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Exploring How Digital Technologies Can Be Used to Improve Business Processes

Master's thesis (30 EAP)

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Uurimus digitaalsete tehnoloogiate võimekusest äriprotsesse parendada

Lühikokkuvõte:

Maailm on järjest enam muutumas digitaalseks. Aina olulisemaks on muutumas digitaalsete tehnoloogiate kasutamine selleks, et edendada äritegevust. Ettevõtted on seetõttu huvitatud digitaliseerimisest, aga vähe on uuritud seda, kuidas digitaalsed tehnoloogiad saavad luua ärilist väärtust. Selle teose eesmärk on täita lüngad teadmuses ja heita valgust sellele, millised on digitaalsete tehnoloogiate võimekused ning kuidas nad võimaldavad protsesse ümber disainida. Selleks, et leida ja analüüsida päriselu juhtumeid, viidi läbi süsteemne kirjanduse ülevaatus. Leitud informatsiooni põhjal koostati nimekiri digitaalsete tehnoloogiate võimekustest. Liites kokku võimekused ja äriprotsesside ümberdisainimise heuristilised meetmed jõuti raamistikuni, mis selgitab kuidas digitaalsed tehnoloogiad võimaldavad äriprotsesse ümber disainida.

Võtmesõnad:

Digitaalsed tehnoloogiad, digitaliseerimine, digimuutused, äriprotsesside juhtimine, protsesside parendamine, protsesside ümberdisainimine

CERCS: P175 Informaatika, süsteemiteooria

Exploring How Digital Technologies Can Be Used to Improve Business Processes

Abstract:

The world is becoming more and more digital. The use of digital technologies to improve business operations is becoming increasingly important and companies are interested in embarking on digital transformation journeys, but there is little research on how digital technologies can be used to bring business value. This paper aims to fill that gap and shed some light on what the capabilities of digital technologies are and how they enable process redesign. A systematic literature review is carried out to identify real-life use cases and extract information. This information is used to derive a list of digital technology capabilities. A framework is created by combining the capabilities with process redesign heuristics to explain how digital technologies enable business process redesign.

Keywords:

Digital technologies, digital transformation, digital innovation, BPM, process improvement, process redesign

CERCS: P175 Informatics, systems theory

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1. Introduction

The use of digital technologies to improve different aspects of a company has become extensively hyped recently [7]. The use of digital technologies to improve an organization's business operation is often called "digital transformation". Digital transformation is often used synonymously with the phrases "digital innovation" and "digitalisation" and at the core of these efforts is business process change. An organization can be thought of as a work system [10] and business processes are at the core of it, as they define how work is done [6]. Digitalization affects every aspect of the organization – value creation model, value proposition model and customer interaction model [1]. In order to enable business agility and optimize business performance, companies are ever more interested in embarking on a digital transformation journey [5].

The paper focuses on a narrow aspect of digital transformation, namely the idea of using digital technologies to redesign business processes.

There are many studies analysing digital transformation from different aspects, such as how to teach business process change in the context of digital transformation [3], how to approach digitalization with business process management (BPM) [2], what are the synergies between business process management and digital innovation [4]. There are some attempts to list digital technologies [1][15] and some attempts to capture technology capabilities [1][5][9][15]. Also, there are several frameworks that are used to guide business process redesign, one of them being Heuristic Process Redesign [6]. Process redesign performance can be measured by Devil's Quadrangle [6].

However, there is no comprehensive framework that illustrates a cause-effect relationship between digital technologies and their impact on business processes. A comprehensive direct correlation would even be unfeasible, as there exist many individual technologies. Technologies enable the user to achieve something and therefore, many serve a similar purpose. This property of a technology to enable something is in this paper referred to as a digital technology *capability*.

The thesis therefore aims to answer three research questions:

- **RQ1: What digital technologies have been used to redesign business processes?**
- **RQ2: What capabilities of digital technologies have enabled business process redesign?**
- **RQ3: How can digital technologies enable business process redesign?**

To answer these questions, a systematic literature review was carried out to identify 71 papers that include case studies which discuss how digital technologies have been used to redesign business processes. From these papers, it was extracted:

1. The main implemented solution;
2. Which digital technologies enabled the creation of the main solution and what were the other concurrent digital technologies;
3. How the main solution was technically implemented and how each digital technology contributed;

4. How the business processes were changed;
5. The impact of the implementation;
6. Which Devil's Quadrangle performance effects best characterized the business process changes;
7. Which Redesign Heuristics best characterized the business process changes.

This extracted information was used to create a digital technology capability framework. First, the list of digital capabilities was derived by analysing earlier attempts for frameworks and combining them in a way, that they support information extracted during the systematic literature review. This resulted in a list of 16 digital technology capabilities with definitions and example technologies from the identified literature.

These capabilities were then assigned to all the identified papers. The resulting information was then used to assemble the final framework, which includes the digital technology capabilities, the relevant process redesign heuristics, and examples from identified literature.

This framework can be a tool for business professionals to assist in carrying out digital transformation. The framework will provide them a reference point to start the digital transformation journey as it will enable them to explore the capabilities of digital technologies and how each capability can be used to redesign processes.

The framework could also theoretically be used as an input structure for the development of an AI-based recommendation tool that helps companies make better choices with digitalization.

The paper is structured as follows: section 2 contains background information on important concepts from the perspective of the thesis, in section 3 an overview of related work is given, in section 4 the systematic literature review protocol, results and limitations of the data are discussed, in section 5 the framework creation is discussed and the framework is presented, in section 6 the results are discussed and in section 7 the work is concluded. In Appendix 1, a list of papers identified in the systematic literature review is presented.

2. Background

This section explains some of the important concepts in the paper - business processes and digital technologies. The first subsection covers business processes, their management and business process redesign. The second subsection cover digital technologies and their capabilities.

2.1. Business processes, management, and redesign

An organization or a business can be thought of as a Work System [10], that at the core has processes and activities, that use participants, information and technologies to deliver products and services to customers. A work system is affected the environment and the organizational infrastructure and strategies.

Business process management roughly falls into the value creation model in the dimensions of digital transformation [1].

According to Dumas et al. [6] Business Process Management (BPM) is the discipline of managing how work is done in an organization to make sure, that outcomes of processes are consistent improvement and opportunities are taken advantage of. The improvement might refer to cutting costs, reducing time spent, increasing quality, or adding flexibility to processes. A process is made up of chains of events, activities, and decisions. Processes exist at every organization and are usually defined by clear starting and end criteria, such as order-to-cash, quote-to-order, procure-to-pay, issue-to-resolution and application-to-approval. BPM is a continuous process and the major steps in a BPM lifecycle include identifying the process architecture and the overall picture, discovering as-is processes, analysing any issues with the as-is process, identifying possible improvement areas, implementing the to-be process and monitoring the performance of improved processes.

Their book gives a comprehensive insight into the fundamentals of BPM. In the book they give clarify the meaning of a business process, discuss how to identify business context and process architecture, how to model processes, how to discover specific processes, how to analyse them both qualitatively and quantitatively, how to carry out the redesign of processes, explain what are process-aware information systems, how to make process models executable, how to monitor processes and how BPM should be treated as an enterprise capability.

The most relevant part to the thesis is the topic of business process redesign. It is done to improve the performance of the process. The four previously mentioned parameters - time, cost, quality, flexibility - make up what is called the Devil’s Quadrangle and lie at the heart of every process redesign effort. An effort to improve one aspect of the quadrangle might negatively affect another dimension. For example, automating a process might improve quality through standardisation and reduce the cost of manual execution, but lose flexibility as any further small change or deviation to the process might require a new automation effort.

