) define digitalization as "*the use of digital technologies, particularly technologies that use digital data, to generate insights into new business models and processes such as supply chain management, e-governance, smart transport, etc".* According to Neely *et al.* (2019) a well-managed digitalization of the construction industry has the potential to improve building performance thereby reducing the impact on the environment. Building information modelling (BIM) is one of the most promising digitalization developments within the construction sector (Azhar, 2009). Supplementing Azhar, Razali *et al.* (2018) describe BIM as *"one of the most positive inventions in the fields of architecture, engineering, and construction (AEC) industry".* Azhar, Hein and Sketo (2008) define building information models as a representation of the development and use of building in computer generated n-dimensional models to simulate facilities throughout their entire life cycle.

In many studies, BIM is described as a very useful tool in project preparation (SBRCURnet, 2013). Thurairajah and Goucher (2013) argue that the most reported benefit of using BIM in

construction projects is collaborative working. Diaz (2016) lists several advantages of using BIM. These are: [1] Better project quality and performance, [2] improved productivity, [3] failure cost reduction, [4] new business model opportunities and [5] lower operating cost. Recently, there has been a trend to investigate the benefits of using BIM in the phases following construction (Suprabhas & Dib, 2017). *However, the biggest operational shortcoming of BIM is its inability to show real-time building performance in the operational stage (Kazado, Kavgic & Eskicioglu, 2019).*

Up to and including today, BIM has been implemented primarily in building design and construction phases (Ciribini, Ventura & Paneroni, 2016). Significantly less literature describes the use of BIM when a building is in its operational phase. The literature that does describe this subject, often does so from a technical point of view (Suprabhas, 2017). This study, on the other hand, describes the implementation of BIM in the building operational phase from an organisational point of view. In doing so, this study supplements existing literature about BIM implementation from a new perspective. In addition to knowing how to implement BIM, organisations can now also see the consequences at an organisational level. The theoretical review continues below by describing what supportive technologies can be used to overcome the operational shortcoming of BIM. Six of these supportive technologies are discussed below. Chapter [5] describes how a combination of some of these technologies can be used to successfully implement a BIM at the organisational level.

2.4.1 BIM - RFID

Hammad and Motamendi (2009) propose BIM supported by radio frequency identification (RFID) as a tool for managing life cycles of facility components. RFID technology consists of three components (Motamendi, 2013): A RFID reader, a RFID tag, and an antenna. A basic RFID system is shown in the picture below.

Figure 2: Basic RFID system (Iotlab.com, n.d.)

Two types of RFID tags exist: Passive versus active. Active tags are powered by an internal battery source providing them with a limited lifetime with a maximum of ten years. Passive tags obtain their power generated from the reader. In theory, they therefore have an almost infinite life span.

Since the construction industry is highly fragmented, i.e., each phase has its own operator, information about a building is not shared throughout the various phases. For example, a maintenance company was often not involved in the design or construction of a building. The emergence of digital support technologies such as BIM ensures that information can be easily shared during the implementation of the various lifecycle stages (Motamendi, 2013). Throughout the different stages, RFID tags can be used to facilitate information storage (Hammad and Motamendi, 2009). Distributed storage on RFID tags allows for a decentralised database and access for those who do not have access to the central database. Hammad and Motamendi propose a framework in which they combine BIM and RFID such that the current status (e.g., manufactured, shipped, installed, waiting for repair, etc.) of a construction component can be accessed at any time. However, within the scope of this research, specific focus should be on the relation between component maintenance and radio frequency identification. Although the model proposed by Hammad and Motamendi offers numerous value-adding benefits (e.g., quickly locating hidden components), the added value regarding the maintenance of components is practically non-existent. Within this model components can have one of the following three statuses: [1] in service, [2] inspected and [3] waiting for inspection. The information recorded in the RFID tags does not provide any information about the quality of the component nor does it provide any advice on when or how to properly maintain the component. However, as current literature accurately describes; the application of microchips in the construction industry is still in its infancy (Song *et al.,* 2006). In conclusion, RFID tags as facilitators of BIM modelling increase predictability of building performance and operation but do not add value in terms of smart maintenance.

Li, Xue and Li (2018) optimise the use of BIM in the on-site assembly services by enabling real-time visibility and traceability using radio frequency identification. In doing so Li *et al.* (2018) designed a platform that integrates data source services, smart construction objects, design support systems and platform gateway. However, like the initiative described above, this project also focuses on new constructions. To my best knowledge, there are no known initiatives using RFID for maintenance optimisation of existing buildings.

Initiatives such as the ones described above, but also the scope of this study overlap to a very large extent with the vision of the National Building Information Model Standard (NBIMS) (2005). It concerns the following vision: *"an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format usable by all throughout its lifecycle."* East and Brodt (2007) concluded that the minimal data needed for maintenance management is the location, warranty duration and component supplier information. Cavka, Staub-French and Pottinger (2013) support this statement by stating that the use of building information models has attained widespread attention over the last few years. The biggest challenge for property maintenance firms in migrating to BIM is to implement this change in the same way in all layers of the organisation. Despite the difficult implementation of such BIM models, the ROI of 634% on average makes it worthwhile (Azhar, 2009).

When zooming in on the Dutch construction sector, several initiatives emerge that make use of RFID sensors. Jongeleen (2016) published a report which describes how the frame quality is measured using smart sensor technology. The technology consists of a sensor with a chip, a gateway and a smart router. These three things together measure the moisture content and temperature in the frames. Based on the condition of the window frame, the frequency of maintenance can then be adapted. At first glance, such a system appears to be perfect. However, the potential of this project is not fully utilised until it is integrated into a BIM framework.

2.4.2 BIM – Digital Twin

Having a BIM framework is not necessarily sufficient during the operational phase of a building (Qiuchen & Xie, 2020). Therefore, future developments of smart asset management are aimed at integrating Digital building Twins. Boschert and Rosen (2016) describe a Digital Twin as being a digital and functional description of a building or component that contains all information necessary for operation in the current and subsequent lifecycles. Despite the apparent similarities, there is a difference between BIM and Digital Twins. Whereas a Digital Twin is merely a digital representation of a physical component, BIM is also involved in generating and managing these digital representations (Jung, 2017). However, digital twins offer various benefits in solving today's challenges in property management: [1] digital twins can be used to simulate the degradation process of a real estate complex during the operational phase, [2] by connecting digital twins with their 'real-life' counterparts, the digital twins become an attractive entity to test with (smartspaces, 2020; ogwijzer, 2021)

2.4.3 BIM - Artificial intelligence (AI)

By placing sensors in building components, it becomes possible to plan maintenance based on real-time data. The literature refers to this as the Internet of Things (IoT) (Shah & Yaqoob, 2016). The concept of IoT was originally derived from the RFID system in 1999 (Dong, Mingyue & Guoying, 2017). Kovalev, Shanin and Stupnikov (2018) propose an architecture for predictive maintenance of housing infrastructure. In this infrastructure, temperature, pressure and sound sensors placed in devices provide the user with encrypted data which is then translated via various steps into a regular event message or error code. Of all these steps, the module that predicts errors, detects, and monitors in real-time is particularly interesting from a maintenance perspective. Analysing means standardisation, missing value analysis and data quality assessment (Kovalev *et al.*, 2018). From the analysed data, several descriptive statistics are drawn. These statistics are then put into the model building and validation module. This model performs several statistical tests, on the basis of which faults can be detected and lifespan can be predicted. Zhang, Bingham and Garlick (2016) propose multiple fault detection models based on data from multiple sensors. They state that principal component analysis (PCA) is one of the most widely used methods for signal-processing based fault detection methods. The architecture, from device up till the fault alert, can be seen in Figure 4.

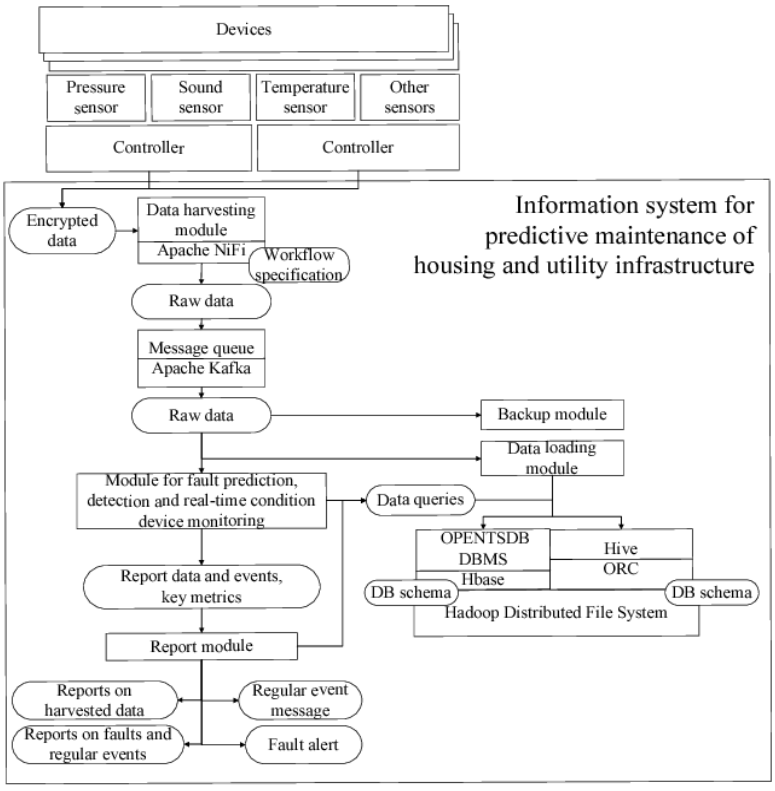

Figure 3: Predictive maintenance architecture (Kovalev, Shanin & Zakharov, 2018)

The architecture described above is a good example of a new development within the construction sector. The ability to process large amounts of data and to extract useful insights from it has revolutionised data processing over the last few years (Bilal *et al.*, 2016). The emergence of sensor technology as well as the Internet of Things (IoT) will result in the construction sector having to process more and more data in the coming years. These increased amounts of data have ensured that the construction industry must focus on Big Data. According to Bilal *et al.* (2016) Big Data has three defining attributes: [1] Volume, [2] variety and [3] velocity. Big Data is concerned with two main processes: [1] Big Data Engineering (BDE) and [2] Big Data Analytics (BDA). BDE is primarily concerned with the storage of data and its security whereas BDA is primarily concerned with the extraction of knowledge from the data. Extant literature often mentions Big Data integrated into BIM models. Kargah-Ostadi (2014) used a Big Data driven BIM model to predict pavement deterioration. Ng and Soibelman (2003) try to extract parameters that increase or decrease maintenance cost from higher education maintenance databases. Liu and Issa (2013) researched undeveloped FM supporting possibilities. They concluded that BIM is widely used in the design and construction phase but requires additional research for it to be applicable in maintenance activities. *This study therefore proposes a framework in which BIM models are used to optimise maintenance activities in the construction sector.* The BIM model will obtain the required data through the use of additional technology.

2.4.4 BIM – Environmental sensors

Kensek (2014) investigated the feasibility of connecting environmental sensors such as light and humidity to a building information model. Revit family editor is used to create a digital model of a building. The input for this model is collected using environmental sensors. The measurements collected by the sensors are translated into a .txt file using an Arduino board. The course of this process is shown in the figure below.

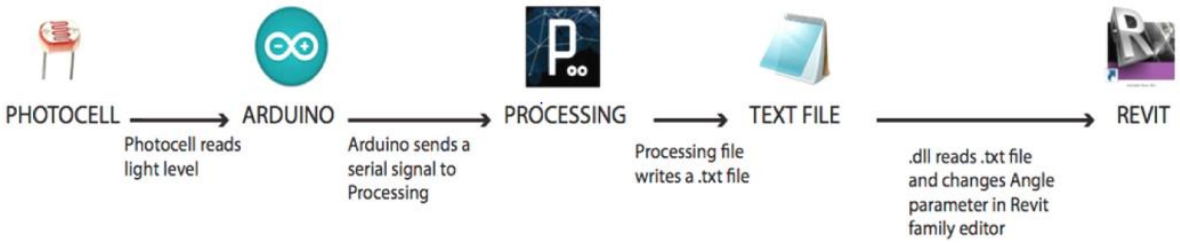

Figure 4: Developping a dgital building model (Kensek, 2014)

Li *et al.* (2020) presents an alternative to the above process. In their automatically generated BIM model, they use low-cost sensors to collect data. Firstly, the sensors are calibrated to

increase their measurement accuracy and operation range. Secondly, a deep-learning-based method is used to create a 3D reconstruction of the environment (Li *et al.*, 2020). The basic BIM model in which (environmental) sensors are used to collect the required data is shown in Figure 5.

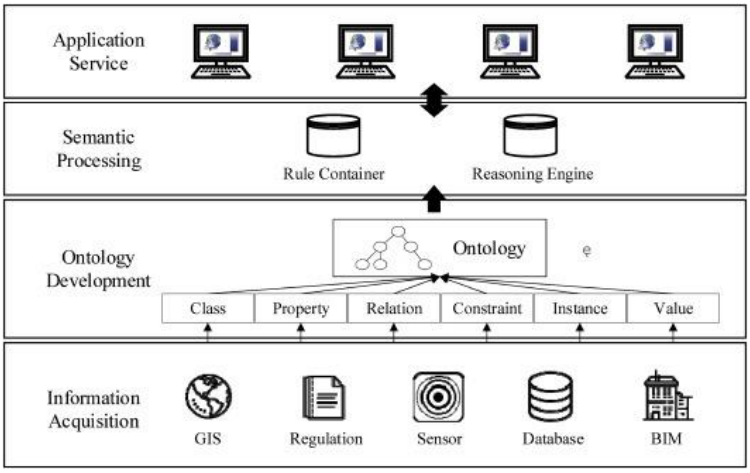

Figure 5: Building environmental monitoring under BIM (Zhong, Gan, Luo & Xing, 2018)

Suprabhas (2017) investigated the feasibility of integrating BIM and sensor data for facility management. Sensor data, collected by means of a wireless network within a virtual model, can be visualized using color patterns. These colour patterns should make it clear where the difference in measured values comes from.

2.4.5 BIM – WSN

Wireless Sensor Networks are used for several purposes, including ambient condition detection such as moisture lever or temperature (Zhang, 2017). These wireless networks consist of multiple low-cost sensing nodes with computation and communication capabilities (Zhang, Meratnia & Havinga, 2010). According to Zhang (2017) three different types of networks exist. [1] Star network. The measuring nodes within a network are all connected to a central device. [2] Tree network. A central note is interconnected with one or more other nodes. [3] Mesh network. Some nodes in the network are interconnected. Zhang mentions several challenges when implementing wireless sensor networks including self-configuration, localization, power supply and communication abilities. Girod and Srivastava (2001) propose three technological approaches that would tackle the above-described challenges. A detailed description of these approaches is beyond the scope of this research.

Particularly interesting within the scope of this research is a special application of Wireless Sensor Networks, namely environmental monitoring with outlier detection. As was made clear in [2.1.1], wood moisture and temperature fluctuations are two of the causes of wood rot. The

recording of these values can be done by means of a wireless network sensor. An outlier is said to exist when the requirements set by Verhaege (2016) in subsection [2.1.1] are met. A basic architecture in which sensor nodes are implemented into different substances is shown below.

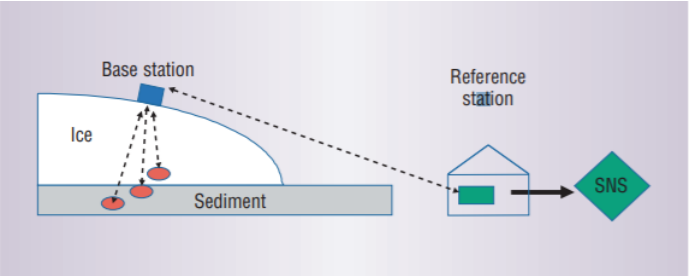

Figure 6: Basic sensor network architecture (Martinez, Hart & Ong, 2004)

2.4.6 BIM - Laser scanning

In contrast to BIM, which is mainly used for new buildings, laser scanning is mostly used for existing buildings. Yet laser scanning can play a major role in a BIM model. Gleason (2013) described how scanning technology can be applied within building information modelling. Traditionally, laser scanning is used to indicate the location of an object. A laser sends out a signal and it is measured how long this signal takes to return. Based on this measurement, it can then be determined how far away an object is. Recent developments in laser scanning have shifted the focus from determining a location to determining the quality of materials. Peng, Yue and Xiao (2016) proposed a model in which a three-dimensional laser scanning scheme is used to detect wood defects and species. To carry out these non-destructive scans a portable scanner is used. The image below shows what this scanner looks like.

Figure 7: A portable Artec 3D laser scanner (Peng, Yue & Xiao, 2016)

An integration scheme is proposed to calculate the surface area and volume of each defect. The result is a list of defects with their location and volume. In this way, it is possible to calculate exactly where the defect is located and how large the defect is.

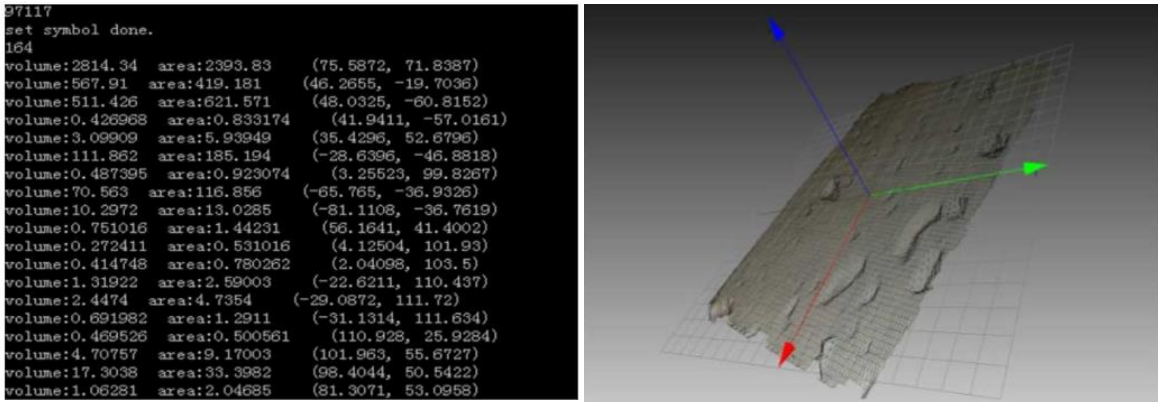

Figure 8: Wood defect's measurement results (Peng, Yue & Xiao, 2016)

2.5 Literature research – conclusion

This section provides an overview of the most important findings resulting from the literature research. The theoretical review showed that innovation offers numerous benefits for organisations. It also showed that not every organisation can innovate, i.e., multiple factors have to be present to be able to innovate as an organisation. Trovoll *et al.* (2020) argued that digitalization enables firms to innovate their product and service offerings. Neely *et al.* (2019) argued that a well-managed digitalization of the construction industry has the potential to improve building performance thereby reducing the impact on the environment. Azhar (2009) described BIM as the most promising digitalization within the construction industry. Kazado, Kavgic and Eskicioglu (2019) describe why BIM is not ready to use for maintenance companies yet. They state that current BIM is not able to show real-time building performance in the operational stage. Therefore, six supportive technologies were described that could solve this shortcoming. Furthermore, the theoretical review showed a major shortcoming in extant literature. If the implementation of BIM in the operational phase is described at all, it is only from a technological perspective (Suprabhas, 2017). This also underlines the academic relevance of this research. This study describes the implementation of BIM in the operational phase from an organisational perspective rather than a solely technological perspective.

The theoretical framework has guided this research. The versatility of BIM makes it ideally suited to be used in this study. To make BIM applicable within this research, one or more of the described supportive technologies will be used to capture the state of the building in the operational phase. This digitalization contributes, through innovation of the offerings, to achieving the research goal of company growth (Figure 1). This study continues with a description of the findings made based on multiple interviews and observations.

3. Research methodology

In addition to performing a theoretical review, this chapter describes two other methods of data collection, namely interviews and observations. An interview survey was carried out to provide an overview of the main inspection process in its current form. The purpose is to get operational level understanding of how an inspection is carried out. Observations were made to see what is encountered when carrying out such an inspection.

3.1 Interview survey

In the interview survey five different experts in efficient property maintenance and inspection were interviewed. The experts represented various firms within the Dutch construction sector, varying from the client company [two], inspection bureaus [one] to commercial firms who repair wood rot [two]. The interviews had an open structure and were carried out using the interview guides as can be seen in Appendix A. The interview transcripts can be found in Appendices B to G. The findings from the literature review were not discussed in the interviews. The purpose of this is to avoid so-called politically correct answers. To keep the information shared anonymous, the interviewees are only referred to by their title within their organisation as follows:

V: Calculator at a Dutch maintenance firm
W: Calculator at Dutch maintenance firm
X: Co-owner at a Dutch maintenance consultancy firm
Y: Project leader at a Dutch maintenance firm
Z: CEO at a Dutch repair innovation firm

All interviews were conducted using the Interview Guide as can be seen in Appendix A. After conducting the interviews, they have been transcribed. The transcriptions were then uploaded to Microsoft Excel. Microsoft Excel was selected because it enables both qualitative and quantitative analysis of the interviews. Compared to coding programs such as Atlas.ti, the chosen method will be slightly more time-consuming. However, as with Atlas.ti it is also possible to reproduce the results using Microsoft Excel to increase the reliability of the findings.

3.1.1 Interview data analysis

The interview data is analysed using the coding practices as described by Locke *et al.* (2020). Literature mentions data analysis as a critical component of qualitative research (Gibbs, 2013). The methodology chosen, determines the steps needed to be taken in data analysis. With some methods the steps are fixed, grounded theory for example, while other methods offer more freedom in the order of execution (Pratt, 2009). Within the process of analysing data, two

concepts are central (O'Kane, Smith & Lerman, 2019). [1] Transparency as being the *"the degree of detail and disclosure about the specific steps, decisions, and judgment calls made during a scientific study"* (Aguinis *et al.*, 2018). [2] Transparency as indicated by credibility, consistency, and the lack of bias. It is therefore these two concepts that will be used at the end of this chapter to assess the research methodology. This analysis will look for patterns in the data and the explanation for them, so called inductive research. This is not done using software. So called Computer Aided Qualitative Data Analysis Software (CAQDAS) was not available. However, the functionalities of such tools have been tried to mimic using Microsoft Excel. The analysis will be carried out using the six steps as presented by O'Kane *et al.* (2019). Where it is not possible to follow these steps due to lack of software, the Coding Manual by Saldana (2012) will be leading. O'Kane *et al.* state that these building blocks can be used for initial exploration of data, building codebooks, and coding and exploring data.

Text retrieval

Transcriptions of the interviews can be found in Appendices B up till F. The transcriptions were uploaded to Microsoft Excel. One question is plotted in each row. This is important to be able to see later which question a certain word belongs to. Deliverables of the text retrieval building block are texts, tables, or tree diagrams. The search function facilitates a search for a key word or phrase. Key words or phrases are those that represent the meaning of a code (O'Kane *et al.*, 2019). Saldana (2012) defined a code as *"word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data".* The following key words have been set up for the qualitative analysis:

- Wood rot
- Inspection
- Process
- RGS

Each key word came up repeatedly in the interviews with various experts. Thus, a text-retrieval search using the above-mentioned key words was conducted. The first search explored in how many of the cases these words appeared. The results can be found in the table below.

Key word	**Appearances**
Wood rot	6/6
Inspection	6/6
Process	4/6

RGS	3/6

Table 2: Key word appearences

Next, we looked at how often each key word was mentioned in the interviews. The results are presented in Table 2.

Key word	**Count**
Wood rot	39
Inspection	30
Process	3
RGS	6

Table 3: Key word appearences

Thus, a first exploration of data identified which key words are used frequently by respondents. According to O'Kane *et al.*, the next step is to code the data. Saldana states that coding begins with selecting the appropriate coding method(s). Selecting the appropriate coding technique strongly depends on the type of answers one is seeking for. The research questions formulated in this study attempt to give substance to the way in which an organisation can increase turnover. The expected answers of the respondents are therefore ideas, obstacles and goals. Respondents' answers must guide the solution. The analysis of the interviews should therefore be directly applicable in this research. Saldana (2012) outlines the following methods that are appropriate for this purpose: Structural, Provisional, Hypothesis, Protocol, and Elaborative Coding. Patel (2014) describes structural coding as a labelling and index device to be used as a categorisation technique. Saldana (2012) argues that Structural coding is appropriate for almost every qualitative study in which hypothesis or exploratory investigations are gathered. In this study the following research questions will be answered:

1] *How can property maintenance companies innovate their value propositions by means of digitalization**?*** **[Innovation of value proposition] [digitalization as a tool]**

To be able to answer the central research question, it has been further broken down into the following sub-research questions:

[1.1] *What is digitalization and how does this drive the construction industry**?*** **[digitalization definition]**

[1.1.1] *What digitalization initiatives are known in the construction sector?* **[digitalization examples]**

[1.1.2] *How can these initiatives support the digitalization of property inspections?* **[property inspection supportive methods]**

[1.2] *What is the relationship between digitalization and innovation within the construction industry?*

[innovation and digitalization relation]

After each research question, a conceptual phrase that relates to the specific research question is printed in bold. These six conceptual phrases are used to categorise text fragments.

The result of structural coding is the identification of text segments on broad topics. MacQueen *et al.* (2008) state that these segments can form the basis for an in-depth analysis within or across topics. Next, determining code frequencies helps identifying which themes or ideas were common and which were not (Namey *et al.*, 2008, p.137-162). The quantitative results are, in descending order, presented in the table below.

Conceptual phrase	Total occurrences
Other	102
Property inspection supportive methods	21
Innovation of value proposition	15
Digitalization as a tool	6
Digitalization definition	3
Innovation and digitalization relation	0
Digitalization examples	0

Table 4: Code frequency

Code retrieval

O'Kane *et al.* (2019) state that, depending on the research question, the code frequency can help the researcher to determine where to perform in-depth analysis. From the code frequencies mentioned in Table 3, several conclusions can be drawn. [1] The large number of text fragments under the label 'Other' says something about the validity of the interview questions. Many of the questions asked do not contribute to solving the research questions. These questions are purely aimed at identifying the current inspection process and its shortcomings. The reason for this is the switch that has been made in the meantime. The perspective of this research has gradually changed from technical to business-like. As a result, the focus was no longer on optimising the inspection process but more on the business results. [2] Respondents are actively involved in improving their companies' value proposition. However, only one of the respondents uses digitalization techniques in doing so. Other respondents have only heard about it. [3] In the workplace, concepts such as digitalization and innovation are not commonplace. Information on this will mainly come from the theoretical framework.

Saldana (2012) outlines many different techniques to further analyse the previously identified structural codes. Ayres *et al.* (2003) argue that qualitative analysis depending solely on coding and categorising strips much of the contextual richness of individuals away. To prevent this within- and cross code patterns will be identified. This is done using the qualitive content analysis method (Jansen, 2020). Previously, the large samples of text have already been translated into seven codes. From these seven codes, the five least mentioned are the most interesting (Table 3). In total, nine statements occurred about digitalization. No respondent was able to mention any digitalization examples about the wood rot inspection. There are dozens of reasons for this: It may be that no examples exist; that the interviewees are not aware of the presence of these examples or that they are not aware of what digitalization entails and therefore cannot cite examples. Not surprisingly, all three codes about digitalization are infrequent since they are strongly interrelated. Statements coded under 'Property inspection supportive methods' often indicate the use of manual instruments. A logical next step in this research is to examine which of these instruments can be translated into a possible digitalization. To reiterate: The exact interpretation of digitalization is not known, even after analysis of the interviews. However, it is known from the literature that digitalization is a means of changing the value proposition to customers. Analysis of the interviews concluded that respondents already try to improve the value propositions they deliver. However, instead of innovating these processes by means of digitalization, they rather implement small changes that only slightly improve the value proposition. Respondents are not yet aware of the major advantages that digitisation has to offer, if implemented correctly.

3.2 Observation

Two observations were made to gain insight into the flow of the inspection process at UOL. Based on these observations, a good estimate can be made of how much time is needed to conduct inspections. It is also possible to reserve which components of the building are included in the inspection and which are not. Several experts from a Dutch property management company have been observed. Observations were made at several projects.

First of all, there is a brief description of the tools and teams used for wood rot inspections. When carrying out wood rot inspections, the inspectors go out with a ladder, a blunt instrument and a paper recording sheet. Ideally, the inspectors have already been provided by the client with a view of the facade on which they can make notes during the inspection. This was the case for both observed inspections. The interviews already revealed that the aim is to carry out the inspections in pairs of two. One person tracks down the defects while the other records

them. However, this was not the case during the observations; here, both inspections were carried out by one person.

Secondly, inspectors use a simple rule of thumb for the number of homes to be inspected: A minimum of 10 percent of the homes to be maintained must be inspected. The results of this sample will be extrapolated and a representative result for the whole project is expected. Again, the interviews have shown that this is often the case in practice. The execution of the inspections is not standardised. This means that each inspector carries out the inspection in his or her own way. Prior to the inspections, the inspector prepared three pages listing all possible wood rot defects: one page for the front facade, one for the end facade and one for the side facade. These lists are then used to count how often these defects occur per façade.

Adres: Wayerkamp 13

Nr.	Soort	Aantallen Voorgevel	Aantallen Achtergevel	Totaal aantallen
0	Afronden scherpe kanten			
1	Verbindingen uitfrezen		III	
2	Kleine houtrot pastareparatie (<50 ml)		I	
3	Middel houtrot pasta reparatie (50-100 ml)		I	
4	Grote houtrot pasta reparatie (>100 ml)			
5	Houtrotreparatie kozijn d.m.v. laminatie klein < 50 cm	I		
6	Herstel houtrotschade door lamineren, gehele kozijndorpel [tot 1000 mm]	II		
7	Vervangen van een stijlstuk [excl. de-/montage aansluitende gevelvlakken] [tot 1000 mm.].			
8	Vervangen van een L -stuk [excl. de-/montage aansluitende gevelvlakken] [tot 1000 mm.].			
9	Vervangen van een T -stuk [excl. de-/montage aansluitende gevelvlakken] [tot 1000 mm.].			
10	Vervangen van een dorpel met twee stijlstukken [excl. de-/montage aansluitende gevelvlakken] [tot 2000 mm.].			
11	Onderdorpel vervangen tot 200 cm			
12	Omtrekspeling aanpassen [excl. de-/montage deur].			
13	Omtrekspeling deur aanpassen [excl. de-/montage deur].			
14	Omtrekspeling raam aanpassen [excl. de-/montage raam].		I	
15	Omtrekspeling deur aanpassen [incl. de-/montage deur].			
16	Omtrekspeling raam aanpassen [incl. de-/montage raam].			
17	Draairaam vervangen		I	
18	Klepraam vervangen			
19	Voordeur vervangen			
20	Achter-/tuin-/balkondeur vervangen			
21	Neuslat vervangen, contramal DTS			

Bijzonderheden:

Figure 9: Wood rot assessment state as utilised by UOL

During the performance of the inspections, experience plays a major role. A less experienced inspector pricks his awl much more often than an experienced inspector. The experienced inspector also has better insight into where wood rot may occur.

Thus, through the observations, two main conclusions have been reached. [1] There is no standard structure for carrying out inspections. [2] Although the importance of moisture measurements was discussed in the interviews, it appears that this is usually ignored in practice. Chapter [4] discusses the consequences of these two conclusions by means of two practical examples.

4. Uw onderhoudspartner Lenferink Case study

This chapter elaborates on two projects executed by UOL. First the company will be briefly explained [4.1]. Section [4.2] describes the current business model of UOL. Section [4.3] explains how UOL deals with wood rot. Sections [4.4] and [4.5] illustrate this by means of two case examples. The last section [4.6] describes to what extent the findings of the literature hold true for UOL.

4.1 Uw Onderhoudspartner Lenferink – The organisation

Appendix G shows the UOL organisation chart. The top level of the organisation is divided into the commercial director on the one hand and the managing director on the other. The commercial director is responsible for bringing in work and thus turnover. The general director is responsible is responsible for the execution of the work and thus the generation of cash flow.

4.1.1 Descriptive statistics

UOL is a company founded in 1949. The company has been run by the Lenferink family since its establishment. Today the company has over 80 craftsmen, an annual turnover of more than EUR 9 million and 4 offices in the east of the Netherlands. The company's mission is:

"Samen maken wij meer van uw bezit" (Together, we make more of your property)

They realise this mission by offering smart multi-year maintenance plans. Their target market mainly consists of housing corporations, owners' associations and private individuals. What sets UOL apart from its competitors is the focus on teamwork, delivering quality together, improving together and long-term partnerships.

4.2 Business Model Canvas - RGS

Appendix H shows the Business Model Canvas for UOL. They distinguish themselves by establishing long-term relationships with clients and partners. Engaging in such relationships builds trust between different firms and ultimately leads to improved results. UOL's second tool to differentiate from competitors is the so-called "Resultaat Gericht Samenwerken" (RGS). This RGS is best described visually. The figure below describes two situations: the situation without RGS and the situation with RGS.

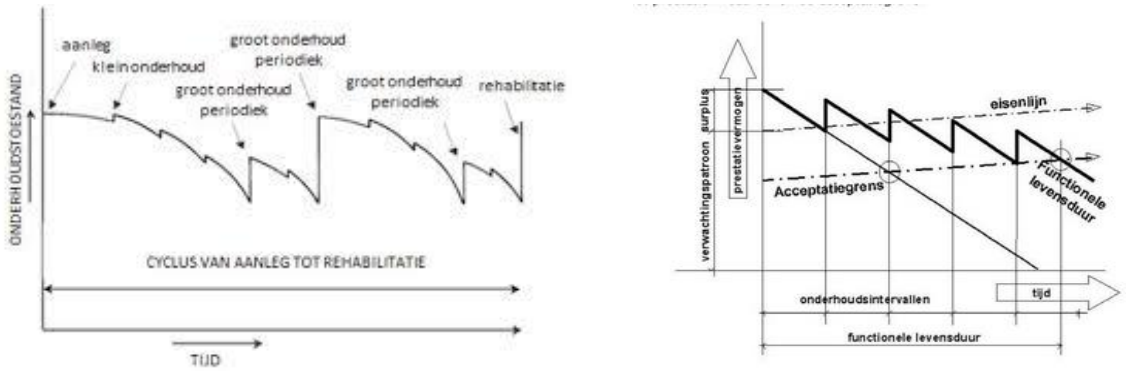

Figure 10: Building condition in relation to time (Source: Beleidsplan wegen, 2017)

The left diagram in Figure 11 describes the lifespan of a building with standard maintenance activities being performed. Maintenance is divided into small maintenance and major periodic maintenance. In other words, predetermined types of maintenance take place periodically. These periods are fixed and do not depend on the quality that is delivered. This type of maintenance is called performance based (SBRCURnet, 2013). In this situation, maintenance is carried out based on performance requirements only. The right diagram in Figure 10 displays the building life span in case of RGS application. In the right situation, the client and the contractor agreed on an acceptance limit that the building must always meet. The property maintenance firm is then free to schedule the maintenance as conveniently as possible. A longer cycle, for example, requires a greater investment in the initial year, but pays for itself in having to perform maintenance work less often in the long run. These investments must be continuously weighed against the savings to achieve an optimal result.

As a result of applying the RGS methodology, the way revenues are generated has also changed. When a company must compete with several companies in a tender, the margins are very low. The company that offers the job for the lowest price is allowed to do the job. When implementing the project, the focus will mainly be on minimising costs rather than maximising quality. The executing company is paid once for the project. What the quality is in the years after the maintenance is of no importance to the executing party. In other words, the company that carries out the work has a duty of effort rather than a duty to produce results. The revenue stream changes significantly when applying RGS. In this case, the responsibility for the work delivered is placed on the executing party. The contractor must ensure, by means of smart maintenance plans, that the buildings to be maintained meet the agreed quality requirements for the entire duration of the contract. UOL generates revenue by minimising the number of maintenance cycles. To do this, they make additional investments at the beginning of the

cooperation. This extra investment pays for itself later by saving on one or more maintenance cycles.

One of UOL's main targets is increasing the return on projects. The selling price of the work delivered is contractually agreed in advance by UOL with the client. This means that the return can only be increased by reducing costs. In addition to the performance of work, one of the most important key activities is the optimisation of business processes. Through a channel called 'Innovatiehub Salland', they try to bind young talent to the organisation to achieve innovative improvements in existing business processes. The following section describes the significance of wood rot from the perspective of extending maintenance cycles.