Process redesign is a complex effort, but there are many related books, articles and frameworks that provide valuable methods and guidelines. One of the thoroughly described approaches is Heuristic Process Redesign. It is a systematic consideration of principles, which based on different elements of business processes, namely the internal or external customers of the process, the business process operation view, the business process behaviour view, the organization structure, the information involved, the technology involved and the external environment. At the end of the book they bring out 29 different heuristics, which are categorised based on these elements. 7 of them were identified to be enabled by digital technologies:

1. Integral technology. It is defined as "Elevate physical constraints in a business process by applying new technology";
2. Automation. It is defined as "Consider automating activities";
3. Control addition. It is defined as "Check the completeness and correctness of incoming materials and check the output before it is sent to customers";
4. Interfacing. It is defined as "Consider a standardized interface with customers and partners";
5. Contact reduction. "Reduce the number of contacts with customers and third parties";
6. Integration "Consider the integration with a business process of the customer or a supplier";
7. Buffering "Instead of requesting information from an external source, buffer it and subscribe to updates".

The goal of the thesis is to find and look at use cases where business processes are redesigned using digital technologies and extract which Devil's Quadrangle parameters were improved and which redesign heuristics applied.

2.2. Digital technologies and their capabilities

Many papers talk about digital technologies and using them, but until recently, there was not a good definition for digital technologies [9]. Some even say that the phrases "digital technology" and "digital transformation" are just hype words and build on concepts, that have been around for a long time [7]. Lipsmeier et al. [9] take a general definition of technology and define digital technology as "something that is made up of knowledge, skills and know-how for the creation, processing, transmission and use of digital data as well systems and procedures for practical implementation". Simply put, digital technology is any technology, that at its core has digital data. An important distinction is to be made between a digital technology and an application of a digital technology. For example, videoconferencing or videotelephony is a digital technology, but an implemented solution, like Zoom [93] or Skype [94], is an application. Also, to implement a solution, other technologies are used as well. For example, to implement RFID, a tag is needed to store the identity information, a reader is needed to read the information and radio waves are used to transmit the information [26].

Digital technologies are hard to understand in real life use cases, as 2 important aspects were observed during the effort to identify their effects on business processes:

- Digital technologies are not a thing of itself and build up on other technologies and concepts. For example, in a case [19], where a digital twin was implemented in a petrochemical factory to achieve the emergent property of real-time overview and control of the manufacturing operations, it was made up of different technologies, like sensors, PIMS, MES, LIMS to capture data, industrial IoT to collect and transfer data over a network, a real-time database and a historical database to store this information, different analytical tools to process and clean the data, machine learning algorithms to train models and extract knowledge from the data and a dashboard to display this information to users and a DCS which uses the data and input from operators to control the operations.

- In real life applications, digital technologies do not usually exist in isolation and a positive business effect is achieved through the application of different technologies. For example, to create an automatic control and real-time monitoring system for humidity management of trucks in dam construction [40], RFID was used to uniquely identify a watering truck, GPS and GIS to locate the trucks and visualise them on a map, PDAs were used to collect field data and provide warning information to engineers, GPRS was used to communicate information in the field environment and information was stored in a database and visualised in a monitoring PC via a software app.

Digital data in digital technology can be treated as information in a Work System and therefore it can be "used, created, captured, transmitted, stored, retrieved, manipulated, updated, displayed, and/or deleted by processes and activities" [10]. Based on what the digital technology does with the data, Lipsmeier et al. [9], classify digital technologies into 4 categories: Creation – the technology creates output data, Processing – the input and output data are different and therefore are processed, Transfer – the input and output data are not changed, but merely transferred, Application – the technology only takes input data and therefore uses it for functional purposes. Furthermore, digital technologies can be categorized based on where the data input is from and to what medium the output is to – either human, physical, or digital. Also, if data is transformed by the technology, then it can be transform based on time, meaning temporary storing, location, meaning moving over physical distances, or state, meaning new information is generated. The authors say that these make up the technology characteristics of a digital technology.

What are digital technology capabilities? Capability is defined by Cambridge Dictionary as "the ability to do something" [92]. Therefore, a digital technology capability tries to answer the question – what does the technology enable the user to do? Taking the example of the automatic control and real-time monitoring system for humidity management of trucks in dam construction [40], RFID enabled to automatically identify trucks, GPS enabled to track the location of trucks, GIS enabled to virtually represent the trucks, PDA enabled mobility for the engineers, GPRS enabled to connect components over a network and transfer data, database enabled to store the information and a software app enabled to visualise the information. For example, RFID could have been replaced with QR codes as both enable Automatic Identification, PDA could have been replaced with a smartphone as both enable Mobility and GPRS could have been replaced with 4G as both enable Connectivity.

The aim of the thesis is to identify how these digital technology capabilities can enable business process redesign.

3. Related work

This section gives an overview of the state-of-the-art in the world of digital technologies and their relationship to business process management.

The most relevant paper found during the literature review of the state-of-the-art is a conference paper entitled “Technology Impact Types for Digital Transformation” [1]. What makes it important, is that it tries to answer similar research questions as the thesis.

The paper provides a generic model, which helps understand the relationships between the use of digital technologies and how they affect a company. The outcome of the paper is threefold: it proposes a systematic categorization of digital technologies, the impact types of digital transformation and a model which combines the technologies, causes and impact types of digital transformation. The authors classify digital transformation into three dimensions – customer interaction, value creation and value proposition.

To reach the result, they first carried out a literature review to understand the state of the art. The main findings were that there are many proposed ways to conceptualize digital transformation, but it is commonly referred to as a change process that companies go through due to the emergence of new technologies. They found that in research papers there is little knowledge on the potential impact of digital transformation processes on companies. When analysing the empirical contributions, they found that these are usually very context-specific and only handle certain sectors. During the literature review the authors found that there is not a general framework that handles digital transformation in a comprehensive way and covers the causes, impacts and potentials of the digital transformation process in a structured manner.

To understand how digital transformation affects a company, the study in [1] uses a three-step approach. Digital technologies are systemised based on existing literature and structured in a hierarchical manner, then a case-study is conducted on 75 companies and finally the impacts of digital transformation are aggregated into more general impact types. The identified technology instances were further aggregated to a “characteristic” level by using a morphological box methodology. These characteristics somewhat resemble digital technology capabilities.

To gain an understanding of how these technologies can be used for digital transformation, the authors carried out a concept-oriented case-study analysis. They analysed 75 companies of different sizes and from different industries. As a result, they identified 60 different impacts and aggregated them into 10 impact types.

The authors believe that future research could focus to further improve upon their impact types or try to find correlations between the digital technologies and the impact types.

The paper “Approaching Digitalization with Business Process Management” [2] touches upon the digitalization challenges of small and medium-sized enterprises, as they frequently fail to apply digital transformation at its full potential. The authors seek answers to the questions “What are the requirements of digitalization journeys”, “How is BPM related to requirements and challenges of digitalization in SME-s?” and “What capabilities do SME-s need to cope with the requirements and how can BPM be used to increase the feasibility of digitalization?”.

They conducted a systematic literature review, from which they collected 225 requirements that are related to digitalization, which they reduced to nine summarizing concepts. They analysed whether BPM could address these requirements and concluded that it is a good starting point. They proposed a “Process and Enterprise Maturity Model for Digitalized Organizations” framework which could serve as a starting point for companies to approach digital transformation. They found that the necessary capabilities needed to approach digitalization include digital strategy, digital awareness, mindset, and security. The authors also claim that digital transformation remains an emerging topic and requires further research.

The paper by A. Löffler and colleagues [3] tries to find an answer to the question “how to teach business process change in the context of digital transformation?” To carry out their research, they conducted a literature review and focus groups with education experts from different fields. The main identified requirements to carry out a simulation game to teach business process change consist of soft skills, such as working together, making decisions and collaboration, but also knowledge about business process management and knowledge about how to implement a business process in an information system.