4.3 Understanding wood rot

In order to determine the length of the maintenance cycles, it is important to have insight into the condition of a building at all times. Obtaining this insight is currently done by means of an intermediate inspection. This means that one or two years before the planned maintenance, it is checked whether the maintenance can be postponed for another year. In practice, this monitoring is either skipped or done very briefly. Especially when the length of a maintenance cycle has to be converted into revenue, it is important to be able to monitor this condition accurately. In order to gain insight into the condition of the building at all times and to limit the risk, UOL strives for a digital solution to the problem described in Chapter [1].

Insight into the current state of wooden building components is important on the one hand because the responsibility for the state of the property lies with UOL: If damage has occurred due to unwarranted postponement of a maintenance cycle, the cost of repairing the damage shall be borne entirely by the property maintenance company. On the other hand, accurate insight into the condition of the wooden components eliminates the need to charge extra for wood rot. The direct result is a cheaper offer for the client with substantiation through insight into the condition of the window frames. In addition, insight into the state of wooden building components brings another major benefit: UOL can distinguish itself from the competition. As a result of the intended digitalization, offering alternative contract forms becomes possible. The digitalization with its consequences for the existing business model is described in detail in Chapter [5].

In the current situation, the cost for repairing wood rot consist of the material cost plus the labour cost multiplied by a surcharge. The amount of wood rot recorded during the inventory

is multiplied by a percentage. This percentage depends on the type of inspection. With a smaller sample, the chance of wood rot damage in the entire complex is greater and therefore the risk percentage is increased. Usually, the number of defects per property is multiplied by 1.2 or 1.25. The direct consequence of this is that the offer to the client is often too high. The direct consequence of an inaccurate quotation is the occurrence of extra or less work. This is illustrated by two case examples.

4.4 Case example one – 149 properties in Apeldoorn

To illustrate how UOL deals with wood rot in the current situation, two projects are examined. Project one shows how additional work arises, while Project two shows how attempts are made to ensure that additional work cannot occur. Both projects were carried out on behalf of large regular clients.

Project one: Salverda – 149 woningen Apeldoorn OnsHuis (HR180591)

This project had a turnover of more than 400 thousand euro. In this project, 149 homes have been renovated. In this example, only the work related to wood rot is considered. The other work, including glass work, indoor and outdoor painting and shielding measures, is not considered. The budgeted amount for repairing wood rot is calculated at €32.014,37. Converted, this equals an amount of €214,86 per property. The cost item for wood rot is included in the budget in the following way.

Activiteit	4	Activiteit			Houtrotwerkzaamheden	32.014,3...	32.014,37 €
Titel	4.1	Titel			Pasta en laminaat reparaties conform steekproef opname	32.014,3...	32.014,37 €

Figure 11: Wood rot in the calculation

'Activiteit' indicates the type of work and thus in this case wood rot repair. 'Titel' indicates which operations the wood rot repairs consist of in this project. The budgeted amount for wood rot is shown in the last column. Below is a frontage view of one of the houses in this project before it has been renovated.

Figure 12: Front view of one of the project properties

The calculated amount for repairing wood rot damage is not arbitrary. This amount consists of the number of defects included in the sample, extrapolated for the number of defects in the entire complex, and then multiplied by a risk percentage. This realisation is dealt with in detail in the following project. The budgeted numbers per repair are shown in the figure below.

Positie	4.1.1	BK-C1-10	43	stuks	Houtrotreparatie Dryflex RP massief, klein	35,22 €	1.514,46 €
Positie	4.1.2	BK-C1-20	57	stuks	Houtrotreparatie Dryflex RP massief, middel	58,81 €	3.352,17 €
Positie	4.1.3	BK-C1-20	57	stuks	Houtrotreparatie Dryflex RP massief, groot	94,28 €	5.373,96 €
Positie	4.1.5	BK-C2s-50	42	stuks	Dorpel- of stijlstuk lamineren voor de glaslijn tot 20 cm	105,00 €	4.410,00 €
Positie	4.1.5	BK-C2s-50	41	stuks	Dorpel- of stijlstuk lamineren voor de glaslijn tot 50 cm	121,80 €	4.993,80 €
Positie	4.1.4	BK-C2d-100	43	stuks	Dorpel- of stijlstuk lamineren voor de glaslijn tot 100 cm	181,86 €	7.819,98 €
Positie	3.2.6	rh2	10	stuks	Ramen hout	455,00 €	4.550,00 €

Figure 13: Expected numbers plus corresponding amounts per type of wood rot repair

Depending on the type of contractor, in some cases a property maintenance firm may be asked to keep track of the actual number of repairs carried out. The actual number of wood rot repairs executed for this project can be seen in the table below. The first column indicates the actual number of repairs carried out whereas the second column indicates the type of repair.

Aantal	Code	Eenheidsprijs	Totaal
26	1	€ 35,22	€ 915,72
60	2	€ 58,81	€ 3.528,60
194	3	€ 94,28	€ 18.290,32
57	4	€ 105,00	€ 5.985,00
33	5	€ 121,80	€ 4.019,40
75	6	€ 181,86	€ 13.639,50
7	7	€ 455,00	€ 3.185,00
			€ 49.563,54

Figure 14: Number of wood rot repairs actually carried out

The difference between the budgeted work and the work carried out in this case leads to an overrun of the budget by more than 17 thousand euro. How exactly this exceedance is caused is shown in the table below.

Code	Repair	Budgetted (#)	Actual (#)	Unit price	Difference
1	Pasta repair small	43	26	€ 35,22	€ 598,74
2	Pasta repair medium	57	60	€ 58,81	€ -176,43
3	Pasta repair large	57	194	€ 94,28	€ -12.916,36
4	Laminating up to 20 cm	42	57	€ 105,00	€ -1.575,00
5	Laminating up to 50 cm	41	33	€ 121,80	€ 974,40
6	Laminating up to 100 cm	43	75	€ 181,86	€ -5.819,52
7	Replacing windows	10	7	€ 455,00	€ 1.365,00
					€ -17.549,17

Figure 15: Expenses for more/less work as a result of an incorrect wood rot inspection

In this case, permission has been given by the client to charge these additional costs. However, these costs are still considered failure costs. After all, the housing project leader must be able to explain internally how this overrun came about, the housing corporation must deduct money from another project, etc. From the maintenance partner's perspective, this overrun can lead to capacity problems, for example, because the employee carrying out the additional repairs should in fact have been working on another project already. In other words, both the client and the contractor have common interest in having an accurate overview in advance of the wood decay repairs to be carried out. The deviation from this, and therefore the failure costs, must be reduced.

4.4.1 Apeldoorn 149 properties - Conclusion

The project shows how conducting an inaccurate inspection can lead to an incorrect proposal, which in turn has led to a huge budget overrun. This example illustrates how an inaccurate inspection can lead to a budget overrun afterwards.

4.5 Case example two – 243 properties in Zutphen (HN200211)

Unlike the previous example, in this project the focus will be on the front end of the process. In other words, this project serves to illustrate the inspection of the wood rot damage present in a complex. In contrast to the project in Apeldoorn, in this project the decision was made to outsource the inspection process, whether by force. Common reasons for outsourcing an inspection are time constraints and lack of experienced personnel. The external agency contracted to carry out the inspection is called Polyfilla. The great advantage of outsourcing to a party that specialises in this is obtaining very detailed results. Also, such parties often use software that significantly reduces the margin of error. The image below shows part of the

results as obtained by Polyfilla in Zutphen. The Figure below is a visual representation of how Polyfilla displays data during the inspection. They add damage codes to digitally displayed façade views in a software application.

Figure 16: A door with minor wood rot damage (Source: Polyfilla inspection report, 2021)

It is also interesting to note that the wood rot damage almost always occurs in one of the two bottom corners. This has also emerged from the interviews. Figure 17 shows how these results are reported.

L050	Laminaat <50 cm1	€	73,20	18	2	36	41	€	3.030,48
L100	Laminaat 1 m1	€	95,00	7	2	14	16	€	1.529,50
L150	Laminaat 1,5 m1	€	142,50		2	0	0	€	-
L200	Laminaat 2m1	€	190,00	1	2	2	2	€	437,00
L250	Laminaat 2,5m1	€	237,50	1	2	2	2	€	546,25
L300	Laminaat 3 m1	€	285,00		2	0	0	€	-
L400	Laminaat 4m1	€	380,00		2	0	0	€	-
OSD+	Omtrekspeling deur incl uitnemen	€	38,50	87	2	174	200	€	7.703,85
OSD-	Omtrekspeling deur excl uitnemen	€	26,00	3	2	6	7	€	179,40
OSR+	Omtrekspeling raam incl uitnemen	€	24,50	27	2	54	62	€	1.521,45
OSR-	Omtrekspeling raam excl uitnemen	€	18,00	14	2	28	32	€	579,60
P03	Pasta 3 cm/10<>25 cm3	€	25,00	556	2	1112	1279	€	31.970,00
P05	Pasta 5 cm/25<>75 cm3	€	38,00	170	2	340	391	€	14.858,00
P10	Pasta 10 cm/75<>150 cm3	€	69,00		2	0	0	€	-

Figure 17: Inspection results Polyfilla

Often, these results are also more reliable due to a larger sample size. In the project in Zutphen, half of all homes were inspected. To obtain the result for the entire complex, the numbers per defect have been multiplied by an extrapolation factor of two. To ensure that the budget will not be exceeded, the number of damages found has been multiplied by a risk factor of 1.15. This can be seen in the figure below.

Opdrachtgever	Uw onderhoudspartner Lenferink	Aantal woningen		243	Risk		15%
Complex	243 woningen Stokebrand	Factor extrapolatie		2			
Symbool	Omschrijving	Indicatieve prijs	Aantallen inspectie	Extrapolatie factor	Aantallen extrapolatie	Aantallen incl risico	Subtotaal handeling
OSD+	Omtrekspeling deur incl uitnemen	€ 38,50	87	2	174	200	€ 7.703,85
OSD-	Omtrekspeling deur excl uitnemen	€ 26,00	3	2	6	7	€ 179,40
OSR+	Omtrekspeling raam incl uitnemen	€ 24,50	27	2	54	62	€ 1.521,45
OSR-	Omtrekspeling raam excl uitnemen	€ 18,00	14	2	28	32	€ 579,60
P03	Pasta 3 cm/10<>25 cm3	€ 25,00	556	2	1112	1279	€ 31.970,00
P05	Pasta 5 cm/25<>75 cm3	€ 38,00	170	2	340	391	€ 14.858,00
P10	Pasta 10 cm/75<>150 cm3	€ 69,00		2	0	0	€ -
S010	Scheur 10 cm1	€ 4,30	21	2	42	48	€ 207,69
S020	Scheur 20 cm1	€ 6,80	42	2	84	97	€ 656,88
S030	Scheur 30 cm1	€ 15,00	17	2	34	39	€ 586,50
S050	Scheur 50 cm1	€ 22,00	18	2	36	41	€ 910,80
S100	Scheur 1m1	€ 34,00	4	2	8	9	€ 312,80

Figure 18: Total numbers found per defect in Zutphen

In the column 'Aantallen extrapolatie' the number of defects is shown because of the inspection. In the 7th column, 'Aantallen incl risico', the numbers found during the inspection are multiplied by 1.15. The 243 properties are divided into several complexes. For one of the complexes, equalling a total of 55 properties, the budgeted amount for systematic maintenance including the repair of all existing wood rot damage equals €412.295,24 with a total of more than 3200 hours of work. The actual cost of implementing this project has been calculated at €394.338,27. Thus, in implementing the project, costs of roughly 18 thousand euros were saved. Since UOL did not work with cost allocations until recently, it is not possible to see automatically where these savings come from. Cost placement means that all costs incurred for wood rot repair are booked on a specific number. In this way at the end of a project it is exactly clear which costs have been booked on which item. The following overview shows the main cost centre structure as used in current projects.

Nummer	Type	Groep	KorteTekst	Omschrijving
100	Hoofdkostenplaats	100	Buitenwerk	Buitenwerk
200	Hoofdkostenplaats	200	Binnenwerk	Binnenwerk
300	Hoofdkostenplaats	300	Glaswerk	Glaswerk
400	Hoofdkostenplaats	400	Houtrotreparatie	Houtrotreparatie
405	Hoofdkostenplaats	400	Timmerwerk	Timmerwerk
500	Hoofdkostenplaats	500	Werkvoorbereiding	Werkvoorbereiding
600	Hoofdkostenplaats	600	Garantiewerk	Garantiewerk
650	Hoofdkostenplaats	600	Meerwerk	Meerwerk
700	Hoofdkostenplaats	700	Reisuren	Reisuren
800	Hoofdkostenplaats	800	Bouwteampartner	Bouwteampartner
805	Hoofdkostenplaats	800	Gevelreiniging	Gevelreiniging
900	Hoofdkostenplaats	900	Algemeen	Algemeen / adm.
905	Hoofdkostenplaats	900	ATV	ATV
910	Hoofdkostenplaats	900	Vakantiedagen	Vakantiedagen
915	Hoofdkostenplaats	900	Dokter/tandarts/spec	Dokter/tandarts/spec
920	Hoofdkostenplaats	900	Scholing	Scholing
925	Hoofdkostenplaats	900	Ziek	Ziek
930	Hoofdkostenplaats	900	Bijzonder verlof	Bijzonder verlof
935	Hoofdkostenplaats	900	Feestdagen	Feestdagen

Figure 19: UOL cost centre structure

The figure shows that all costs incurred for wood rot repair are booked under number 400 (‘Houtrotreparatie’). Since this has only been introduced recently, the total cost for wood rot repair in this project must be calculated manually. This was done by filtering all recorded costs for this project according to their affinity with wood rot. The result is an amount that is several hundred euros below what was initially budgeted.

4.5.1 Zutphen 243 properties - Conclusion

This example illustrates how increasing the knowledge of the state of the frame before the start of a project results in the project being carried out within or even under budget. Accurate insight into the state of the woodwork is therefore of great importance to be able to carry out a project within budget.

5. Results

This chapter present the most important findings. The chapter is divided into four parts. The first part discusses the set-up of BIM within the client organisation. In agreement with UOL, it has been decided to digitalise the wood rot inspection process using a combination of some of the initiatives discussed in the theoretical framework. In order to do this, it is important to understand the state of the paintwork applied to the wood (M. Wagtelenberg, personal communication, June 4th, 2021). The second part explains how BIM can be successfully implemented within the organisation. In the third part, the costs and benefits are weighed against each other. The final section describes the consequences of the above three steps at the company level.

5.1 BIM set-up

This part discusses the set-up of BIM within the client organisation. The necessary technical support was provided by Tricas. Tricas is an organisation that has specialised itself in product development. This section is sub-divided into seven steps. When it becomes too technical to fit within the framework of this study, reference will be made to the Appendix.

5.1.1 Paint deterioration process

The frequency of painting depends on many factors. Two well-known examples are the choice of colour and the treatment chosen. A heavier treatment (repainting twice instead of once) results in a thicker protective layer and therefore a longer maintenance cycle. Lighter colours absorb less heat, therefore cause the wood to swell and shrink less, and therefore require less maintenance than window frames painted in a darker colour. Other factors cannot be influenced directly, such as geographic location and design factors. Once the paint system has been applied, it is subject to many factors that accelerate its degradation. UV light is the most important factor, but factors such as salt and other substances in the atmosphere also play a role. Based on the above information, it may be assumed that there is a reasonable chance of wood rot when the gloss level of the applied paint system falls below 20 GU. This implies that window frames with a paint system of sufficient gloss level are not at risk. However, experience shows that this is not always true. A direct cause of this are open joints (Wagtelenberg, 2021). If these are present, it is possible that the paint system appears to be in good condition while wood rot is occurring from the inside.

Under the influence of many factors, a paint system degrades over time. How the theoretical life span of a paint system depends on several factors is illustrated by Wijzonol's life expactancy tool. This tool is therefore used to indicate when risk of wood rot starts to occur. The technical

lower limit of a paint system is 20 GU. In practice, however, this level is never achieved for the following two reasons: [1] there is an aesthetic requirement from the client, which states that the paintwork must achieve a minimum number of gloss units throughout the maintenance cycle or [2] the swelling and shrinking of the wood causes open joints to form, which retain moisture and consequently cause wood rot. Joints open more easily at 50GU. Therefore, 50GU is assumed to be the level at which the risk of wood rot is becoming real. To determine after which time interval this level is reached, the Wijzonol life expectancy tool is used. The interface of the tool can be seen in the following Figure.

Figure 20: Wijzonol life expectancy tool

The LBH SDT Ultra High gloss paint reaches the 50GU limit at around four and a halve years. Therefore, when using this lacquer under these conditions, no risk is expected in the first 4.5 operational years after the maintenance. After these four and a halve years, the sensors start measuring data. This is also the moment when part two of the solution is activated [5.2]

In short, for all colours and conditions it can (theoretically) be determined when a paint system loses its protective function. At this point in time the chance of wood rot becomes real. The next section focusses on capturing live data as input for the building information model. Note that this is a theoretical solution, i.e., the solution has not been implemented in a real-world situation. The description in this study functions as the blueprint for a possible implementation of the described findings.

5.1.2 Radio Frequency Identification (RFID)

Data can be stored on RFID tags but are not generated by RFID. Thus, RFID tags are used to store data. As described earlier by East and Brodt (2007), maintenance management requires *at least* the location, warranty duration and component supplier information. However, many more factors are known to increase the risk at wood rot. An overview of these factors is given in Appendix J. In the ideal situation, these factors are transparent for each wooden component. Below is a photo of a house facade as it is commonly made during an inspection for wood rot.

Figure 21: Back facade of house

Step one of creating a digital twin of an existing building consists of recording the fixed factors. These factors set the model parameters in a later stage. The gross of these factors can be deduced visually by a construction inspector. After all, the interviews have shown that this is also part of their job in the current situation. The inspector uses the table presented in Appendix J to note the property fixed factors. After these factors are noticed by an inspector, they are stored on the RFID tag and can be accessed via a phone with NFC chip. How this works can be seen in Appendix K. The big advantage of this system is that the data is always accessible through a

computer with an internet connection. By storing the obtained information in this way, there is also the possibility of easily adapting the data when it changes because of, for example, a major renovation. A passive RFID system is used to store the information. This means that the data is only sent if the user requests it. How this RFID tag is placed in the wooden building parts is shown in the image below.

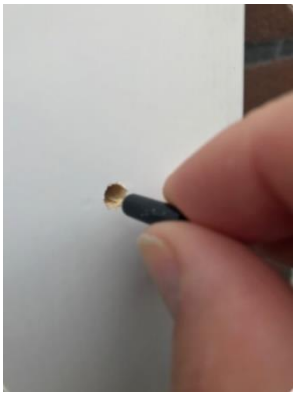

Figure 22: RFID-tag into wooden frame (Chipitall.nl, n.d.)