The authors mention that further research should develop detailed teaching scenarios.

The paper by A. Van Looy [4] analyses how organizations apply BPM to realize Digital Innovation (DI) and which problems and obstacles companies face when implementing BPM for DI. The author uses the phrase Digital Innovation synonymously with Digital Transformation, by saying that DI is an innovation that brings along business transformations and uses IT to accomplish that. Even though the author examines different frameworks for Digital Innovation, the common finding is that DI brings along transformations in business processes and work environments.

To carry out the research the author conducted 19 interviews with industry experts related to BPM and DI. The experts were from different sectors and had various experience in terms of seniority. The author analysed the most important synergies between BPM and DI by combining generic critical success factors and strategic dimensions. He observed that the approach of combining BPM and DI is dependent on the profiles of the organization and the person carrying out the task. The author also found that a common obstacle is that the business and the IT are not usually well aligned.

The paper entitled "The shape of Digital Transformation" [5] approaches the digital transformation from a more generic viewpoint and tries to understand its nature. The authors found that digital transformation is usually only viewed from the aspect of technological innovation, but it affects all the parts of the organization. They discuss questions like what digital capabilities are affected by digitalization and how the process affects business models, operational processes and user experience.

The authors conduct a systematic literature review and as result they find answers to their initial questions:

1. Digital capabilities impacted by digital transformation are:
    a. Digitization / dematerialization;
    b. Internet technologies;
    c. Analytics;
    d. Mobility;
    e. Social network;
    f. Knowledge and skills.
2. Digitalization transforms business models in the areas of:
    a. Extending market;
    b. Focusing on customer value propositions;
    c. Reshaping existing business model due to market imperatives.
3. Digitalization transforms operational processes in the areas of:
    a. Supplier relationship;
    b. Customer relationship;
    c. Knowledge management;
    d. Marketing;
    e. Delivery;
    f. Sales / Engagement.
4. Digitalization transforms user experience in the areas of:
    a. Digital natives & user maturity;
    b. Collaboration;
    c. Interactions.

They found that the research on how digitalization impacts business models, operation processes and user experience should be deepened.

The paper by Ahmad [12] discusses an approach for conducting PhD research. The research questions and the aim of the study is similar to this paper. Their research questions are "What is the state of the research regarding the link between BPM and IT/technologies?", "How do organizations adopt the best fitting technologies for specific business processes, given the organization's business context?" and "How can a decision tool be build and tested that selects the best fitting technology/-ies for specific business processes, given an organization's business context? ". Ahmad aims to identify process characteristics, technology characteristics, environmental factors, organizational performance, best fitting technology adoption, ambidextrous BPM Characteristics and 8 relationships between them. The goal of this thesis though, is to only research process and technology characteristics and the relationship between.

Mendling et al. [13] discuss about how digital innovation and business process management have so far been researched by different communities and under different assumption, but argue that it is possible to combine them. The authors say try to examine their characteristics and how the different assumptions in these practices could be converged. They say that processes, technologies, and products are intertwined and therefore should be investigated together.

As a result of the state-of-the-art analysis, it was determined that currently there is no comprehensive framework that describes a cause-effect relationship of digital technologies and their effect on business processes. The findings also indicate that there is a need for it.

Pousttchi and colleagues [1] propose a framework for digital technologies and a framework for impacts of digital transformation and call for further research to investigate their correlations. The authors of [3] say that the main focus of teaching business process change should be on how digital technologies affect business processes of an enterprise. A key problem brought out in digitalization by Van Looy [4] is business-IT alignment. Henriette and colleagues [5] say that a research focused on digitalization impacts would be interesting, especially one that considers IT aspects. Ahmad [12] is also aiming to research among other things the relationship between process and technology characteristics. Mendling et al. [13] argue that currently the research into digital innovation and BPM is divergent but should be combined.

4. Systematic literature review

This section gives an overview of the systematic literature review. The first section describes the protocol for the Systematic Literature Review, capturing how it was carried out. The second section provides an overview of the data captured in Systematic Literature Review. The third section describes limitations of the data extracted.

4.1. Protocol

The systematic literature review was conducted following the guidelines given by Kitchenham et al. [14]. The literature review can be separated into 6 distinct phases – planning of the study, initial search, scanning based on title and abstract, analysing paper contents and extracting information, extracting capabilities and finally, framework generation. The data extraction protocol is described in Table 1.

Table 1. Data extraction protocol

Field	Description	Data structure	Extraction time
Identifier	Unique id of the paper	Number	Phase 2
Title	Title of the paper	Free text	Phase 2
Source	From which database the paper information was exported	1 discrete value	Phase 2
Start page	Starting page of the article	Number	Phase 2
End page	Ending page of the article	Number	Phase 2
Abstract	Abstract of the paper	Free text	Phase 2
Page numbers	Number of pages in the article. Used to filter out papers that are 1-4 pages long.	Number	Phase 2
Relevance	Defines how is the paper relevant. Used to capture if matches IC3, IC4 or is related work.	0 OR 3 OR 4 OR R	Phase 3
Result	Defines if the final paper was valid, invalid, or inaccessible.	Valid OR Invalid OR Inaccessible	Phase 4
Main Tech	The main implemented solution	1 discrete value	Phase 4
Other Techs	Which digital technologies enabled the creation of the main solution and what were the other concurrent digital technologies	1..15 discrete values semicomma separated	Phase 4
Tech Description	How the main solution was technically implemented and how each digital technology contributed	Free text description	Phase 4
Process Change	How were the business process changes discussed in the paper	Free text description	Phase 4
Impact	How was the impact of the implementation discussed in the paper	Free text description	Phase 4
Sector/industry	In which sector or industry was the use case from	1 discrete value	Phase 4
Time	Was the business process improved regarding time	0 OR 1	Phase 4
Quality	Was the business process improved regarding quality	0 OR 1	Phase 4
Flexibility	Was the business process improved regarding flexibility	0 OR 1	Phase 4
Cost	Was the business process improved regarding cost	0 OR 1	Phase 4
Heuristic	Which Redesign Heuristics best characterized the business process changes	1..7 discrete values semicomma separated	Phase 4

Field	Description	Data structure	Extraction time
Capability	Which digital technology capabilities were discussed in the papers	1..11 discrete values semi-comma separated	Phase 5

Phase 1 – Planning of the study

First part of the study included identifying state-of-the-art literature to understand what has been done and which areas are not studied yet. The aim was to find any papers that capture any interplay of digital technologies and business process redesign. The state-of-the-art analysis concluded that there are some papers that focus on the digital technologies and their general impact on business, some papers investigate how digital transformation and BPM is related. However, it was identified that there is no comprehensive framework that illustrates a cause-effect relationship between digital technologies and their impact on business processes.

The thesis therefore aims to answer three research questions:

- **RQ1: What digital technologies have been used to redesign business processes?**
- **RQ2: What capabilities of digital technologies have enabled business process redesign?**
- **RQ3: How can digital technologies enable business process redesign?**

To goal was to find papers that include digital technologies, capture process redesign, and present a case study. The following search string was used to identify the initial set of papers:
((digital AND technology) AND (process AND (improvement OR redesign OR change OR optimization OR innovation OR disruption OR transformation))) AND (case AND study)

To do get meaningful information from the papers, 4 exclusion criteria were identified:

- EC1: Is the full-text version digitally accessible? (I)
- EC2: Is the study in English? (I)
- EC3: Is the study less than 5 pages? (E)
- EC4: Is the study a duplicate? (E)
- EC5: Is the older than 2011? (E)

The first 2 criteria are to ensure that the paper can be accessed and understood. Papers that are open access or accessible via the University are considered accessible. Papers that are in any other language cannot be understood and are therefore left out. Third criterium excludes papers that have less than 5 pages as they most likely do not contain enough information for analysis. The fourth criterium excludes any papers that were exact duplicates, as several digital libraries were used to compile the initial list and some papers are present in multiple libraries. As the technology landscape is shifting fast, the digital technologies used before 2011 are not as relevant in carrying out digital transformation today, and therefore the fifth criterium excludes these papers.

To understand if the papers are relevant to the research questions, 4 inclusion criteria were identified:

- IC1: Does the paper include an actual case study?
- IC2: Does the paper include the use of digital technologies?
- IC3: Does the implementation of digital technologies transform the processes in any way?
- IC4: Does the paper discuss how digital technologies was used to redesign the processes?

The first inclusion criterium filters out papers that do not discuss any certain case studies, because the goal is to find papers that discuss real life scenarios. This leaves out for example theoretical frameworks that have not been tested in practice.
The second inclusion criterium filters out papers that have not used digital technologies in a use case. This leaves out any technologies that do not have digital data at its core, for example, electrical, mechanical, hydraulic technologies, physical mechanisms, production techniques, management methods. It ensures that RQ1 can be answered.
The third inclusion criterium filters out papers that have not used the digital technology to transform a process. For example, a digital technology can be used to change the qualities of a product, increase employee satisfaction, or enable a new business strategy.
The fourth inclusion criterium filters out papers that have not discussed how the digital technologies were used to redesign the process. For example, a paper might say that they carried out digital transformation and achieved some business value, but if the implementation of the technologies is not discussed, digital technology capabilities cannot be extracted and linked to redesign heuristics.
The last 2 inclusion criteria ensure that RQ2 and RQ3 can be answered.

The initial papers were acquired from 3 different digital libraries – IEEE Xplore, Scopus, and Web of Science.

Phase 2 – Initial search
The search started with extracting the papers from the digital libraries. For each digital library, the search string had to optimised and if possible, exclusion criteria were added to the initial search string.

Search string for Scopus was the following:
"TITLE-ABS-KEY (((digital AND technology) AND (process AND (improvement OR redesign OR change OR optimization OR innovation OR disruption OR transformation))) AND (case AND study)) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-

TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011))"
It resulted in **929** papers.

Search string for Web of Science was the following:
(TS=(((digital AND technology) AND (process AND (improvement OR redesign OR change OR optimization OR innovation OR disruption OR transformation))) AND (case AND study))) AND LANGUAGE: (English)
Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH
Timespan=2011-2020
It resulted in **572** papers.

Search string for IEEE Xplore was the following:
((digital AND technology) AND (process AND (improvement OR redesign OR change OR optimization OR innovation OR disruption OR transformation))) AND (case AND study)
Additionally, courses and digitally unavailable papers were excluded via filtering.
It resulted in **353** papers.

The three search results were exported from these digital libraries and added into a single Excel file. These 3 data sources were then combined into a single spreadsheet and data captured was Identifier, Title, Source, Start page, End page, Abstract.
It resulted in **1854** papers.

To satisfy EC4, duplicate papers are then removed:

- Title-based duplicate removal reduced 342 papers.
- Abstract-based duplicate removal reduced 19 additional papers.

It resulted in **1493** papers.

To satisfy EC3, duplicate papers are then removed:

- Total page numbers were calculated using start and end page numbers.
- Papers that had length 1-4 pages were removed.

It resulted in **1327** papers.

Phase 3 – Scanning based on title and abstract
As there was no feasible way to reduce the papers further in large numbers, a semantic scanning approach was next based on the defined inclusion criteria.
The aim of this phase was to manually go through each papers' title and abstract and identify if they are relevant to the thesis. The results were collected into a field "Relevance".
The values were assigned accordingly:

- Value "0" meant that based on information in title and abstract, the paper clearly did not satisfy some of the inclusion criteria;

- Value “3” meant that based on information in title and abstract, it was clear that IC1, IC2 and IC3 were satisfied, but it was not clear if the paper actually discussed the implementation, and satisfied IC4;
- Value “4” meant that based on information in title and abstract, it seemed that the papers satisfy all criteria;
- Value “R” meant that the paper did not satisfy inclusion criteria but might be interesting as related work.

This meant, that papers with value 0 were excluded and other papers needed to be accessed to identify if they are valid.

The results of this phase were the following:
- 157 papers with value “3”;
- 163 papers with value “4”;
- 24 papers with value “R”.

It resulted in **344** papers.

Phase 4 – Analysing paper contents and extracting information
The second semantic analysis phase included actually looking inside these papers and extracting information shown in Table 1. During the data extraction, the following information was identified:
- What was the main implemented solution;
- Which digital technologies enabled the creation of the main solution and what were the other concurrent digital technologies;
- How the main solution was technically implemented and how each digital technology contributed;
- How the business processes were changed;
- The business sector / industry;
- The impact of the implementation;
- Which Devil’s Quadrangle performance effects best characterized the business process changes;
- Which Redesign Heuristics best characterized the business process changes.

In addition to extracting contents, papers were assigned an additional field called “Result” to indicate whether:
- the paper is “Valid”, meaning data can be extracted or paper can be used as related work;
- the paper is “Invalid”, meaning it does not satisfy some of the inclusion criteria or;
- the paper is “Inaccessible”, meaning the full-text version of the paper could not be accessed.

The results of this phase were the following:
- 71 “Valid” papers;
- 78 “Inaccessible” papers;
- 171 “Invalid” papers;
- 7 “Valid” relevant papers.

It resulted in **71** final papers.

The final list of identified papers is described in Appendix 1.

Phase 5 – Extracting capabilities
In phase 5, the information from phase 4 was analysed to create a list of digital technology capabilities. The creation of this list is described in detail in section 5.1.

Once the digital technologies capabilities were derived, the 71 papers were again analysed to understand which capabilities apply. This resulted in a semi-comma separated list of capabilities for each paper.

Phase 6 – Framework generation
The final phase of the systematic literature review included analysing the co-existence of digital technology capabilities and process redesign heuristics. As a result, a framework was created, that is described in section 5.2.