Figure 23 shows how an RFID tag in a 5 x 15-millimetre plastic shell is inserted into a wooden frame. Subsequently, the hole is plugged with a two-component paste to ensure that no moisture can get into the hole.

5.1.3 Digital model creation

The third step into setting up a BIM is to create a digital model. The data recorded is collected in the cloud (Appendix K). The reason for this is simple. The data that resulted from the inspection in step one is the input for the creation of a digital version of the facade. To do this, it is important to have access to the data via the internet. Many different software tools are available for creating digital 3D models. I propose to use Autodesk Revit to create a digital building mode. Autodesk Revit is Multidisciplinary BIM software for coordinated higher quality designs. Revit is preferred because of its compatibility with windows as well as the ability to generate data in different ways. A graphical representation of a property created in Revit can be seen in Figure 24.

Figure 23: Revit model of a single-family home

The next step is to integrate a sensor network into the digital model. This is described in section [5.2.3].

5.1.4 Wireless Network Sensor - Set up

As described earlier, Zhang (2017) mentions that a wireless sensor network consists of multiple low-cost sensors which are mainly used for measuring environmental factors such as temperature and humidity. The technical details of this network can be found in Appendix L. The purpose in this step is to collect data on temperature and humidity. Both the theory and the interview data showed that these two, in the presence of oxygen, can cause wood rot. The following conditions are imposed on the occurrence of wood rot (Verhaege, 2016):

- Fungi: wood moisture content > 20%, temperature $5 \leq T \leq 40$, time > 720 hours.
- Wood rot: wood moisture content > 25%, temperature > 5°C, time > 168 hours.

The Dutch climate naturally provides for this oxygen requirement. The other two variables are measured by sensors. However, measuring the values for these two variables is not sufficient. The next steps are discussed in the following sections.

5.1.5 Integrating BIM and NSW

Step five consists of processing the data obtained in the previous step. The data consists of measurements of the relative humidity and the temperature at pre-defined time slots. I recommended measure these values four times a day. Recording data more often has no added value. After all, once the pattern between day and night is known, the fluctuations within a single day are not significant. The data collected is pushed to a database hosted on a website. In this way the sensor data is accessible to facility managers over the internet. A snippet of what the collected data could look like can be seen in Appendix M.

The data displayed in Appendix M was hosted by purchasing a single web-based database in order to allow access from multiple computers. The first column shows the day on which the data was collected. The second column shows the year the data was collected in. Column three shows which sensor collected the data. It is important to note that only the data from the base sensors is shown here. These sensors are programmed to combine the data from the sensor nodes into an average. In this way one value is displayed per building component for each the humidity level and the temperature. The fourth column shows the time when this data was collected. Four measurements are taken per day, each with six hours in between. Column five shows the orientation of the facade. Column six indicates the weather side of the facade in question. Column seven shows the cluster to which the sensors belong and columns eight and nine give the numerical values for humidity and temperature respectively.

However, analysis of the interviews has shown that the ambient moisture content is not sufficient to make a prediction about the occurrence of wood rot. To be able to make a prediction about the occurrence of wood rot, the moisture content of the wood must be known. Thus, a requirement is to first translate the relative humidity percentage into the corresponding wood moisture percentage. This translation is described in detail in Appendix N. In addition to this translation, an algorithm must be implemented that automatically compares the data with the wood rot conditions presented in [5.1.4].

Both the literature and the interviews have shown that based on the fluctuations in temperature and the associated wood moisture percentage, a statement can be made about the occurrence of wood rot. How this prediction is made, is discussed in section [5.1.5].

5.1.6 Interpreting the results

In order to increase the ease of use of the designed network, the results will be made visible by means of colour indications within the digital Revit model. To keep the interpretation of the results simple, three colour schemes will be used. Based on the requirements for wood rot presented in [5.1.4] the following colour scheme has been developed.

Revit Colour Scheme				
Temperature	Wood moisture content	Time	Oxyegen Present	Colour
< 5 °C	<20 %	∞	Yes	
> 40 °C	<20 %	∞	Yes	
5 ≤ T ≤ 40	<20 %	≥ 720	Yes	
< 5 °C	>20 %	∞	Yes	
> 40 °C	>20 %	∞	Yes	
5 ≤ T ≤ 40	>20 %	≤ 720	Yes	
5 ≤ T ≤ 40	>20 %	≥ 720	Yes	
5 ≤ T ≤ 40	>25 %	≤ 168	Yes	
T > 5°C	>25 %	≥ 168	Yes	

Figure 24: Revit colour scheme

The colour indicates the state of the woodwork. A green colour indicates that nothing is wrong. An orange colour indicates the possibility of mould formation. A red colour indicates that conditions are such that wood rot may occur. A red colour indicates that the wood moisture content has been greater than 25 per cent for at least 168 consecutive hours. In fact, in this case one may assume that the woodwork has degraded to the extent that wood rot has either occurred or will occur soon.

Property maintenance companies should actively review the data they obtain from the above system. In RGS cooperation, attempts are made to extend maintenance cycles in order to save one or more maintenance jobs in the long term. For illustration, a property maintenance company has made large investments in year T to stretch the maintenance cycle to seven years. They receive daily information from the sensors about the condition of the window frames in this complex: Up to year four, there is no chance of wood rot. In year five, slight defects begin to appear. Now the company can choose to make a small repair in year five to possibly extend the cycle to eight or perhaps nine years. If they do not do this, they will almost certainly have to carry out major repairs in year seven. This example illustrates that each property maintenance company can make different choices based on the same information. How the result of this research can be expressed in terms of costs is discussed in section [5.3].

5.2 BIM Implementation

Successful implementation of BIM results in achieving the benefits as described in the theoretical framework. If the benefits are so great why isn't every company within the architecture, engineering, and construction (AEC) industry adopting BIM? As with the development of any system, costs must be incurred to generate revenue. Here, costs are defined as everything that is necessary to implement the described system into the organisation. Many organisations think of BIM implementation as costly and time-consuming. As this picture is not

correct in most cases, an implementation plan will be proposed in this section. This implementation discusses how the way of working changes and how the processes change.

However, to change the result, the process preceding it must also be changed. According to Yahya Al Ashmori *et al.* (2020) the first obstacle in the successful implementation of BIM is the lack of awareness about the technology. This obstacle has been removed by this study. After reading this research, the reader should be sufficiently aware of the existence and potential benefits of using BIM. Yahya Al Ashmori *et al.* also identified a significant relationship between the benefits of BIM and its implementation.

Implementing BIM within an organisation has significant effect on the firms' business model, processes and contractual policy. The respective consequences at company level are discussed in detail in section [5.4]. This section describes the three most important factors that apply to the successful implementation of BIM: [1] Personal commitment, [2] early involvement and [3] appropriate software tool (Yahya Al Ashmori *et al.,* 2020).

5.2.1 Personal commitment

Personal commitment is necessary for successful BIM implementation because it enables to trust each other and work closely together. Small to medium organisation (SMEs) often have numerous people working in the same environment. Often these people all have their own interests which do not always overlap with the interests of others. BIM can only be successfully implemented when everyone demonstrates commitment. In the case of UOL, this can be achieved by informing everyone of the advantages that BIM can offer for him or her. Means to achieve this can be training, but also taster days at companies that are already have successfully adopted BIM.

5.2.2 Early involvement

Following on from personal commitment is early involvement. In my view, early involvement is a means of achieving personal commitment. Involving staff in the implementation of BIM at an early stage creates a sense of commitment. Employees will feel responsible for the successful implementation of BIM and thus will do their best to make it happen. This is achievable at UOL by using the knowledge and skills of the staff. By letting them discuss the implementation with each other, for example during brainstorming sessions, the involvement will increase. Increasing the involvement of the employees increases the chance at successfully implementing BIM within the organisation.

5.2.3 BIM Software

Currently, there is no one within UOL that possesses extensive knowledge about BIM software. This makes it impossible to select the right software needed for a successful implementation. This problem can be solved by bringing the right knowledge into the organisation. Hiring a BIM expert is usually extremely expensive. An alternative solution is to hire a (graduating) student or intern. These are often able to acquire the right knowledge if they do not already have it. UOL could recruit a student or intern with a great affinity for construction-related software. Together with someone who facilitates personal involvement within a project team, this person can be made responsible for implementing BIM within the organisation.

5.3 BIM – Costs and benefits

Based on the theoretical framework, several advantages that the use of BIM can entail have already been identified. To confirm or disprove these benefits, this section examines the actual benefits and costs of using BIM.

5.3.1 BIM – Savings

The revenue from the above-described system [5.1.1 up till 5.1.6] can be divided into several categories. The direct result of this research is equal to the risk margin included in the calculations for wood rot. This margin is often set at 15 percent of the total budgeted amount for wood rot. Because the state of the woodwork is exactly clear after the implementation of BIM, it is no longer necessary to include a risk percentage for wood rot in the quotations. In short, 15 percent of the total item budgeted for wood rot repair is left over and can be spent elsewhere. To complete the net result, add the costs that would be incurred to perform more/less work due to the lack of insight into the state of the wooden building components.

Thus, the net result of this study is equal to all costs that must be incurred if the state of the woodwork is not 100 percent transparent. This includes [1] the execution of additional/less work; in the case of the project discussed in section [4.4] this equals 17,549.17 EUR and [2] risk margins that must be included because of this lack of transparency; 15 percent of the total budgeted amount for wood rot. These two added together equals 22.351,32 EUR. It is important to note that this result can only be achieved in case the proposed BIM system is 100 percent accurate. In practice, this amount is likely to be lower. It is also important to state explicitly that this amount is linked to the project described in section [4.4]. In short, a different project would most likely have led to a different result. Thus, the net result of this research depends on the accuracy with which a project is carried out.

5.3.2 BIM - Costs

In describing the costs, a distinction has been made between the material costs and the labour costs. First, the material costs associated with implementing the above-described system will be outlined.

Material cost

For illustration, it is assumed that the system is applied to an existing complex. This complex is located on the Gerard ter Borgstraat in Deventer and comprises 41 residential units. The complex is maintained on behalf of housing corporation Ieder1. Before actual measurements are carried out, an estimate is made of the degradation curve of the paint. To do this, the life expectancy tool of Wijzonol is used. Since this is a permanent partner of UOL, this tool can be used free of charge. Within the complex 41 RFID tags will be placed. The inspection results for each house are stored on these tags. A micro-RFID tag small enough to fit in the plastic case with a storage capacity large enough to hold all the data is on sale for EUR 1.56. 41 times 1.56 EUR equals 63,96 EUR.

The houses on Gerard ter Borchstraat have an average of five wooden frames per house. This means that a total of 5 times 41 times 2 is 410 sensors are required. With a unit price of EUR 1.57, this amounts to a total of EUR 643.7. To install the sensors, a hole must be drilled just beyond the glass line. A two-component paste is used to close this hole after placing the case with the sensors. It is assumed that this price corresponds to the cost price of a small paste repair, i.e., EUR 30.27. This price includes labour costs. The price is then multiplied by the number of holes to be drilled, equalling a total of 12.410,7 EUR. The second last item that can be placed under the heading of material costs is the price of a server-hosted database with algorithms included. A database is needed to process and the sensor measurements. Because the implementation of the system is still in its infancy, I recommend using the BigML lite version. One server with eight users costs 10.000 EUR. Lastly, developing a Building Information Model to monitor the condition of the window frames in the operational phase of the residential unites is done with the help of Autodesk Revit. The cost price for this is 1040 EUR. The table below gives an overview of all material costs related to the implementation of the system described in this study.

Material	**No.**	**Unit price**	**Total cost**

Life expectancy tool	1	Free	Free
RFID tag	41	€ 1.56	€ 63,96
Sensor	410	€ 1.57	€ 643.7
Pasta repair	41	€ 30.27	12.410,7
Database	1	€10.000	€10.000
BIM model	1	€1040	€1040
Total			**€24.158,36**

Table 5: Total material cost for system implementation

Labour cost

The number of hours required to implement the sensor solution in this complex has been estimated. Since the user receives a notification in case of risk of wood rot, no employee needs to be actively involved in monitoring the data. In other words, only the installation of the sensors in the window frames requires active labour. Since this concerns an existing complex, this will take more time than when the sensors are placed in the window frames at the factory. The time required for measuring, drilling the hole, placing the sensor, and sealing it with a two-component paste is estimated at 20 minutes. The standard rate for construction workers is 55 euros per hour. This means that the labour cost for the installation of one sensor amounts to 18,33 EUR. If we multiply this by the number of sensors to be installed, this brings the total amount to 7.516,67 EUR labour costs. If we add the material costs to this, the total cost of implementation comes to 31.675,03 EUR.

5.3.3 Break-even point

With the above costs and savings, it is possible to calculate a so-called break-even point. Please note that this break-even point also depends on the project. The savings that can theoretically be achieved with this system amounted to 22.351,32 EUR. Especially in the first implementation phases, there will be a (small) margin of error. The assumption is that the system will be able to identify 90% of all existing wood rot defects. This assumption is based on the accuracy of the sensors and the placement of the sensors: In a number of exceptional cases, wood rot will not occur in the bottom corners but in a different place. The expected saving is therefore 20.116,19 EUR. This is the saving when the project from section [4.4] is serviced in the next cycle based on the data logged by the sensors. Implementation of the system in a complex with 41 residential units costs 24.158,36 EUR.

$$Break - even = \frac{24.158{,}36}{20.116{,}19} = 1.2$$

In other words, after 1.2 maintenance cycles, more has been saved than the cost of implementing the system. Assuming a standard RGS maintenance interval of seven years, the break-even point is reached after 8.4 years.

5.4 BIM – Organisational consequences

The operational purpose of implementing the previously described system is to be able to offer premium quality maintenance plans. Implementing BIM in combination with sensors for data input facilitates the emergence of several additional operational benefits. The transparency of all existing defects ensures that no more or less work is done on wood rot repairs. This has direct consequences for the planning of available capacity. Employees can be planned much more efficiently because the amount of work to be done is precisely known. Other operational benefits come from the elimination of human effort. The inventory of existing wood rot damages as well as the monitoring of the condition of the window frames is done automatically. Until now, the execution of this was in the hands of the employees. The time they needed for this can now be spent on other activities. As briefly described, the implementation of BIM primarily affects three business processes (Yahya Al Ashmori *et al.*, 2020). These processes and their consequences are described below.

5.4.1 New Business Model

The goal of the client company is to increase turnover by differentiating from its competitors. As already described, differentiation takes place through the application of a combination of several digitalization techniques. According to Porter (1980) differentiation leads to a competitive advantage aimed at a broad target group.

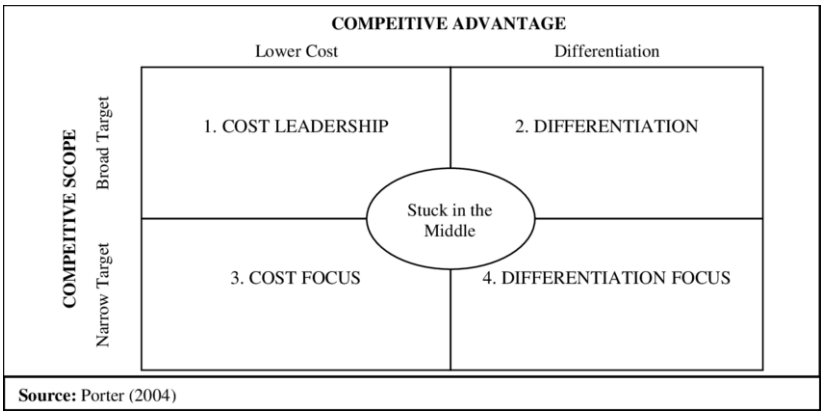

Figure 25: Porter's four generic strategies (Porter, 1980)

In Appendix H, UOL's current business model, as prepared by its own director, is displayed. They, up to a certain extent, have differentiated their value proposition compared to their direct competitors. Whereas direct competitors often enter one-off partnerships driven purely by low prices, UOL enters into long-term partnerships that are primarily focused on long-term results [1.2]. However, the existing business model does not match the differentiation strategy they want to adopt. Applying the digitalization system described earlier enables UOL to offer a differentiated value proposition to its customers. Following is the step-by-step construction of the differentiated value proposal of UOL (Peer, 2017).

Step 1. What do customers really care about?

UOL's customers choose quality, trust, loyalty and transparency over lowest price. Customers appreciate the long-term collaborations. In this way, they are assured of a reliable organization that performs maintenance on their real estate. Customers often see the three generations of craftsman ship within UOL as the foundation for good quality. UOL's key customers find transparency increasingly important. Because tenants' money is used to finance maintenance projects, customers must be able to explain to tenants what their money is used for. To be able to do this, they expect to be told in advance by the maintenance partner carrying out the work exactly what it is going to do.

Step 2. Where is your market headed?

Housing corporations and other property owners are coming under increasing pressure to handle property responsibly. For example, housing corporations must be transparent with their tenants about what they use their money for. Sustainability will also play an increasingly important role in the future. Making real estate more sustainable often involves high investments. Customers want advice on when and how best to meet this sustainability requirement.

Step 3. Define attributes

In order to provide quality that exceeds that of direct competitors, UOL must use a combination of several digitalization techniques. By implementing BIM along with a network of wireless sensors, UOL obtains real-time insight into the condition of wooden components. Based on this information, they can then create their maintenance plans or modify existing maintenance plans.

Step 4. Define differentiated value proposition

Using wireless sensor networks integrated into BIM, UOL creates premium quality maintenance plans. Premium quality in terms of:

- Always ensuring the agreed standards of quality.

- Understanding the exact maintenance costs per year.
- Real-time insight into the current state of woodwork.
- Transparency with respect to the expenditures made by the maintenance party.

Maintenance companies that can offer these premium quality contracts can expect to be in great demand from the market they are operating in. Maintenance companies that can differentiate their offerings at an early stage can set the new industry standard. Margins of error become redundant due to the real-time insight into the condition of the wooden window frames. Companies that do not go along with this change may lose a part of their customer base to parties that do. Early implementation of the system described in section [5.1] can also lead to brand recognition and brand loyalty. The exact impact of this is unknown at this stage. Future research must provide more clarity on this. The second business process impacted by the implementation of BIM is discussed in the next section.