4.2. Results

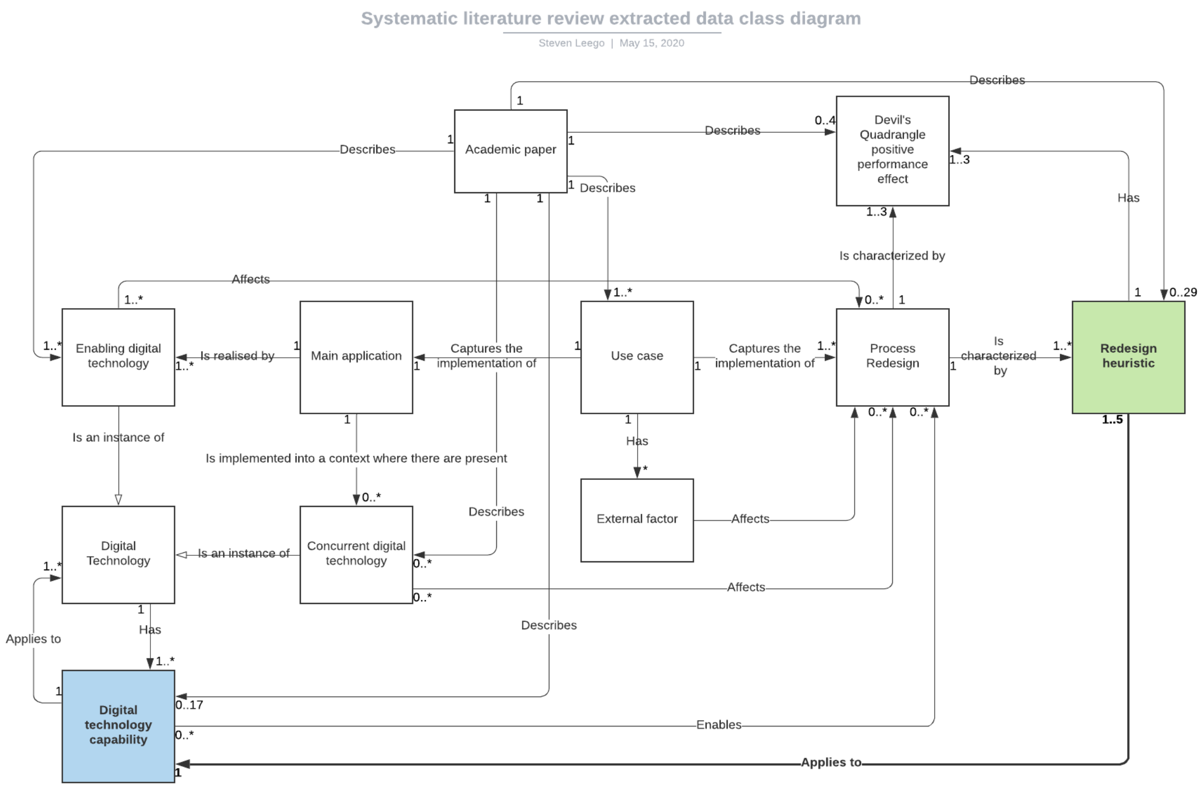

Diagram 1. Systematic literature review extracted data class diagram.

The information in the final list of papers was quite varied and follows a complex structure, which is demonstrated on Diagram 1 and discussed below:

1. Each academic paper discussed one or more use cases, where a main application was implemented.
2. The main application was realised by one or more enabling digital technologies and was usually implemented into a context, where some crucial concurrent digital technologies existed beforehand.
3. Both enabling and concurrent digital technologies are instances of digital technologies and each digital technology has 1 or more digital technology capability.
4. Also, one digital technology capability applies to several digital technologies.
5. The use cases capture the implementation of 1 or more process redesigns and each process redesign is characterized by 1 to 3 Devil's Quadrangle positive performance effects and 1 or several redesign heuristics.
6. The process redesign is affected by both enabling and concurrent digital technologies and any other external factors.
7. The digital technology capabilities enable the process redesign and 1 to 5 redesign heuristics were identified to correlate with a single capability.
8. The paper might or might not discuss the presence of every element and relationship.

For example, in an implementation of BIM-AR solution [36], the following information was captured:

1. **Main Tech** – BIM-AR
2. **Other Techs** - BIM; AR; Web app; Mobile app; Dashboard; Smart device
3. **Tech Description** - BIM refers to a combination or a set of technologies and organizational solutions that are expected to increase inter-organizational and disciplinary collaboration in the construction industry and to improve the productivity and quality of the design, construction, and maintenance of buildings
4. **Process Change** - Quality control process was enhanced with AR technology which gets information from the BIM and displays the planned building information in real life via mobile. Allows for defects reduction, resulting in less rework
5. **Impact** - Improved understanding of the design, access to information, overview of the quality status of the project, reduction in defects and reworking, improved and quicker response and decision-making. BIM approach allows the project team and the stakeholders to share information and to be constantly aware about the project. Adding AR allows to visually retrieve the BIM information.
6. **Sector/industry** - Architecture, Engineering, Construction
7. **Time** - 1
8. **Quality** -1
9. **Flexibility** - 1
10. **Cost** - 1
11. **Heuristic** - Control Addition; Integral technology

12. **Capability** - Real-time; Virtualisation; Coordination; Analytics; Visualisation; Interactivity; Collaboration; Ubiquitous access; Mobility; Sensing

Main technology

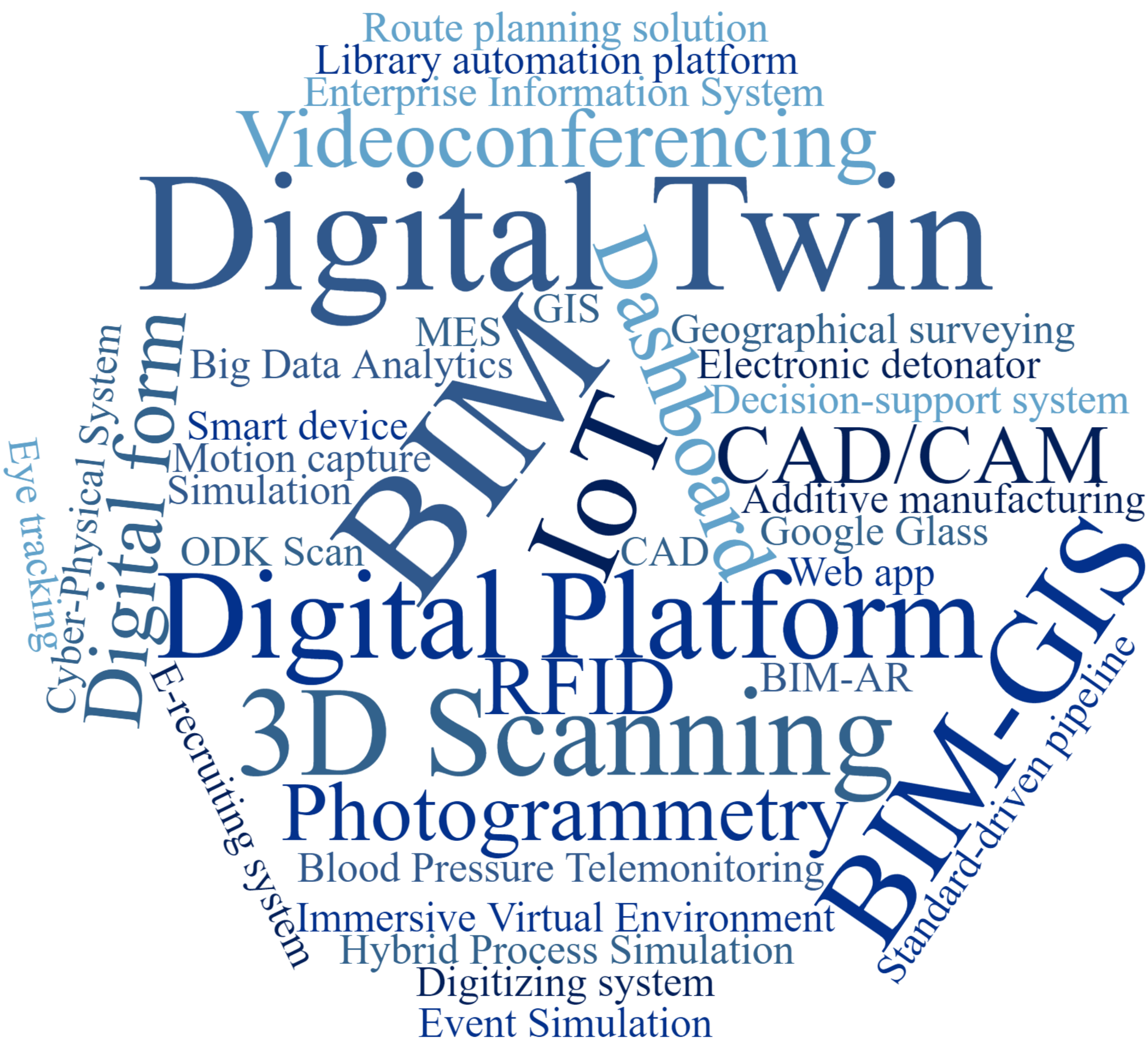

Diagram 2. Main technologies word cloud.

As can be seen from Diagram 2, there are a variety of ways that the main technology / solution has been called in the papers. The main technology can be a single technology like BIM or an ambiguous complex solution, such as Digital Platform. The most common ones are Digital Twin, BIM, BIM-GIS, Digital Platform, IoT, RFID, 3D Scanning, Photogrammetry and CAD/CAM.

Enabling and concurrent technologies

Diagram 3. Enabling and concurrent technologies word cloud.

There is also a great variety of enabling and concurrent technologies among the papers as can be seen from Diagram 3. The most common ones are Smart Devices, Web apps, CAD, Machine Learning, Simulation, Cloud computing, Photogrammetry, and digital image processing.

Technology capabilities

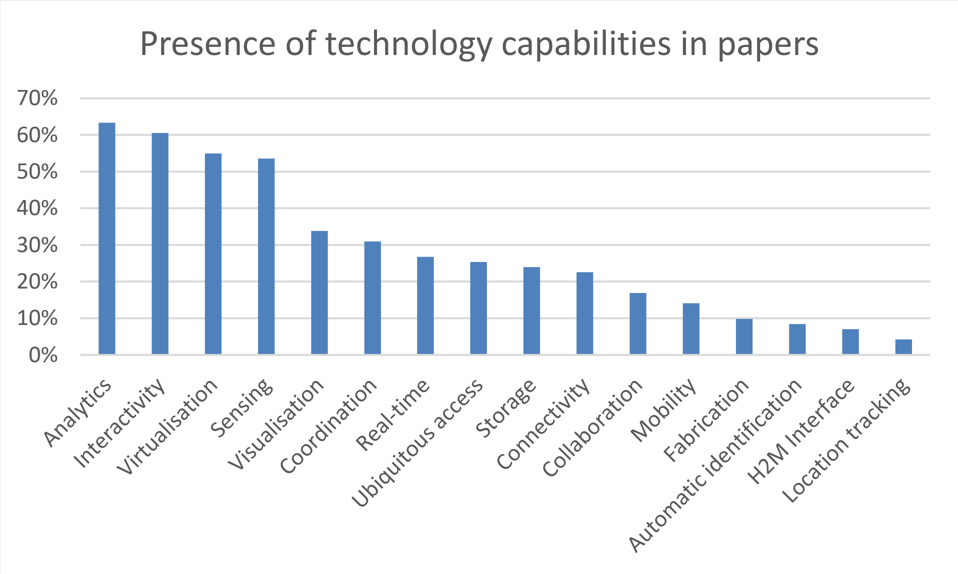

Diagram 4. Presence of technology capabilities in papers.

Diagram 4 shows the presence of digital technology capabilities in the papers. The most common being Analytics, Interactivity and Virtualisation and least common Automatic identification, H2M Interface, and Location tracking.

The capability presence is only captured if it is discussed in the paper. Therefore, a capability like Storage, which is most likely present in almost every solution is only discussed 24% of the times, because it is probably taken for granted.

Sector/industry

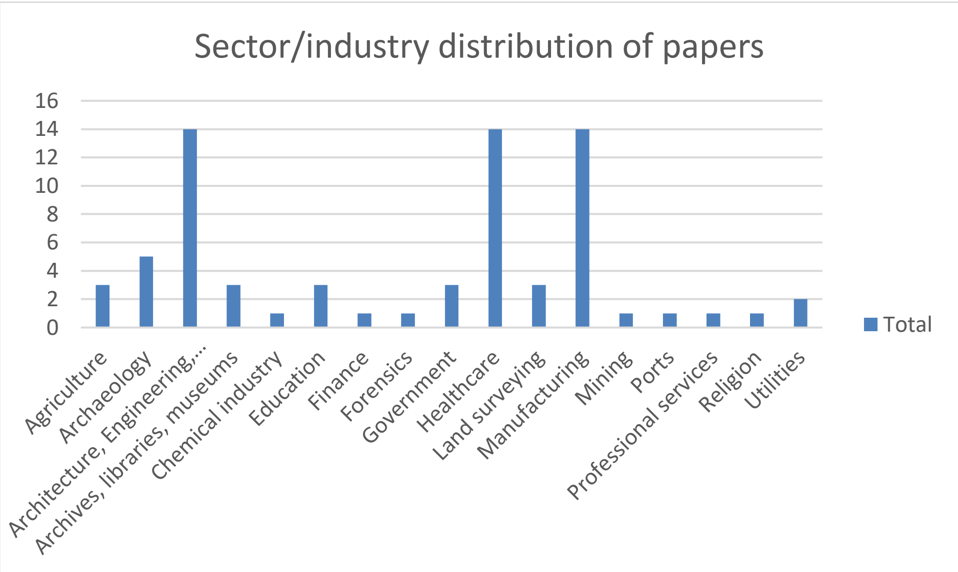

Diagram 5. Sector/industry distribution of papers.

Diagram 5 shows that the most common industries in the papers were Architecture, Engineering, Construction, Healthcare and Manufacturing

Process performance metrics

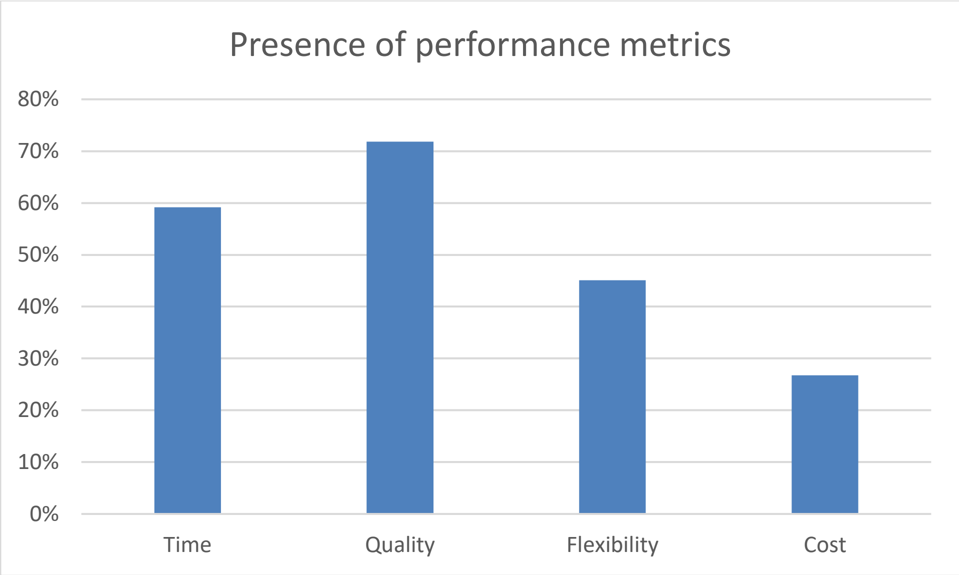

Diagram 6. Presence of technology capabilities in papers.

Diagram 6 shows that introducing digital technologies most frequently resulted in a quality increase and least frequently in the saving of costs.

Redesign heuristics

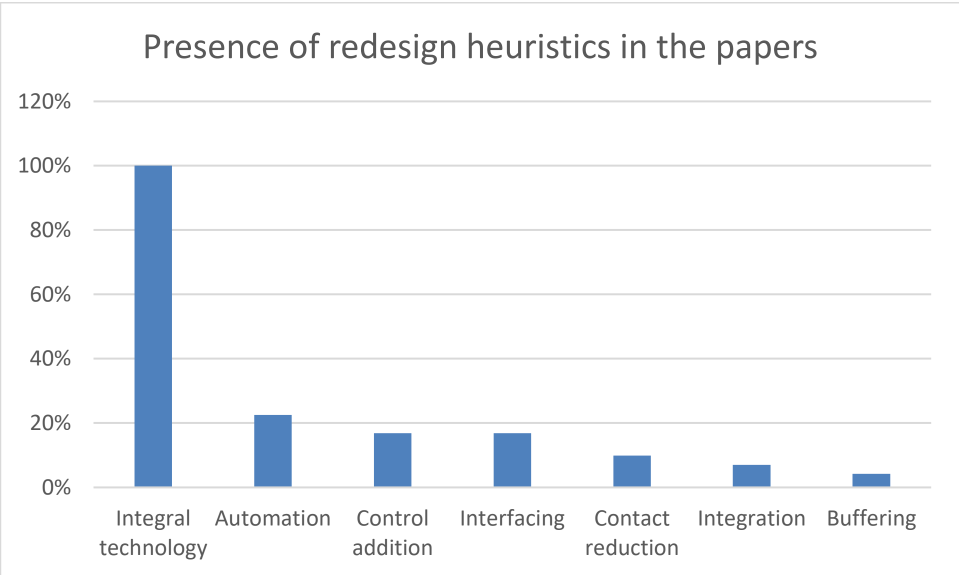

Diagram 7. Presence of technology capabilities in papers.