5.4.2 Contractual policy

The differentiated value proposition discussed above can potentially lead to offering new forms of contracts. Dutch housing corporations are ranked based on the so-called Aedes benchmark. In this list, corporations are assessed on: [1] tenant evaluation, [2] company grid, [3] sustainability and [4] maintenance & improvement. Hereby the different corporations are subdivided since the number of rental houses they own. A snippet of the Aedes benchmark 2020 can be seen in the Figure below.

lnummer	naam	Huurdersoordeel	Bedrijfslasten	Duurzaamheid	Onderhoud & verb	Provincie	Grootteklasse	Letter Huurders oordeel	Huurders oordeel nieuwe huurders	Letter huurders oordeel nieuwe huurders	Huurders oordeel reparatie verzoeken	Letter huurders oordeel reparatie verzoeken	Huurders oordeel vertrokken huurders	Lettter huurders oordeel vertrokken huurders	Letter bedrijfs lasten	Bedrijfs lasten € per vhe	Letter duurzaamheid
L0003	Stichting Wonen Noordwest Friesland	B	A	C	B	Friesland	2.501-5.000 vhe's	B	8,2	A	7,4	C	8,1	A	A	729	C
L0008	Stichting Openbaar Belang	A	B	A	B	Overijssel	2.501-5.000 vhe's	A	7,8	B	8	A	7,7	B	B	839	A
L0013	Stichting Zayaz	C	A	A	B	Noord-Brabant	10.001-25.000 vhe's	C	7,7	B	7,3	C	6,9	C	A	775	A
L0017	Woningstichting Rochdale	C	C	C	B	Noord-Holland	> 25.001 vhe's	C	7,7	B	7,1	C	7,4	B	C	1077	C
L0019	Stichting Intermaris	B	A	A	C	Noord-Holland	10.001-25.000 vhe's	B	7,7	B	7,9	B	8	A	A	780	A
L0029	Stichting deltaWonen	A	A	A	B	Overijssel	10.001-25.000 vhe's	A	8	B	8,3	A	7,6	B	A	687	A
L0033	Stichting voorheen De Bouwvereniging	B	B	B	B	Friesland	1.001-2.500 vhe's	B	7,7	B	7,6	B	6,7	C	B	819	B
L0036	Stichting Lyaemer Wonen	B	A	A	A	Friesland	2.501-5.000 vhe's	B	8	B	7,6	B	8,3	A	A	686	A
L0041	Stichting Bo-Ex '91	C	C	B	B	Utrecht	5.001-10.000 vhe's	C	7,1	C	7,2	C	7,5	B	C	1019	B
L0045	Stichting Domesta	B	B	B	B	Drenthe	10.001-25.000 vhe's	B	7,9	B	7,8	B	7,7	B	B	855	B
L0059	Stichting Parteon	C	A	C	B	Noord-Holland	10.001-25.000 vhe's	C	7,3	C	7,5	C	7,4	B	A	708	C
L0063	Woningstichting Van Alckmaer voor Won	B	B	A	B	Noord-Holland	2.501-5.000 vhe's	B	8,4	A	7,6	B	8,7	A	B	785	A
L0065	Stichting Volkshuisvesting Arnhem	C	A	C	B	Gelderland	10.001-25.000 vhe's	C	7,4	C	7,2	C	7	C	A	638	C
L0077	Stichting Wold en Waard	B	A	C	B	Groningen	2.501-5.000 vhe's	B	8,1	A	7,8	B	7,8	B	A	682	C
L0079	Stichting Woonstad Rotterdam	B	A	A	B	Zuid-Holland	> 25.001 vhe's	B	8,4	A	7,7	B	7,9	A	A	770	A
L0081	Stichting Wonen Zuid	C	B	C	B	Limburg	10.001-25.000 vhe's	C	7,7	B	7,4	C	7,5	B	B	785	C
L0082	Stichting Krijtland Wonen	B	B	B	A	Limburg	1.001-2.500 vhe's	B	7,9	B	7,9	B	7,1	C	B	860	B
L0089	l'escaut woonservice	A	C	A	A	Zeeland	5.001-10.000 vhe's	A	7,9	B	8,3	A	7,8	B	C	954	A
L0093	Woningstichting SWZ	A	A	B	A	Overijssel	5.001-10.000 vhe's	A	7,6	B	8,3	A	7,7	B	A	657	B
L0108	Woningstichting Eigen Haard	B	A	C	B	Noord-Holland	> 25.001 vhe's	B	7,6	B	7,9	B	8,1	A	A	764	C

Figure 26: Aedes benchmark results for 2020

A letter is assigned to each of the four categories with A being the top score and C the lowest possible score. In the second last column the charges per lettable unit per year are shown. Not shown in the illustration, but the 25th column indicates the price at which a lettable unit can be

maintained for a period of 5 years. This benchmark shows that there are many housing associations that, despite high maintenance costs per unit, do not score well on one or more of the criteria mentioned. This fact together with the differentiated value proposition as discussed earlier provides an opportunity to draw up a new form of contract, namely: The maintenance of a rentable unit at a fixed, pre-agreed price per month or per year. Data from the sensors should show what is spent on wood rot. In fact, this is the lower price limit of the new contract. The upper price limit is equal to the cost that the housing corporation pays in the current situation to maintain its rentable units. With this information, it is possible for the maintenance partner to offer the following new contract type: Premium quality contracts. In these new contracts the maintenance partner offers premium quality maintenance plans at a surcharge. By applying digitalization techniques, the quality of the maintenance plans is higher compared to traditional plans. The maintenance partner can therefore charge a higher fee for this.

5.4.3 Processes

Implementing BIM has several consequences for existing processes within the organisation. [1] The inspection for wood rot is gradually disappearing. The more complexes are equipped with digital twins, the fewer wood rot inspections need to be carried out. A first follow-up step is to launch a pilot project. This project should either disprove or confirm what is claimed in this study. The wood rot inspection process also switches from active to passive. The system warns the user when there is a risk of wood rot. In this way, the maintenance partner can use the available workforce capacity much more effectively. [2] The BIM model can be expanded in such a way that other processes can also be optimised through its use. Theoretically it is possible to digitise the entire outer shell of a building. To this end, the maintenance party should investigate which factors influence which processes and in what capacity. [3] The implementation of BIM facilitates further digitalization within the organisation. A good example is simulation. If the outer shell of a structure is fully digital, it is possible to simulate it. By recreating real world examples, it is possible to find out exactly what damages will occur in the future.

6. Conclusion and discussion

First, section [6.1] discusses the main findings to answer the research questions as described in section [1.3]. Secondly, section [6.2] elaborates on the most important limitations regarding this research. Lastly, the most important avenues for future research are described.

6.1 Main findings

This study provided a detailed description on how a maintenance company can use digitalization techniques to support new asset management value propositions. In order to answer the main research question, the four sub-questions will first be answered below.

[1.1] *What is asset management?*

Based on the literature, it is possible to answer this question as follows. Asset management is the concept of balancing performance, risks, and costs in order to achieve an optimal maintenance plan. Traditionally, the owner of the physical object is responsible for its maintenance. Owners often contracted once with the maintenance party that could perform work at the time for the lowest price.

[1.2] *What is digitalization?*

Based on the theory presented in this study, digitalization is a facilitator for the provision of new products and services. These products and services not only provide an organization with greater economic value but are also important from a strategic perspective. Digitalization is a major driving force within the construction industry for the following two reasons. [1] Digitalization techniques allow for better building performance and can thus contribute to making real estate more sustainable to meet the set climate targets. [2] The industry in which property maintenance partners operate is one with very low margins. These low margins encourage the search for ways to further reduce costs. According to the theoretical framework, digitalization is ideally suited to do this.

[1.3] *What is business model innovation?*

Based on the results presented in this study, business model innovation is adjusting the value proposition in such a way that it provides an organisation with long-term sustainable competitive benefits. Business model innovation should go hand in hand with successfully adopting one of the four generic strategies as presented by Porter. If an organisation's strategy is to differentiate itself from its competition, then the value proposition will also need to be adjusted accordingly. Innovating a value proposition can be done by answering the following

four questions. [1] What do customers really care about? [2] Where is your market headed? [3] Define attributes. [4] Define innovated value proposition. From the perspective of this research, does the adoption of a differentiation strategy by the client company lead to the ability to offer a premium quality value proposition.

[1.4] *How can digitalization support new asset management value propositions?*

Successful implementation of a combination of digitalization techniques known in the construction industry can facilitate the implementing organisation adopt a differentiation strategy. The organization in this case can differentiate because they have attributes at their disposal that allow them to offer a value proposition that excels in quality over the direct competition. The application of various digitalization techniques and thus increasing the quality of the maintenance plans offered manifests itself in the following four ways: [1] By implementing NSW and BIM, the maintenance partner can always guarantee the agreed quality. [2] Understanding the current condition of the woodwork allows the maintenance partner to create detailed maintenance plans. In this way, the customer always knows exactly what maintenance costs need to be paid. [3] Because it is clear to the customer exactly which maintenance measures will be applied, it is easier for the customer to provide transparency about how tenants' money is spent. Because the maintenance partner has real-time insight into the condition of the property, it is possible to shift the risk from the customer to the maintenance partner. In return, the maintenance partner can charge a premium price for this. Thus, implementation of digitalization techniques facilitates the provision of alternative contract forms.

Answers to the above four sub-questions facilitate answering the main research question below.

[1] *How can a maintenance company innovate its businessmodel using digitalization?*

Successful implementation of Building Information Modelling with a network of different sensors integrated into it, facilitates offering new, long-term contracts to customers. The consequence of this is twofold. [1] The maintenance partner, UOL in this case, can optimise the maintenance process by means of digitalization. Real-time insight into the current state of the property, following from the use of BIM and environmental sensors, allows for the creation of premium quality maintenance plans. Premium quality because the plans offer the following benefits to customers. [1] Always ensuring the agreed standards of quality, [2] understanding

the exact maintenance costs per year, [3] real-time insight into the current state of woodwork and [4] transparency with respect to the expenditures made by the maintenance party. UOL its market position by providing a unique and attractive value proposition to its customers. [2] By implementing a BIM integrated wireless sensor network, maintenance parties can reduce costs. Whereas inspecting wooden components used to be a manual process, it has now become an automated passive process. As a result, less labor is required and thus the costs for this process are reduced. On top of that, the costs caused by inaccuracies in a manual inspection are overcome by applying the digital solution described in this study. Finally, smart scheduling of maintenance intervals can ensure that the frequency and therefore the cost of maintenance is reduced.

Thus, maintenance companies can innovate the value proposition by offering long term contacts to customers. In these contracts they take over the risks and thus unburden the customer. They can take the risk because of the application of wireless network sensors. At the same time the maintenance partner can reduce costs because the frequency of maintenance activities can be lowered by smartly scheduling maintenance intervals. The premium quality offering in combination with lower costs strengthens the market position of maintenance companies.

6.1.1 Findings – theoretical perspective

From a theoretical perspective, this research contributed to the gap in literature identified by (Kazado *et al.,* 2019). They argued that there is no literature available that discusses how BIM can be used to monitor real-time building performance in the operational stage. This study fulfils this gap by describing how integrating a Wireless Sensor Network into a successfully implemented BIM model can be used to monitor real-time building performance in the operational stage.

6.1.2 Findings – practical perspective

From a practical perspective this study has contributed by providing a blueprint for the implementation of BIM that can be used as a tool for business model innovation. By digitally measuring the values of the factors that cause wood rot, the maintenance partner has insight into the current state of the window frames at any time. Having insight into the current state of the window frames always results in the maintenance partner being able to offer premium contracts.

6.2 Limitations

After critically reviewing this study, several implications can be made. First, the assumption is made that when quality levels are increased, customers are automatically willing to pay a

premium. This is only true under certain circumstances. The customer should be aware of the benefits it gets for paying a premium price. Thus, an additional marketing campaign needs to be set up to promote the premium quality maintenance plans because of applying digitalization techniques.

Secondly, the economic value as presented in section [5.3.3] could be achieved by implementing the system in the project described in section [4.4]. A different project would have led to a different result. To make the results generalizable, an average amount of savings should be calculated over all projects performed. The same applies to the risk margin that is included in the calculations.

Thirdly, the research in its current form does not quantify the change in turnover due to differentiation of the value proposition. For this reason, its value has been completely disregarded up till now. Thus, his research has not examined the numerical impact on turnover by applying digital techniques.

Fourthly, implementation of BIM has only been researched for one organisation. To get a more reliable result, the sample size should be increased.

Lastly, the digitalization proposal as described in this study has not (yet) been implemented. Because no measurements have been made, no justified statements can be made about the reliability of the model proposed in this research.

6.3 Avenues for future research

Based on this study and the limitations, a number of recommendations can be made. To overcome potentially detrimental consequences on the validity of this study, I recommend implementing the methodology described in this research. The results from the implementation of this study should then be compared with those from manual measurements. Thus, the wood moisture content obtained by translating the ambient moisture content measured by the sensor into a wood moisture content should be compared with measurements taken with a manual wood moisture meter. The same applies to temperature measurements. Based on this comparison, it is possible to make a statement about the validity of the proposed method.

Secondly, future research should be aimed at maximizing the benefits from using Building Information Models during the operational stage of buildings. This research shows how a combination of a BIM model with a wireless sensor network can be used to gain insight into the current state of wooden components. Future studies should put focus on how other types of supportive technologies can be implemented in a BIM model. Ideally, the entire life cycle of a

building and/or individual components can be simulated to determine in advance when maintenance is required.

Thirdly, building on the above-described point, the opportunities that arise at the strategic level as a result of optimisation at the operational level must be examined. Section [5.4] already described the strategy level consequences of the wood rot optimisation. Future research must unravel what it takes to agree with the client on a fixed maintenance price per residential unit.

Lastly, a market survey must be executed to align the offerings proposed in this research with the market needs. Key customers should be involved in fine tuning the offerings resulting from this research. In this way, it will be necessary to examine for which contracts there is possible demand from the market.

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Appendix A: An Interview Guide

Gaining insight into the wood rot inspection process within construction industry

Introduction: Welcome and explanation of the interview session

1. Welcome the interviewee and thanking them for participation and tell them that the interview will take about 30-60 minutes

2. Informing them about their rights and the audio-recording:

- **Right to withdraw** from the interview at any time without giving a reason
- **Audio-recording** via small device (Mobile phone), audio-recorded will later be **transcribed**
- In transcription, the data will be completely **anonymized**
- You talk about your team members today, but it doesn't matter if you mention their names. These names will be made anonymous later so that's no problem at all (same for company names, places, etc., so for all identifying information)
- **Confidentiality**, because nothing that is said here will be shared with anyone outside of the research team, in a way that it points to a certain person, company, etc.

3. Introducing the topic to the interviewee

"In this interview today, we are going to look at the inspection process regarding wood rot. This will involve mapping out the process from start to finish. The first part of the interview will focus on how the inspection is conducted. Mainly of interest are the methods that are used, the tools but also the choices and considerations that are made during such an inspection. The second part focuses on translating the inspection into the right repair. How is it determined which measure is needed and how often does this measure turn out to be inadequate afterwards? It is important here that you give the answers from your own experience. It is not the intention to answer with how it should be done on paper but how it happens in practice".

"In dit interview vandaag gaan we kijken naar het inspectie proces omtrent houtrot. Hierbij zal het proces van begin tot eind in kaart worden gebracht. Het eerste deel van het interview is gericht op het uitvoeren van de inspectie. Voornamelijk van belang zijn de methoden die worden gebruikt, de gereedschappen maar ook de keuzes en afwegingen die men maakt bij zo'n inspectie. Het tweede deel is gericht op het vertalen van de inspectie naar de juiste reparatie. Hoe wordt bepaald welke maatregel nodig is en hoe vaak blijkt deze maatregel achteraf niet afdoende te zijn? Het is hierbij belangrijk dat je de antwoorden geeft uit eigen ervaring. Het is dus niet de bedoeling dat er wordt geantwoord met hoe het op papier zou moeten gaan maar juist met hoe het in de praktijk gebeurt".

Interview questions derived from the research question: *How is the human aspect reflected in the inspections? What makes one inspection better than another? How is it determined what constitutes a good inspection? What is the impact of inspections on the maintenance to be performed?*

The actual interview: Asking open questions to the interviewee in four parts

1. Part A: General Wood rot inspection – In the first part of this interview I would like to receive some more information about the inspection process. How is it carried out and with what tools?

- What are your main daily activities?
- To what extent does wood rot play a role in performing these activities?
- How does the inspection for wood rot take place in the current situation?

- What difficulties do you experience in conducting this inspection?
- How do you deal with these difficulties in the current situation?
- Are there any tools available to overcome these difficulties?
- How do you think this process could be simplified given the problems you are experiencing in the current situation?

1. Part A: Algemene houtrot inspectie – In het eerste deel van dit interview ontvang ik graag wat meer informatie over het houtrot inspectie proces. Hoe wordt deze uitgevoerd en welke gereedschappen zijn hiervoor beschikbaar?

- Wat zijn uw belangrijkste dagelijkse werkzaamheden?
- In hoeverre speelt houtrot een rol bij het uitvoeren van deze werkzaamheden?
- Hoe vindt de inspectie naar houtrot plaats in de huidige situatie?
- Welke moeilijkheden ervaart u in het uitvoeren van deze inspectie?
- Hoe gaat u in de huidige situatie om met deze moeilijkheden?
- Zijn er instrumenten beschikbaar om deze moeilijkheden te verhelpen?
- Hoe kan volgens u dit proces vergemakkelijkt worden gezien de problemen die u in de huidige situatie ervaart?

Part B: Wood rot repair – After performing a wood rot inspection, its findings must be translated into the appropriate repair work. I would like to find out how this happens and what factors play an important role in this.

- How is it determined which repair options are adequate?
    - What considerations are involved?
    - How often does the measure taken prove inadequate?
    - To what extent is the answer to question 8c attributable to inaccurate detection?
- From a planning perspective, how is wood rot repair handled?
    - How often does planning based on inspection turn out to be incorrect?
    - Is too much or too little capacity scheduled for a repair?

Part B: Organisatie verschillen – Na het uitvoeren van een inspectie moeten de bevindingen hiervan vertaald worden naar de juiste reparatiewerkzaamheden. Ik wil er graag achter komen hoe dit gebeurt en welke factoren hierbij een belangrijke rol spelen.

- Hoe wordt bepaald welke reparatie mogelijkheden voldoen?
    - Welke afwegingen zijn hierbij van belang?
    - Hoe vaak blijkt de getroffen maatregel niet voldoende te zijn?
    - In welke mate is het antwoord op vraag 8c toe te wijden aan een onnauwkeurige detectie?