Diagram 7 shows that every paper's process redesigns exhibit the integral technology heuristic, which makes sense, as the goal of SLR was to capture only papers, where a digital technology is used to redesign a process. Automation, Control addition and Interfacing are also common, each being present in approximately 20% of the papers and Buffering was only present in 4% of the papers.

4.3. Limitations of literature review data

During the Systematic Literature Review, several problems were identified, which constrain from creating a simple "digital technology-to-process redesign impact" framework. These issues are illustrated on Diagram 1 and described below:

1. It is hard to capture quality information, as the information is inconsistent among papers:
    a. Scholars might interpret similar elements, such as digital technology, capability, redesign impact, differently, as there are no widely accepted definitions nor standards describing them. For example, concepts AI, machine learning, data analytics, big data, data mining, SVM might all refer to the same application.
    b. Authors might not always capture all the related elements in the papers, e.g. it is not deemed necessary to capture concurrent/obvious technologies, some process redesign effect or technology capability is not observed/described. For example, things like the Internet and database technology exist in most use cases, but they are rarely discussed, because they are so widespread and obvious in a modern application.
    c. Not all enabling digital technologies and concurrent digital technologies are described in a use case. Similarly, not all process redesigns and their impacts are described in a use case comprehensively, as they are hard to measure, and assessments are usually subjective.
    d. In the papers digital technologies and their capabilities are usually described separately from the whole process redesign impacts, therefore often it cannot be understood how each technology contributed to the impact.
    e. Digital technologies are not implemented in isolation and it is almost impossible to assess their singular effect on a business process, because complex sociotechnical systems contain numerous other external factors, which might affect the process redesign.
    f. Digital technology might not exhibit all of its capabilities in a use case or the capabilities might not be described in papers comprehensively nor homogeneously. For example, BIM by itself exhibits many capabilities, like collaboration, coordination, ubiquitous access, virtualisation, interactivity, storage, but in the context of a building an "Immersive Virtual Environment", BIM was only used a digital data source and most of its inherent capabilities are not relevant [55].
    g. All use cases exhibit the "integral technology" redesign heuristic. Some papers do not even exhibit any other heuristics, therefore extracting redesign heuristics does not provide any valuable information in many cases.
2. In a use case, companies almost always implement complex solutions to achieve intended complex business process redesigns in complex sociotechnical systems, therefore there are several complex multiplicities present:

a. These complex solutions are made up of different technologies with different capabilities. Also, when implementing a new solution, there are usually already other digital technologies present. Both enabling and concurrent technologies though contribute to the process redesign. For example, in a case [19], where a digital twin was implemented in a petrochemical factory to achieve the emergent property of real-time overview and control of the manufacturing operations, many technologies were already present, and many new technologies were implemented, but all of them together create a digital twin application.
b. Digital technologies might have several capabilities, especially more complex technologies. As applied digital technologies are realised by other technologies, their capabilities are dependent on which technologies are used to realise it in a specific scenario. For example, a software application might have ubiquitous access capability if it is realised as a web application, but not if it is realised as a desktop application. Also, one capability applies to several technologies.
c. The paper might contain multiple similar use cases and in one use case redesign several processes but describe process redesign effects only from a general viewpoint.
d. Similarly, the implemented main application might have several enabling and concurrent technologies, which might not be discussed. Also, if any capabilities are even discussed, they might not be discussed in relation to specific technologies.
e. Even though the papers capture use cases where digital technologies enable a process redesign, it is not always possible to capture how each technology and its capability contributed to a process redesign. Also, several capabilities might enable a single process redesign and a single capability might enable several process redesigns, producing another many-to-many relationship.

5. Digital technology capability framework

This section presents the list of digital technology capabilities and the final framework.

This first subsection discusses the derivation of digital technology capabilities from analysing relevant literature and data identified from systematic literature review. The second subsection discusses the creation of the final framework.

5.1. Deriving digital technology capabilities

This section answers the second research and discusses the derivation of digital technology capabilities, as no suitable frameworks were identified, that could comprehensively capture the essence of the digital technologies discussed in the Systematic Literature Review papers. There were 3 main criteria in creating a capability list:

1. The capabilities must be able to explain the inherent abilities of all the technologies identified in the SLR papers;
2. The capabilities must not be overlapping and have to be independent, meaning that any capability can exist without having to have another specific one present;
3. The capabilities should be as general as possible, to capture as many similar technologies as possible, but detailed enough to not become trivial.

There are several sources [9][1][15][11][5] that in some way classify digital technologies or describe their capabilities, but each by themselves do not satisfy these 3 criteria. These sources are analysed and combined into a final list in Table 6. For each of the source, it is brought out what was the limitations and how their classification fits into the final list.

Lipsmeier et al. [9] have identified 8 different digital technology classes - connectivity, storage, analytics, fabrication, visualization, interactivity, H2M interface and sensing (initially named *sensoring*). They aggregate these classes to match the digital data operations, with an addition of Interaction:

- Creation covers H2M interface and sensing;
- Processing covers analytics;
- Transfer covers connectivity and storage;
- Application covers visualisation and fabrication;
- Interaction combines H2M interface and visualisation and covers interactivity.

These technology classes can be thought of as technology capabilities, but as they are based on digital data operations, they only capture the essence of enabling digital technologies. As complex real-life solutions, that were identified in the papers, exhibit many other capabilities, these technology classes are not sufficient to satisfy the first criteria. All 8 of these classes were used to describe the functional technology capabilities.

Pousttchi et al. [1] have identified a long list of technologies, which they categorized into 22 characteristics. It is quite a good characterisation, but there some limitations, which makes in unsuitable to be used fully – some characteristics are not capabilities in the sense, that they do not express "an ability to do something", e.g. it is actually just a technology or technology group, and some characteristics could be captured with a more general capability. Also, there were no definitions for the characteristics, just some examples. The characteristics are shown in Table 2, where each characteristic is either classified into final capabilities or given a justification if it is not applicable.

Table 2. Digital technology characteristics. Adapted from [1].

Characteristic	Final capability/justification
Mobile communication systems	Connectivity
Auto-identification systems	Automatic identification
Positioning	Location tracking
Additive manufacturing	Fabrication
Computer architecture	*Not a capability*
Operating systems	*Not a capability*
Application software	*Not a capability*
Mobile devices	Mobility
Stationary devices	*Not a capability*
Ubiquitous computing	Mobility
Human-computer interface	Interactivity / H2M Interface
Technical augmentation of human body and mind	H2M Interface
Robotics	Fabrication
Mobility	Mobility
Internet of Things	*Not a capability (Virtualisation / Connectivity / Sensing)*
Established database technologies	Storage
New database technologies	Storage
IT infrastructure	Ubiquitous access
Data analytics	Analytics
Big Data	Analytics
Artificial intelligence	Analytics
Information security	Coordination

Cearley et al. [15] define technology capabilities in the context of describing autonomous things and therefore only focus on a specific application and capture a very narrow set of capabilities. The characteristics are shown in Table 3, where for each original capability it is described how it is captured by the final capabilities.