- Hoe wordt er vanuit planning-technisch perspectief omgegaan met de reparatie van houtrot?
    - Hoe vaak blijkt een planning op basis van de inspectie niet juist?
    - Wordt er te veel of juist te weinig capaciteit ingepland voor een reparatie?

Part C: Detailed wood rot inspection – Using the following questions, I would like to gain insight into the detailed process. I am particularly curious about the deviations and the possibilities that you see with respect to improving this process.

- Can you provide a detailed description of the wood rot detection process?
    - What steps do you take in this process and what are the results?
    - How do you document these results?

    - What is the time frame in which this entire process takes place?
    - How accurate is the current process?
    - What difficulties, if any, do you face in carrying out this process?
- What are the most common deviations in the above process?
- How is it ensured that the agreed quality requirements can be guaranteed?
- Which components are most often subject to wood rot?
    - Regarding the frame, how is the type of frame determined?
    - How is it determined if it is just the style, sill or both parts?
- Do you have any ideas on how this process could be optimized? Considering your own needs
- What is the consequence of shortcomings in the process described earlier?
    - How is this effect visible at the back end of the process?
- Are there concrete figures available on the cost of inaccurate detection?
- To what extent does the cause of wood rot play a role?
    - How is it determined whether wood rot originated from the inside or the outside?

Part C: Gedetailleerde houtrot inspectie – Aan de hand van de volgende vragen zou ik graag inzicht verkrijgen in het gedetailleerde verloop van het proces. Hierbij ben ik met name benieuwd naar de afwijkingen en de mogelijkheden die u ziet met betrekking tot het verbeteren van dit proces.

- Kunt u een gedetailleerde omschrijving geven van het houtrot detecteer proces?
    - Welke stappen onderneemt u hierin en wat zijn de resultaten?
    - Hoe documenteert u deze resultaten?
    - Wat is het tijdsbestek waarin dit gehele proces plaats vindt?
    - Hoe nauwkeurig is het huidige proces?
    - Welke moeilijkheden ondervindt u zoal bij het uitvoeren van dit proces?
- Wat zijn de meest voorkomende afwijkingen in het hierboven genoemde proces?
- Hoe wordt ervoor gezorgd dat de afgesproken kwaliteitseisen gewaarborgd kunnen worden?
- Welke onderdelen zijn het vaakst onderhevig aan houtrot?
    - Wat het kozijn betreft, hoe wordt vastgesteld om welk type kozijn het gaat?
    - Hoe wordt vastgesteld of het gaat om alleen de stijl, dorpel of beide onderdelen?
- Heeft u een idee over hoe dit proces geoptimaliseerd zou kunnen worden? Gezien vanuit uw eigen behoefte
- Wat is het gevolg van tekortkomingen in het eerder beschreven proces?
- Hoe wordt dit effect zichtbaar aan de achterkant van het proces?
- Zijn er concrete cijfers beschikbaar over de kosten die onnauwkeurige detectie met zich meebrengt?
- In hoeverre speelt de oorzaak van houtrot een rol?
    - Hoe wordt bepaald of houtrot ontstaan is van binnen of van buiten uit?

Part D: Detailed repair – Through the questions below, I wish to gain insight into the technical side of repairing wood rot. I'm also curious about the effect of incorrectly carrying out the right repair or carrying out the wrong repair correctly.

- What types of measure are available for repairing wood rot?
    - What is the cost of these measures?
    - What is the time frame for these measures?
- How is it determined which measure is necessary for repair?
    - What considerations are involved?
    - How often does the measure taken prove to be inadequate?
    - To what extent is the answer to question 8c attributable to inaccurate detection?
- How is the composition of surrounding wood determined?

    - What is the importance of determining this composition?
- What are the implications of any deviations in the survey plan?

Part D: Gedetailleerde reparatie – Door middel van onderstaande vragen wens ik inzicht te krijgen in de technische kant van het repareren van houtrot. Ook ben ik benieuwd naar wat effect is van het verkeerd uitvoeren van de juiste reparatie of het juist uitvoeren van een verkeerde reparatie.

- Welke typen maatregel zijn er beschikbaar voor het verhelpen van houtrot?
    - Wat kosten deze maatregelen?
    - Wat is het tijdsbestek van deze maatregelen?
- Hoe wordt bepaald welke maatregel noodzakelijk is ter reparatie?
    - Welke afwegingen spelen hierbij een rol?
    - Hoe vaak blijkt de getroffen maatregel niet voldoende te zijn?
    - In welke mate is het antwoord op vraag 8c toe te wijden aan een onnauwkeurige detectie?
- Hoe wordt de samenstelling van omringend hout bepaald?
    - Wat is het belang van het bepalen van deze samenstelling?
- Wat zijn de gevolgen van eventuele afwijkingen in het onderzoeksplan?

Part E: Extras – These questions were added in a later stadium after consultation with the client company. The questions cover multiple aspects of the inspection process. The added value lies in the fact that the relationship between the performer and its clients is now being investigated.

- What type of measures are there to address wood rot and what do they cost?
- How does a professional go about what does he do in this case?
- Which measure is chosen in which situation?
- What are the consequences in deviations from the maintenance plan?
- How do you determine what type of window frame you are dealing with?
- How do you determine whether it is just a doorframe or a style?
- Where exactly is the wood rot? But also, the composition of the wood around it.
- Project managers deal with the planning, how do you plan time for wood rot repair?
- Wood rot from the inside or from the outside?
- Deviations at the front: how to work out the budgeting at the back? If sills are not ready, carpenters can't get to work, for example.
- Ceiling amount: risk because everything has not been seen, fixed price, 100 is the maximum if it is 90 you get change.
- Client: What do you require from the property manager?

Part E: Extra's – Deze vragen zijn in een later stadium toegevoegd na overleg met de opdrachtgever. De vragen bestrijken meerdere aspecten van het inspectieproces. De toegevoegde waarde ligt in het feit dat nu de relatie tussen de uitvoerder en zijn opdrachtgevers ook wordt onderzocht.

- Wat voor maatregelen zijn er om houtrot aan te pakken en wat kosten die?
- Hoe gaat een vakman in dit geval te werk?
- Welke maatregel wordt in welke situatie gekozen?
- Wat zijn de gevolgen bij afwijkingen van het onderhoudsplan?
- Hoe bepaal je met welk type kozijn je te maken hebt?
- Hoe bepaal je of het alleen om een deurkozijn gaat of ook om een stijl?
- Waar zit precies het houtrot? Maar ook de samenstelling van het hout eromheen.
- Projectleiders houden zich bezig met de planning, hoe plan je tijd in voor houtrot reparatie?
- Houtrot van binnenuit of van buitenaf?
- Afwijkingen aan de voorkant: hoe werk je de budgettering aan de achterkant uit? Als dorpels niet klaar zijn, kunnen timmerlieden niet aan de slag, bijvoorbeeld.

- Plafondbedrag: risico omdat alles niet gezien is, vaste prijs, 100 is het maximum als het 90 is krijg je wisselgeld.
- Opdrachtgever: Wat verlangt u van de vastgoedbeheerder?

Debriefing: The end of the interview

“We have now come to the end of this interview, and I would like to thank you very much for all the information you have been willing to share with me. I’m planning to interview some of your colleagues too. Therefor I would kindly ask you not to share any information about this interview with them. In this way, I try to maximise the reliability of the outcomes.

As I have already explained, my next step will be to transcribe the interviews to be able to analyse the data provided. During the transcription, the entire interview will be made anonymous. Names of organisations and colleagues have been mentioned, but everything that has been said will then no longer be relatable to individuals, companies, etc. The information will not be distributed outside the research team.

Do you have any further questions for me? If you have a question later, you can contact me.”

"We zijn nu aan het einde gekomen van dit interview en ik wil u hartelijk danken voor alle informatie die u bereid bent geweest met mij te delen. Ik ben van plan om ook enkele van uw collega's te interviewen. Daarom wil ik u vriendelijk willen verzoeken om geen informatie over dit interview met hen te delen. Op deze manier probeer ik de betrouwbaarheid van de uitkomsten te maximaal te houden

Zoals ik reeds heb uitgelegd, zal mijn volgende stap de transcriptie van de interviews zijn om de aangeleverde gegevens te kunnen analyseren. Tijdens de transcriptie zal het gehele interview geanonimiseerd worden. Namen van organisaties en collega's zijn wel genoemd, maar alles wat gezegd is zal dan niet meer te relateren zijn aan personen, bedrijven, etc. De informatie zal niet buiten het onderzoeksteam worden verspreid.

Heeft u nog vragen voor mij? Als u later nog een vraag heeft, kunt u contact met mij opnemen."

Appendix B: Interview transcript respondent V (Henk)

Question 1. *How often do you encounter wood rot?*

You come into contact with it a lot during an inspection and it is a tricky business.

Question 2. *How does wood rot affect your daily work?*

With an inspection, you often can't get to everything, but you can of course look at critical things; it's the ground floor where we can inspect most things. Floor level is always more difficult, you don't always have a ladder with you plus you often can't get to everything, behind a house for example because the residents prevent this. From my experience I know that almost all wood rot damages occur in one of the bottom corners. I actually quite rarely see wood rot damage at the top of a window frame.

Question 3. *And if you can't reach it, what do you do with it?*

Where we can look, we extrapolate, so if you have inspected ten homes and there are thirty, you keep a bit of an average and then times the number of homes, but that remains a very rough estimate.

Question 4. *Does that prove sufficient in practice?*

Most of the time, but you can be unlucky if you have had a few good homes and there are some bad ones in between. Generally, it's a pretty good 90% match. And we often keep a margin of 20-25% that we raise it slightly. These are often costs that must be settled. In our experience, you should keep it as high as possible. We estimate it to be slightly higher than it actually is.

Question 5. *Do you consciously estimate the defects higher than they are in practice?*

Yes, it is better to give something back to the client than to ask for more. It's still a bit of a wet guess.

Question 6. *What causes this "guessing"?*

That's because you can't access everything properly, it's also a bit like the type of request, is it a tender or one-to-one. You can spend more time on it because if it is a tender, you don't want to spend a lot of time on it. Because sometimes it's only a 1 in 3 chance. They expect the provider to make a longer assessment of this.

Question 7. *How do you mean chance of 1 in 3?*

Well, if you have a tender with three companies and the wood rot has to be reasonably included. They often want to have a reasonable estimate.

Question 8. *Does it make any difference if you know in advance that you will be allowed to execute the project?*

If you know that you are doing it one on one then you can basically do a better inspection, also in terms of time, you know you can take that time back.

Question 9. *So, what makes the difference between a good inspection and a less good one?*

So, the type of application. With one-to-one, you basically make a good inspection or a better inspection. You don't go all the way to every house to check it out, not normally.

Question 10. *Suppose you have something that would make it much faster, would you inspect every house?*

Yes, it does have to do with time, with planning.

Question 11. *When you do those inspections, do you always go as a couple or alone?*

If I have to do almost 100% inspections, it's best if there are two of us, but usually I'm on my own.

Question 12. *What tools do you take with you?*

A moisture meter.

Question 13. *Do you use them a lot?*

We do when we are one on one. I don't take a moisture meter with me in a tendering phase. But a lot of them come with technical advice during the tendering phase. We rely more on that, on the inspections of the advice. I also take an awl and a feeler gauge.

Question 14. *Is that for open joints and cracks?*

Also, if you have open seams, I go in with the feeler gauge and see how far it goes in.

Question 15. *What do you do with the results you get from that?*

I check those off on a facade view. We usually take a view of the facade view with us.

Question 16. *Would this be easier if it was digital?*

Yes, in principle. I hear from companies that they already have. It's all just a piece of paper and then you tick it off. Inspections often take place in the autumn or early spring, so the weather is often not so good, it's cold and papers fly in all directions. This is often a hindrance as well.

Question 17. *Do you do the inspections faster when the weather is worse?*

Yes, that is human, I think. You have a few houses and every time the same defects at the same point, it will be like that everywhere. So, you make a lot more assumptions.

Question 18. *If you find a lot of wood rot in a certain area of a project, do you assume it will be the same in another project?*

Yes, you often know where the most critical things are. Critical places are often sills and thresholds at ground level. In the lintel, if you find wood rot there, there's really something else going on. Then there is something wrong with the building. In principle, you do not have any open connections at the lintel, or there may be some, but they have no adverse effect; moisture can never get into them.

Question 19. *How much time is required to carry out a wood rot inspection?*

The time needed per home can easily amount to one hour.

Question 20. *One hour per home?*

You only must measure one house like that if you have all the same types. And then an inspection is probably half an hour per house. To pin it down, yes, a quarter in front and a quarter in back.

Question 21. *And you do that in 5-10% of the homes approximately?*

Yes, depending on the type of house, what the orientation of the facade is. The type of occupant is also very important. Whether they keep the inside a bit tidy. But on average I think between 10-15% of homes.

Question 22. *So that appears to be sufficient?*

Yes, if it is a bit of a reasonable number. If you have 20 houses you have a bit more than 2. If you have 100 you have 10-15 homes. And you come across the same defects everywhere. It depends a little bit on the defects, then you will do some more.

Question 23. *To summarise, the biggest obstacle to inspection is the inaccessibility of some locations.*

Yes, that is difficult. And keeping a good record of the inspections. If you have a facade view and it becomes a mess, especially in bad weather, it would be handy if you could record it immediately with codes, with photos, photos of the facade where you can tick it off with an arrow.

Question 24. *Is it true that the current inspection process is not uniform?*

That is right. I am currently working on an internal project that focuses on creating uniformity. In this way, every inspection will be carried out and recorded in the same way.

Question 25. *Is this a shortcoming in the whole process or only in the inspection?*

Simple things like painting can be done by anyone. With wood rot, however, a certain level of expertise is required.

Question 26. *Does clamping of a door also have to do with wood rot?*

That is possible, because then moisture remains in between, which in turn is a cause of wood rot. Putty work is also important to inspect. Especially the underlying sealant. These parts are also sensitive to wood rot.

Question 27. *So, wood rot is always caused by moisture?*

Yes. Under certain conditions it is.

Question 28. *So, it is not the case that you monitor every few years to see what the state of the woodwork is?*

We are now entering into these processes more often. At Salland wonen, we now have a contract for that. Then we will monitor two years before the maintenance has to be carried out. Can we then postpone the maintenance period or not? So that's going to happen more and more, but it's not yet in the system.

Appendix C : Interview transcript respondent W (Arne)

Question 1. *What are your activities related to wood rot?*

Often you start with a recording. You go to the complex and you assess the condition of the painting. You try to find as many detail defects as possible and make some judgments about them. Detail defects are often the causes of damage. Which often makes a lot of time and money go into repairing that. Damages, defects and repairing those defects and preventing it from happening again in the future is very interesting. Also, for the client.

Question 2. *Does the client determine what you should inspect, or do you do it yourself?*

It depends on the partnership you're in. In a tender, you get complexes, just specify damage items, wood rot repairs and that's the price you're going to tender with. They require us to make a more detailed plan with scenarios that will allow us to reduce costs in the future

Question 3. How often do you encounter wood rot during inspections?

It is very rare that I do not encounter wood rot. I am mainly involved in the larger works such as housing associations. It is not self-evident that all details are perfect. You often come across naked sills or single glazing. Not the optimal details, which encourages damage where there is a greater risk of damage.

Question 4. *Do you know in advance that there are damages?*

No, often not, so you come across things like that during a survey. You then go to the client to present it to them, can I include it in my plan to implement an improvement proposal with some scenarios of what it will cost if you tackle that shortcoming. To see what the client thinks about it.

Question 5. *Could it be that the client says leave all the wood rot in place?*

No you don't. The moment you don't start repairing a small paste it can lead to bigger damages in the future.

Question 6. *Is wood rot also related to the position of the sun?*

Yes often the weather sides have much more wood rot than the sheltered parts. Very often in the bare lower sills where there's no vented nose slat you see a lot of damage. Anywhere it can water in you have risks. These are details that you can fix and improve. Kit joints you also come across a lot.

Question 7. *What percentage of homes do you inspect and to what extent is the inspection realistic?*

Depending on who is doing the recording, I often find that we are very good. They know how to highlight the details, they know where the flaws are. That is the best way to get a reliable sample. Someone who knows less about this writes down less damage and defects. I regularly get it right but the inspection remains an important point of attention.

Question 8. *Do you always do the wood rot inspections in pairs?*
I regularly do it on my own but construction-wise I do like to take someone with me who has more experience with it.

Question 9. *What are the bottlenecks you encounter in the inspection process, for example, accessibility to a property?*

You ha ve to have that kind of information in advance. If the accessibility is difficult and you can't inspect properly, it's wise to think about that beforehand and take something with you. For example, an

aerial platform, but you don't do that at every complex. It costs you and money and there has to be an aerial platform available. I find this technically difficult sometimes. The other area is what the client wants. You can't always be clear about what kind of plans they have at the complex. That can be tricky sometimes.

Question 10. *How long do you spend on an inspection process with about 200 homes?*

If you want to do an inspection and inventory for 200 homes, so recording and mapping everything, it will take at least a day.

Question 11. *What all do you use in an inspection besides an aerial platform?*

On a standard inspection day, you often take a ladder with you. You take that with you structurally to be able to tackle the 100% inspection per house. What is tricky are facades that cannot be reached. This makes the sample not 100% reliable.

Question 12. *How do you deal with samples that are not 100% reliable?*

Then you start estimating and try to be on the right side of the line. So, you take a risk. These are parts, though, that you have to make sure you have a good discussion with the client. If you can't reach certain facades you take 20% of the extrapolation.

Question 13. *Do you also take an awl or a moisture meter to an inspection?*

Yes, with the awl you detect wood rot and with the moisture meter you map out the risks. We do not use these enough. Moisture should be a very important part. Visual inspection is of course also very important.

Question 14. *How do you map inspection data?*

The current way is that we hardly map adhesion and moisture with particular focus on wood rot.

Question 15. *Why is adhesion and moisture not mapped?*

Moisture percentages still vary somewhat from one window frame to another, so it's not easy to indicate where it's coming from. And if a window frame is damp and you don't see any damage it doesn't necessarily matter in your maintenance plan. If you're going to prick on wood rot you have to get to it immediately if there is damage.

Question 16. *Is detachment a consequence of wood rot?*

No. Deterioration is a result of poor pre-treatment. It is not properly roughened by painters. Wood rot is a subsequent damage of detachment.

Question 17. *Do you already look for the cause of wood rot during an inspection?*

Yes absolutely, that makes a lot of difference what measures you are going to apply to prevent it in the future. You start poking and you come across certain spots and so you often see the cause right away. A sill that's exposed or below ground level. Are you going to repair it in the base or can we prevent it structurally by pulling another measure?

Question 18. *How do you determine the exact location of the wood rot?*

The awl is your tool for that. You can recognize a joint with a feeler gauge, which is also an instrument: A narrow aluminium strip with a certain thickness. If a joint is open 2 mm you can put your feeler gauge

in it and you will see that it is an open joint. We usually do this visually. So, you have these gradations, these have to do with the size of your damage. The size of a bitter ball is a big repair. Then you're going to deploy to a piece of wood quickly. Can you prise away an entire frame set or an entire under sill you don't get away with a paste or a piece of wood. Laminating is putting a piece of wood in front of it, that is if the glass runs up to the glass line and if it runs behind it you must replace the whole sill.

Question 19. *In terms of cost, do you prefer to use paste?*

This would be most beneficial to the client because it is the cheapest compared to the bigger repairs. Personally, I prefer to use the laminate or the partial replacement because it is better for the longer term.

Question 20. *How often do you perform the inspections, annually?*

Also depends on the partnership. If it is a tender, you are going to execute and give a warranty period and it has to be expiring good by the warranty date. Then you are not going to monitor either. If there is a complaint in the interim you get a call and you would have to go back.

Question 21. *So, if you agree in 6 years it is still 80% of what it should be you don't look at it again in those 6 years until there are complaints?*

With a client who does tenders often not. In other collaborations you issue a cycle of 6 years, and we have a monitoring after year 2 and year 4 for example.

Question 22. *Would it be of any benefit if you could do that monitoring annually, does that prevent wood rot at a later stage?*

That would certainly be beneficial. It provides a lot of valuable information if you have made the right choices in the initial year. If a client says no, we are not going to invest and not do it. And you see after 2 or 3 years those damages occur anyway you must prove that it does have an effect. You could also do updates in the interim if it doesn't go well anyway.

Question 23. *So, you want to go less to repairing wood rot and more to preventing it?*

Exactly, prevention and stretching cycles as much as possible, so that you stay away from painting if possible.

Question 24. *Are there things that you say are really lacking during an inspection?*

Yes. what I am still missing is an easy to apply sheet or format so that you are there on location and can get that data easily, completely, and effectively.

Question 25. *Would a step-by-step plan on an A4 sheet be an improvement during an inspection?*

That would already be the first step for us to carry out better inspections. I think the technique will be the second. An unambiguous format is on the most important for me. On the second place is digitizing the format and a third step would be to introduce a drone or a laser.

Question 26. *Based on the degrees of wood rot, how do you determine what technique to use?*

On the one hand I have my facade view where I have different wood rot measures and then I go by with someone else, and they detect the repair measures.

Question 27. *Do you get a facade view sent to you by the client?*

Yes, if you ask for that. You ask for drawings so that you can indicate in your sample where the damage is. Now we still name the solution right away. I write that down and we look at the cost of repair. Then what's even more interesting is to look at the prevention of the damages.

Question 28. *So, that's not interesting to the client, they just want to know what it costs?*

That's right, although they are increasingly thinking that it will cost me this to repair it, and then they won't have to do it again in 20/30 years.

Question 29. *Have you ever experienced a full maintenance cycle?*

No, I have not.

Question 30. *Have you ever inspected something that has been inspected/replaced before?*

Yes, I have surveyed a complex for next year. This will be an RGS complex. Details and defects have already been identified.

Question 31. *So, can you see now that there was not proper inspection at that time?*

I felt that it was properly inspected at the time.

Question 32. *How do you get the idea that something was properly inspected?*

At the time, a plan was made where all the defects are and what kind of investments would have to be made to prevent it. This does lie pretty much in envy with what was thought of at the time. And places that were not invested in properly you can see that there has been some damage now. Because of that you see that it has been reliable.

Question 33. *How do you include an inspection in a maintenance plan?*

You first discuss it with the client. Then you take the results of the conversation to the inspection. What does the client like to see as a measure that you're going to implement? You have all that mapped out and you start pricing it. That's often your base case scenario. Apart from that, you often have additional scenarios. For example, removing a defect will give me less wood rot in so many years.

Question 34. *Do you then know exactly how much that will yield?*

No, that is an estimate. But often it always yields something because the investment is lower compared to the future cost

Question 35. *Is wood rot generally expensive to repair?*

Yes, it is expensive because in one frame you can have severe damages in multiple places.

Question 36. *Do you always choose wood when you see wood rot, or do you also often choose plastic?*

Yes, very often we choose to replace an existing wooden window frame with another material. Or we replace a wooden threshold with a DTS plastic threshold. In this way we try to include sustainability.

Question 37. *How do you make sure the craftsmen on site have the right tools?*

Often based on your inspection you can see what the damage is and then in your work planning you can take that into account.

Appendix D: Interview transcript respondent X (Daan)

Question 1. *What is the role of your company and your role within the company?*

I am co-owner of Bureau onderhoud. We are an independent facade maintenance consultancy. We do not sell products, we only sell our own labour, so we manifest ourselves completely independent and from that role we carry out our services. Advising in facade maintenance by giving training courses to acting as an independent expert for courts where we support the judge in damage accidents.

Question 2. *Why do you think independence is so important in the company?*

In our view, when it comes to advice, it's about who does what at the right time and who dares to call out when something is not right. My experience with parties who are brand-related is that they often have something to complain about after the fact. There are certainly colourful technical advisors who dare to call out when something is wrong, but in my experience, they are hard to find. It is not their role.

Question 3. *Why do you think RGS is so important?*

RGS is the way to put the responsibility of implementation where it belongs. In result-oriented cooperation, you agree with each other that the executing company is responsible for any mistakes. How do you repair and fix that? There is no obligation to perform to the best of one's ability but rather an obligation to produce results, and you are responsible for achieving results and ensuring that they continue to be achieved. An obligation to perform to the best of one's ability could not actually go wrong if you follow how, it is written down by the client. I think that result-oriented cooperation is the format for specialists like you. You put the responsibility where it belongs. Many parties want to move towards the RGS because they want to get rid of the uncertainty.

Question 4. *Is that why collaborations always start with a base year?*

Yes, the contracts have been signed, so we will see. What do you mean by a starting year? I think that you have started and later you will have contracts that could be settled very harshly. I think a starting year is very limited. It is good to get a good sense of what you mean to each other and what the criterion is that could be used to judge you.

Question 5. *Why did you develop the tool?*
We are a consultancy firm that is used to inspecting a lot. You use inspection forms to record your measurement data and analyse them later. We have a training course that ensures risk-oriented inspection. Then we also used our inspection forms and left them as forms. We then created forms which are a little more user-friendly and so you can also provide them in the form of a free beginner's version. Where you as parties can use it like we do. The purpose of the inspection form is to be able to deliver it so that we can also use it in collaborations.

Question 6. *Is the inspection data for wood rot collected by hand and do you do it with an awl and a moisture meter?*

Yes, inspecting is and remains physical work. We think about how you inspect, about how you inspect properly, about how you should collect data, why you should collect data in that way. In that respect, we are very old-fashioned and prefer to inspect with paper and pencil. Whether you do it with an app or paper, the inspection takes just as long. The only advantage of the app or tablet is that you don't have to paste it into Excel because you've already done that in the field. Doing moisture measurements and looking upside down for wood rot are the actions you must keep doing and that takes the most time.

Question 7. *Have you ever investigated whether the pricking or measuring of moisture can be replaced by something else?*

We have done it with heat cameras. However, working with thermal cameras is very precise and accurate work. You must set it up very well. For example, house 1 needs to be set differently from house 2 because the heat radiation is different. Being able to read colour differences on images requires a great deal of knowledge and is also affected by things. We think that the moisture meter tool is a very important tool in determining the causes of wood rot. A moisture meter is very reliable if you use it in the right way. We have thought about it but see some limitations. Measuring moisture in a window frame is a technological solution to prevent wood rot.

Question 8. *Last week I spoke to someone from Tricas, they developed a heat sensing camera. What do you think about the use of this for wood rot inspection?*

A window frame where the wood moisture content is high, is not by definition wood rot. To be able to tackle wood rot, one must look for the cause. The switch needs to be made from symptom perception to the detection of the cause. The use of a heat camera could mean something in the faster and more targeted detection of the problem, but a heat camera alone will not do the job. In RGS thinking, it only starts with the detection of wood rot. The cause is important to be able to extend the maintenance cycle in the future. To do this, we must and will always be pricked.

Question 9. *How do you deal with difficult-to-reach areas during inspections?*
It is important to make a distinction here between whether to perform a baseline measurement. During a baseline measurement, we do a lot of pricking and moisture measurements. The purpose of this is to be able to draw up a plan of approach for our client. If during this baseline measurement it appears that there is a lot of wood rot in the project, your sample will be increased. It is even possible that we perform a so-called one-on-one recording. In this case, we inspect each building component and in fact carry out a 100% inspection. This enables us to give the client a clear picture of the financial picture. A baseline measurement is carried out to be able to plan of approach, a one-to-one recording of wood rot is done to know in advance what the wood rot will cost. If it turns out that 60% of the windows are rotten, it can be decided to replace them all. If we can't get to something, it is important that we record this. In a one-on-one inspection, we need to be able to reach everything, if necessary, using expensive tools such as an aerial platform or scaffolding.

Question 10. *And in such a baseline measurement, is the most important inspection method the measurement of moisture?*

No. As a real estate company, you carry out the baseline measurement. You focus mainly on façade maintenance. You look mainly at the paint system. The paint system is on wood. During this inspection, you list all the defects and their possible causes. Based on this, you can draw up a plan of approach. This is separate from a one-on-one shot to look purely at wood rot. A pricking action only looks at wood rot. The causes of wood rot are often already caught in the baseline measurement. The one-on-one recording is much more labour intensive because every building section has to be inspected separately. When every building component of a house has been inspected, one can start extrapolating to determine the defects for the entire project.

Question 11. *Does the greater labour intensity of a one-to-one shot outweigh the lower risks of wood rot?*

We only recommend a one-to-one recording if wood rot is found in every house during the baseline measurement. In other words, if the cost per house to repair wood rot increases, then the risk also increases. With small repairs, in our terms that means carrying out a small repair here and there, the risk is very low. In this case, we will never recommend a one-on-one shot. It is therefore important for a property maintenance company to ask itself what the importance is of a one-on-one check for wood rot. An unnecessary one-on-one inspection can be prevented by accurately performing a baseline measurement.

Question 12. *If you had to tell us where the biggest gains would be in mapping wood rot, where would it be?*

The profit lies mainly in carrying out more and more accurate inspections. It is very important to have the budget and the complex strategy well mapped out. This is particularly important in RGS collaborations.

Appendix E: Interview transcript respondent Y (Martijn)

Question 1. *What is your role within the company you work for?*

I'm a real estate project manager myself and my role is to train and supervise all the inspectors to look at wood rot with the right view. Among other things, we are mainly working in the RGS issues so for 20–25-year maintenance and then wood rot is definitely going to be at play. So I'm mainly managing and making sure that the right quality is delivered.

Question 2. *How do you accomplish that everyone looks at wood rot with the same view?*

This is quite difficult for us because we are an agency that is called in by VGO parties mostly or by cooperatives. And when we work for VGO parties we try to look at wood rot through their eyes. So we don't always look at wood rot in the same way because everyone has their own idea about it, so that means we have to meet with a VGO party beforehand to go through certain issues and I have to pass them on to our inspectors.

Question 3. *So, if the client places less importance on wood rot, it is also less well looked at?*

No not in that sense but you do have for example very appropriate wood rot in rotating parts, in windows or doors, that can be that one says guys we're just going to fix that and the other says in advance wood rot in rotating parts is just replacement. So those are kind of essential things how you have to look at the damage.

Question 4. *If you get a new project with, say, 200 homes, how many of them do you inspect?*

Again, this depends on the demand that is there. It may be that we do 10%, it may be that we do 33% or 50%, sometimes even 100% but that is not very common. It also depends a bit on the tool we use; we also have software in which the diesel 2859 standard applies, and we use that as a starting point.

Question 5. *How much time do you spend inspecting 1 home if it is just the wood rot damage?*

That depends on the type of house, but I think if you really want to check the house 100% then you should count on three quarters to an hour.

Question 6. *What tools do you use to inspect a home?*

The guys inspecting have an inspection kit with them so that means a good awl, a feeler gauge and a moisture meter.

Question 7. *Do you use the moisture meter by default?*

It is not always requested by our client so if it is not requested, we do not use it.

Question 8. *Do the boys run into problems during the inspection process?*

I think that it is not too bad. I can't think of anything that they're structurally struggling with.

Question 9. *How are the results of an inspection recorded?*

Actually, we only work digitally so we use software from the renovation planner or we apply if we do it in combination with a condition measurement that we run it in the software of Propertyplan or it's a document from a certain VGO party that we run for. But basically, everything is digital.

Question 10. *How is your organization doing regarding the type of repair and desired repair?*

Inspectors need to identify the extent of the damage where they need to differentiate between when something is a fixed repair or a full replacement or a partial repair.

Question 11. *Are there any set standards for this?*
Yes, that difference between front wood and part wood whether something is in front of or behind the glass line so if the damage runs to behind the glass line it becomes partial wood repair. Is it in front of the glass line it requires front wood? Is it smaller it becomes a paste in our case where guys must look closely at the size and what's still a concern there to give me is that they not only include the size of wood rot that they see now but they also have to include the piece of healthy wood that needs to be removed? So, if you see a marble of repair now that means you must remove at least a bitter ball of wood.

Question 12. *If we should optimize this process, do you have any ideas for that, things that would make it easier?*

I know that behind the scenes people are installing sensors in wooden window frames that continuously measure moisture and other things like that. I notice in practice that moisture measurements within wood rot are still used too little because they obviously give a good indication for future actions. Especially if we are working for 25 years, moisture measurement is an important part of getting a picture of the future numbers.

Question 13. *Now if there is something of a tool, for example a drone with a thermal camera to look for moisture in the window frames, would you use it?*

I do know that drones are indeed being experimented with at the moment, I'm a little cautious about that.

Question 14. *Why is it that you are more reluctant to do so?*

Because at this point it's still a visual thing and not so much that you can really do a thorough examination. I don't think there's an awl or a feeler gauge on a drone that you can use to investigate the wood. It's mostly a visual thing yet. I think the moment the technology is further along, and it can indeed also look with thermal images or really at the content I think that could be quite something for the future.

Question 15. *Within the organization, is this already being addressed?*

Yes, these are areas that we follow. Because as soon as those developments become interesting, we will also focus on them.

Question 16. *Is it common for you to notice that an inspection was not done properly? `*

No, in general, I haven't had many experiences of people coming back with concerns about the damage, for example, that the damage is greater or different than what was put on paper. Of course, there will always be some left and right because it is still human work, so that is logical. But no, I have no experiences with that.

Question 17. *So, is the biggest profit to be made on the time it takes for an inspection?*

Yes. I think so.

Appendix F: Interview transcript respondent Z (Nico)

Question 1. *To what extent do you find the traditional way of wood rot inspections reliable?*

Traditional ways of inspecting only look at symptoms. For example, poking with an awl or measuring with a moisture meter are only aimed at detecting symptoms. This adds nothing to a measurement of the quality of wood. In fact, you want to be able to make the diagnosis in such a way, with environmental and material factors, that a definitive damage picture emerges from this. You want to have a blueprint of the current perception under certain conditions. For example, when poking with an awl, it is not clear whether the damage occurred because the facade is in the weather side or not. In short, the situation very much determines the severity of the damage. Measuring environmental conditions, together with an analysis of the situation a property is in, will provide a more detailed picture of the wood rot damage.

Question 2. *What is the biggest shortcoming in the current process?*

A common complaint within our industry is the following: 4-5 years ago, we repaired this piece of wood, why do we have to repair it again? this question exposes the biggest shortcoming. The mere observation of the symptoms were also the cause is very important. Wood is a natural product. Often this is not realized and therefore the necessary biological knowledge to come to a correct conclusion is also lacking. If one does not do anything about the ideal conditions in which a fungus can grow, then naturally, a few years later, wood rot will have occurred again.

Question 3. *How should the above fact affect the current inspection process?*

The detection of wood rot must be complemented by its analysis. What type of wood am I dealing with? What is known about this? What is the weather condition this wood is in? Is this situation suitable for the growth of fungi? All these questions need to be answered after an inspection.

Question 4. *If what needs to be done is known, why is it not yet happening in practice?*

That has to do with the fight against the establishment. Many clients see their window frames managed by maintenance partners for the next 25 to 30 years. This can also be done through traditional repairs. In other words, there is no motivation to change anything. However, it does become interesting for clients when they can make a financial profit. This is where the challenge currently lies for maintenance partners.

Question 5. *What exactly does this challenge look like?*

Traditionally, wood rot repair is also performed during a repaint. By investing in this, the technical life of the window frame is maintained. Depending on how much value a corporation places on the condition of the window frames, this will happen every 5, 6, or 7 years. If they opt for the longest cycle and thus the lowest maintenance costs, they must accept that dissatisfied residents will call because wood rot will occur.

Question 6. *And in practice? How does this work out?*

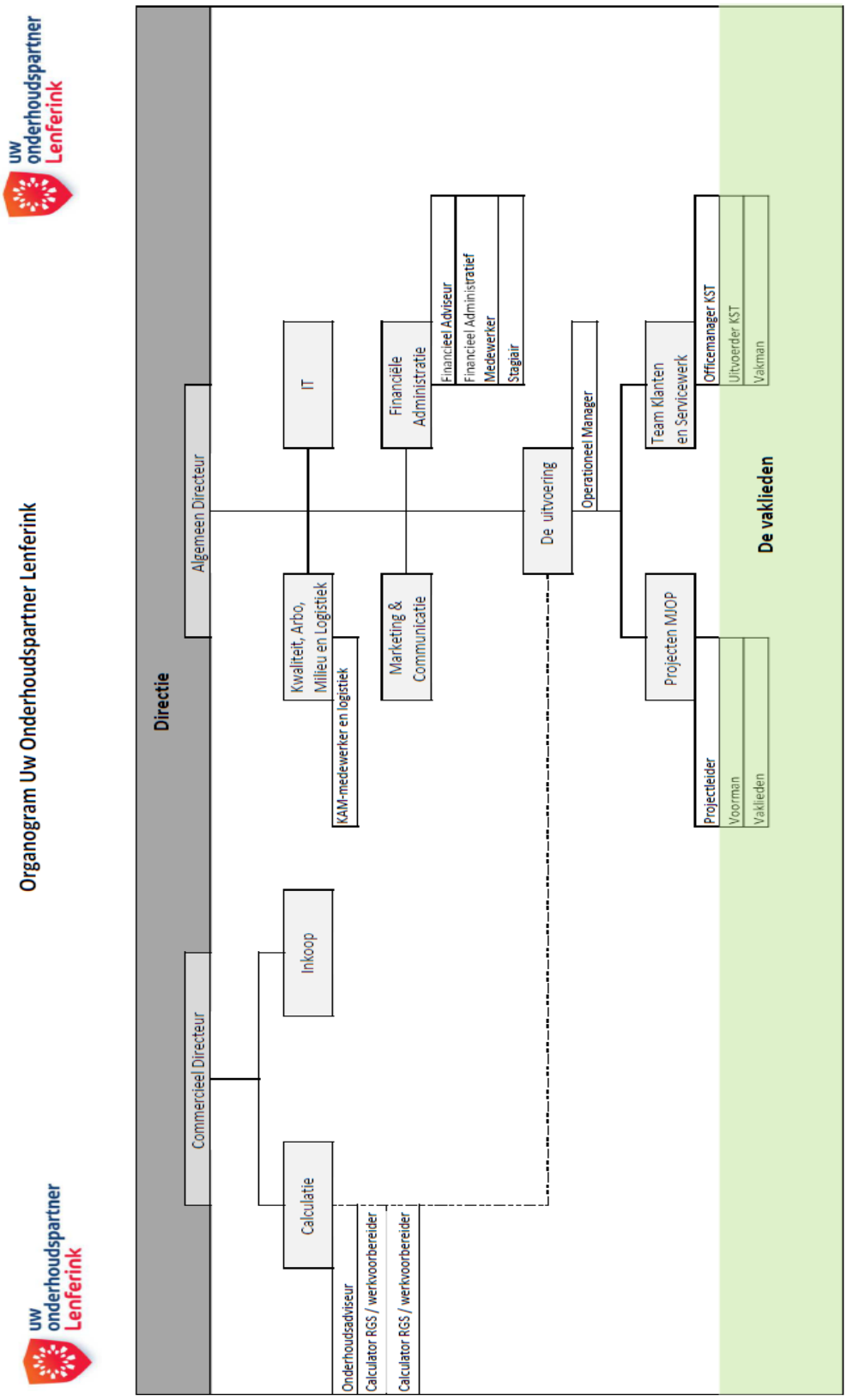
This is different for each corporation. This is different for each corporation. There are corporations that choose to install plastic window frames. However, from a sustainability perspective this is anything but desirable. Due to degradation of the materials, plastic window frames run out after 30 years. Wooden window frames, on the other hand, can last 80 to 90

years if properly maintained. Besides, we all invest billions of dollars to clean up the plastic soup.

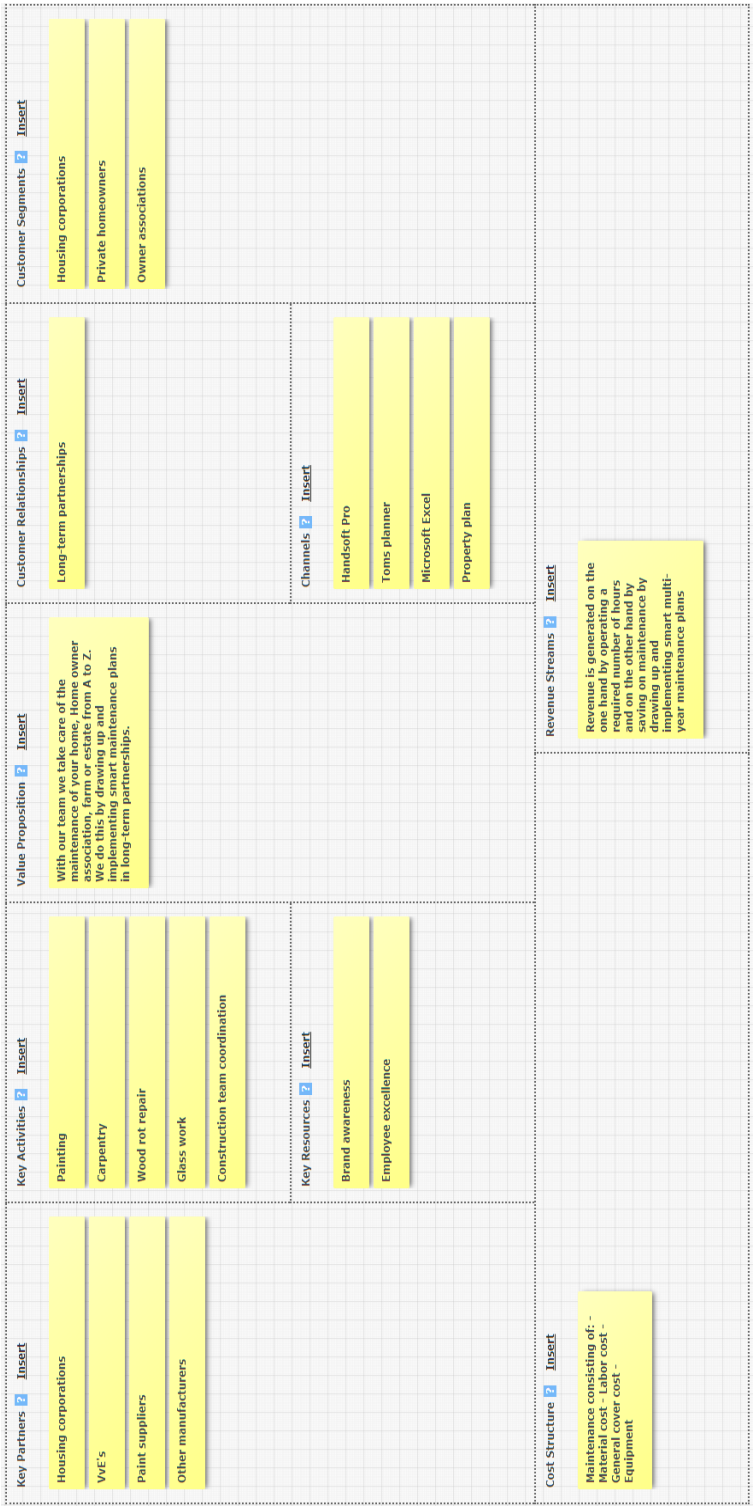
Question 7. *In conclusion, how do you correctly perceive a frame?*

The solution is not in using an innovative technique to replace a traditional problem. In other words, using a digital tool to observe symptoms does not add value. The solution lies in getting to the bottom of the problem. Not only the symptoms need to be observed, but also the causes and their longer-term consequences. Only by doing this can a reliable total cost of ownership calculation be made.

Appendix G : UOL Organisation chart



Appendix H: Business Model Canvas



Appendix I: Wood rot – Causes

Factor	Parameter	Effect
Environmental factor	Moisture	Swelling and shrinkage
Environmental factor	Light	Discoloration
Environmental factor	Temperature fluctuations	Small material loss potential
Environmental factor	Temperature, moisture and micro-organisms	Wood rot
Environmental factor	Salt	Unlikely to have an impact
Implementation factor	Painted and glazed on site, or placed ready to use	Significant impact on degradation
Design factor (building)	Height of the facade Orientation of the facade Slope of the facade.	Significant impact on degradation
Design factor (component)	Accessibility for maintenance; Position of the window frame in the facade; Roof overhang or no roof overhang; Mounting or masonry frame How much wood outside the glass line.	Significant impact on degradation
Design factor (component level)	Interior or exterior glazing; Cover profiles / nose battens; Sloping of the threshold Presence of capillary seams; Application of cover profiles or nose battens. Rounding off the edges.	Significant impact on degradation
Design factor (product - and material level	Type of wood (quality or durability) Finishing / no finishing. Colour finishing (dark - light - clear). Choice of frame connection type. Finger load/ laminated.	Significant impact on degradation

Table 6: Overview of the factors influencing the wood degradation process (van der Vlies et al, 2012; Manders-Maanders, 1990)

Appendix J: RFID network

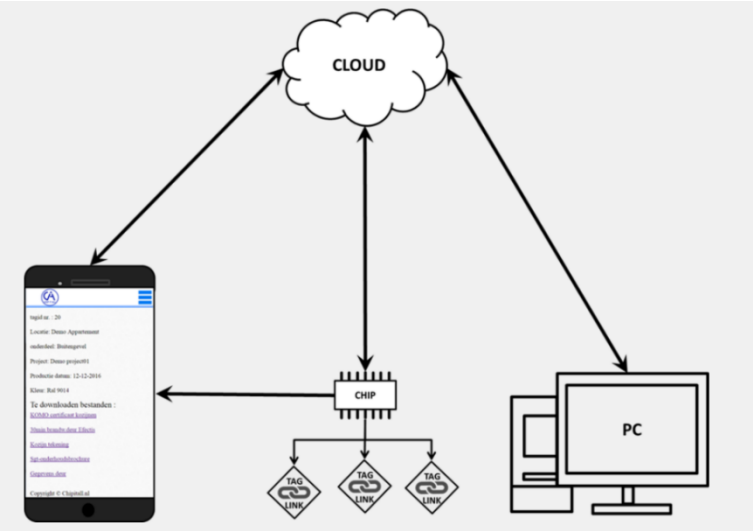


Figure 27: Loading fixed factors onto RFID-chip (Chipitall.nl, n.d.)

Appendix K: Wireless Sensor Network – Set-up

Within the wireless sensor network either the sensors communicate directly to an external base station or communicate among each other. A Low Energy Adaptive Clustering Hierarchy (LEACH) wireless sensor network strategy is chosen. Each cluster in this network represents a wooden building component i.e., a door or a frame. Each of these clusters contain two sensors, of which one is in direct connection with a base sensor. The sensor in direct connection with the base sensor is called 'clusterhead'. The clusterhead within a cluster is rotated to evenly distribute the load among the sensors. An overview of the wireless sensor network is shown below.

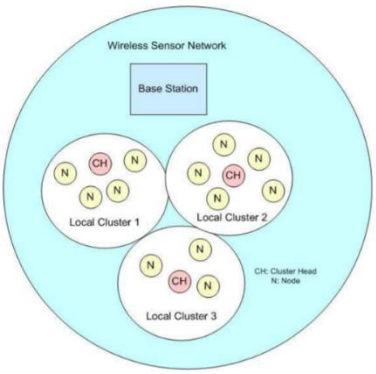


Figure 28: Wireless sensor network set up (Zhang, 2017)

The wireless network sensors are referred to according to the following rules: IDHT11, where ID stands for identity, H for humidity, T for temperature, 1 for the corresponding cluster and 1 for the facade. Facades are coded using the following rules.

1 = Front façade

2 = Left end wall

3 = Right end wall

4 = Rear façade

This coding is important to be able to see at a later stage which data has been generated by which sensor. This is also important to be able to take the difference in weather conditions into account. Facades on the west side of the house are more susceptible to weathering than other facades. Base sensors are added an extra letter B. Base sensors form the link between the sensor nodes and the internet. Below is an image of the SHT 30-DIS-B SENSIRION. This sensor node contains a humidity sensor and a temperature sensor. The temperature is measured with a maximum deviation of ±0.3°C. The relative humidity is measured with a maximum deviation of ±3%. In fact, any micro sensor that measures both temperature and humidity can be used. Sensors differ in accuracy, size and price. The sensor in Figure 26 is for illustration purposes only.

Figure 29: Temperature and Humidity sensor (https://www.soselectronic.com/)

The sensor displayed in Figure 27 consists of the following four basic elements.

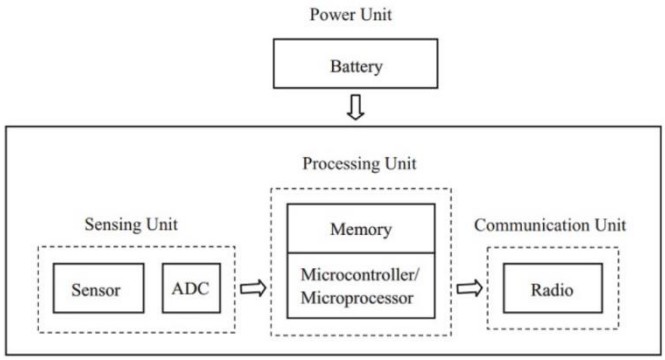


Figure 30: Sensor node basic elements (Electronics hub, 2019)

The sensor is powered by a battery. These sensors must be programmed to start collecting data when the maximum permissible number of hours of sunshine for the paint system in question is exceeded. Since the sensor actively collects and communicates data through the base sensor, the lifespan is limited. Based on the 1200mAh battery as it powers the sensor in Figure 27, the life expectancy is as follows.

Interval (min)	*Lifetime (days)*	*Lifetime (years)*
1	3379	9,25
15	50683	139

Table 7: Sensor life expectancy

Thus, when the sensor measures and transmits data every 15 minutes, the lifetime of the sensor exceeds the average lifetime of a wooden building component. The senor node collects analog data and digitalises this with the help of and ADC. The processing unit stores the collected data after which the data is communicated using the communication unit.

Due to their very small sizes, the sensors can be placed together with the RFID tag in the 5x15mm plastic shell. Expert interviews have shown that the critical parts of a wooden door or window frame are almost always the two bottom corners. For this reason, these corners will both be fitted with a plastic case containing the sensors. In addition, one of these cases contains the RFID tag. To avoid any confusion about this, the RFID tag is always placed in the case that is in the bottom left corner of the wooden frame.

Note: To obtain correct measurements, it is important to place the plastic shell at the level of the glass line. Only here can the correct measurements be obtained with regard to temperature and moisture content.

Appendix L: Temperature/humidity sensor data

	Date	Year	SensorID	TimeStamp	Façade	Weatherside	Clusternumber	HumidityVal	TemperatureVal °C
1	01-Jul-2020	2020	IDHTB1	0:00:00.00	Front	South-West	1	79	12,0
2	01-Jul-2020	2020	IDHTB2	0:00:00.00	Front	South-West	2	79	12,0
3	01-Jul-2020	2020	IDHTB3	0:00:00.00	Front	South-West	3	79	12,0
4	01-Jul-2020	2020	IDHTB4	0:00:00.00	Side	North-West	4	79	12,0
5	.	.		.			.	.	.
6	01-Jul-2020	2020	IDHTB1	6:00:00.00	Front	South-West	1	81	15,0
7	01-Jul-2020	2020	IDHTB2	6:00:00.00	Front	South-West	2	81	15,0
8	01-Jul-2020	2020	IDHTB3	6:00:00.00	Front	South-West	3	81	15,0
9	01-Jul-2020	2020	IDHTB4	6:00:00.00	Side	North-West	4	81	15,0
10	.	.		.			.	.	.
11	01-Jul-2020	2020	IDHTB1	12:00:00.00	Front	South-West	1	80	23,0
12	01-Jul-2020	2020	IDHTB2	12:00:00.00	Front	South-West	2	80	23,0
13	01-Jul-2020	2020	IDHTB3	12:00:00.00	Front	South-West	3	80	23,0
14	01-Jul-2020	2020	IDHTB4	12:00:00.00	Side	North-West	4	80	23,0
15	.	.		.			.	.	.
16	01-Jul-2020	2020	IDHTB1	18:00:00.00	Front	South-West	1	80	22,0
17	01-Jul-2020	2020	IDHTB2	21:00:00.00	Front	South-West	2	80	22,0
18	01-Jul-2020	2020	IDHTB3	23:00:00.00	Front	South-West	3	80	22,0
19	01-Jul-2020	2020	IDHTB4	25:00:00.00	Side	North-West	4	80	22,0

Figure 31: Humidity and Temperature data stored online

Appendix M: Wood moisture translation

From physics a relationship has been established between wood moisture and humidity. For example, wood can never contain more than 18% wood moisture at a constant humidity of 85% (Nagel, 2017). According to Manders-Maanders (1990), Wood with a moisture content of less than 20% will not be affected by fungi. According to Manders-Maanders (1990) the saturation point of most wood species is around 30% and is defined as the moisture content of wood in an environment with 100% relative humidity. According to the moisture content achieved by drying, the wood is classified into five classes. These classes are shown in the table below.

Class	*Description*	*Moisture content*	*Relative humidity*
1	Room dry	< 10%	<45%
2	Thoroughly air-dry	10-16%	45-70%
3	Air-dry	16-24%	70-90%
4	Wind-dry	24-30%	90-100%
5	Wet	>30%	>100%

Table 8: Classification of wood according to moisture content (Manders-Maanders, 1990)

The literature has already shown that mold growth occurs at a wood moisture content of 20% and wood rot at a wood moisture content of 25%. For this reason, both the 20 and 25% will be limit values in wood moisture content. The translation of the ambient moisture percentage to the wood moisture content is therefore as follows.

Relative humidity	Wood moisture content	Direct consequence
< 80%	< 20%	No risk of wood rot
80%	20%	Fungi growth
92%	25%	Wood rot occurrence

Table 9: Relative humudity values based on wood moisture content limit values

Within MySQL the following line of coding has to be added to transform the relative humidity data into the corresponding wood moisture content.

```
RECODE HumidityVal (0 thru 45=10) (46 thru 70=15) (71 thru 80=19) (81 thru
90=23) (91 thru 92=24)
    (93 thru 100=25) INTO WoodMoistureContent.
VARIABLE LABELS WoodMoistureContent 'WoodMoistureContent'.
EXECUTE.
```

Since only one value can be obtained for each interval, the highest value is chosen. In this way, the moisture content of wood can never be underestimated. In practice, this will result in an excessive sum per property for wood rot. The interviews showed that this is not a major problem. After all, analysis of the interview data showed that clients prefer to receive money back rather than having to pay extra. In the following overview, the previously measured moisture contents have been transformed into the corresponding wood moisture contents.

HumidityVal	TemperatureVal °C	WoodMoistureContent
79	12,0	19,00
79	12,0	19,00
79	12,0	19,00
79	12,0	19,00
.	.	.
81	15,0	23,00
81	15,0	23,00
81	15,0	23,00
81	15,0	23,00
.	.	.
80	23,0	19,00
80	23,0	19,00
80	23,0	19,00
80	23,0	19,00
.	.	.
80	22,0	19,00
80	22,0	19,00
80	22,0	19,00
80	22,0	19,00

Figure 32: Relative humidity with corresponding wood moisture contents