Table 3. Autonomous things capabilities. Adapted from [15].

Capability	Definition	Final capability
Perception	The ability to understand the physical space in which the machine is operating. This includes the need to understand the surfaces in the space, recognize objects and their trajectories, and interpret dynamic events in the environment	Sensing / analytics / real-time
Interaction	The ability to interact with humans and other things in the physical world using a variety of channels (such as screens and speakers) and sensory outputs (such as light, sound and haptics).	Sensing / analytics / real-time / interactivity
Mobility	The ability to safely navigate and physically move from one point to another in the space through some form of propulsion (such as walking, cruising/diving, flying and driving).	Mobility
Manipulation	The ability to manipulate objects in the space (such as lifting, moving, placing and adjusting) and to modify objects (for example, by cutting, welding, painting and cooking).	Fabrication
Collaboration	The ability to coordinate actions through cooperation with different things and to combine actions to complete tasks such as multiagent assembly, lane merges and swarm movements.	Collaboration
Autonomy	The ability to complete tasks with a minimum of external input, and to respond to a dynamically changing space without recourse from cloud-based processing or other external resources.	Coordination

Silva et al. [11] identified 24 key factors that firms should consider when implementing digital factoring in the context of Industry 4.0. This included 12 Critical Success Factors belonging to Technical category. Even though they are not presented as technology capabilities and no definition is provided, they capture important digital technology capabilities. The critical success factors are shown in Table 4, where for each critical success factor it is described how it is captured by the final capabilities.

Table 4. Technical critical success factors. Adapted from [11].

Critical success factor	Final capability/justification
Data management interoperability related to tools and systems integration	Connectivity
Infrastructure, operating system speed and ease software configuration (computers, networks)	*Not a capability*
Real-time data	Real-time
Connectivity	Connectivity
Ability to transform Big Data into knowledge and decision-making	Analytics
System architecture that support data from IoT	Sensing / Storage / Connectivity
Advanced robotics	Fabrication

Critical success factor	Final capability/justification
Cybersecurity	Coordination
Traceability	Coordination
Logistic automation	Coordination
Technical support for DM tools	*Not a capability*
Availability of collaborative tools	Collaboration

Henriette et al. [5] carry out a systematic literature review to identify which digital capabilities are impacted by the digital transformation. Their capabilities capture some important aspects, but do not describe enough of the

Table 5. Digital capabilities. Adapted from [5].

Digital capability	Final capability/justification
Digitization / dematerialization	Virtualisation
Internet technologies	Connectivity
Analytics	Analytics
Mobility	Mobility
Social Network	Collaboration
Knowledge and skills	*Not a capability*

To create a final technology capability list, Table 6 was assembled. It was assembled by analysing the classifications described in this section and digital technology descriptions and terminology in the extracted SLR data. A total of 16 capabilities were identified, that satisfy the 3 criteria. The capabilities have two distinct purposes – to provide functionality regarding digital data or provide business value. These capabilities are given a definition and some example technologies are presented from the identified frameworks and Systematic Literature Review papers.

Table 6. Description of digital technology capabilities.

Purpose	Technology capability	Capability description/definition	Example technologies
Functionality	**Connectivity**	Connectivity enables the technology to send and receive digital data [9].	5G, 4G, General Packet Radio Service (GPRS), Bluetooth, ZigBee, Near-field Communication (NFC), Wi-Fi, Application Programming Interface (API), Electronic Data Interchange (EDI), Internet of Things (IoT), OPC UA
	Storage	Storage enables the technology to store digital data without changing it [9].	Cloud storage, Database technology, Knowledge base, Geographic Information System (GIS)

Purpose	Technology capability	Capability description/definition	Example technologies
	Analytics	Analytics enables the technology to perform evaluations and analyses with digital data [9]. It also enables the user to extract useful information from the data and therefore make better decisions.	Artificial Intelligence (AI), Big Data Analytics, Machine Learning, Process Mining, Optical Character Recognition (OCR), Digital Image Processing
	Fabrication	Fabrication enables the technology to create a physically measurable output, e.g. creating a material object, controlling physical movement, initiating explosion [9].	Additive manufacturing (3D printing), CNC machine, Industrial Robotics, remote detonating, Computer-assisted manufacturing (CAM)
	Visualisation	Visualisation enables the technology to make it visually available to people [9].	Augmented Reality (AR), Virtual Reality (VR), Diagrams, Animation
	Interactivity	Interactivity enables the technology to simultaneously create and use digital data [9].	Smart devices, Distributed Control System (DCS), Supervisory Control and Data Acquisition (SCADA), Graphical User Interface (GUI)
	H2M interface	H2M interface enables the technology to create digital data based on information that is initially available in humans [9].	Brain-computer interface, eye tracking glasses
	Sensing	Sensing enables the technology to generate digital data based on the presence or changes in something [96].	3D scanning, Light Detection And Ranging (LiDAR), Radio Detection And Ranging (Radar), sensors, Unmanned Aerial Vehicle (UAV), satellite, photogrammetry, IoT
Business value creation	**Real-time**	Real-time enables the technology to communicate, show, present etc. at the same time as events actually happen [97]. This is usually present in complex systems that want to control critical business operations.	Real-time computing, Digital Twin, DCS, SCADA, videotelephony
	Virtualisation	Virtualisation enables technologies to change something that exists in a real form into a virtual version [98] (e.g. a building, a product, a machine, a landmark, a worker). Simulation is a special form of virtualisation, as it enables technologies to create a model of a real activity for the purposes of training or solving a problem [99].	GIS, Building Information Management system (BIM), Computer-assisted design (CAD), Computer-assisted engineering (CAE), Digital Twin
	Coordination	Coordination enables technologies to organise separate things so that they work together [100]. This capability is usually exhibited by complex technologies in the context of a business organization and the things organised are different resources, such as people, clients, suppliers, machines, processes, projects, finances etc.	Digital Twin, Enterprise Resource Planning system (ERP), Manufacturing Execution System (MES), Customer Relationship Management system (CRM), Supply Chain Management system (SCM), Product Lifecycle Management system (PLM), BIM, DCS, Robotic Process Automation (RPA), Industrial robotics
	Mobility	Mobility enables technologies to provide their services on smart devices, while travelling from place to place, without being connected by wires [101].	Smartphone, tablet, smart watch, UAV
	Ubiquitous access	Ubiquitous access enables technologies to be accessible from everywhere [102]. This is made possible with networks, such as the Internet.	Cloud computing, web app, mobile app
	Collaboration	Collaboration enables technology users to work together to create or achieve the same thing [103].	Office technology (e-mail, word processing, spreadsheets etc.), collaboration platform, videotelephony

Purpose	Technology capability	Capability description/definition	Example technologies
	Automatic identification	Automatic identification enables technology to automatically recognize and name someone or something [104].	QR codes, bar codes, radio frequency identification (RFID), biometrics, optical character recognition (OCR)
	Location tracking	Location tracking enables the technology to wirelessly locate the position of an item anywhere in a defined space (local/campus, wide area/regional, global) at a point in time that is, or is close to, real time [105].	Global Positioning System (GPS), Bluetooth, RFID, Indoor positioning

5.2. Correlating capabilities to redesign heuristics

The final framework was created to find an answer to the third research question of how digital technologies can enable business process redesign. It was assembled by listing the identified digital technology capabilities and adding to them any redesign heuristic that was simultaneously identified. The framework therefore captures every capability-heuristic pair found in the papers.

In the framework it is described how a capability enables the redesign heuristic. For each capability-heuristic pair 1-2 technologies with use cases are brought out to exemplify the real scenarios of how the technology exhibiting that capability enabled redesign and how the process was redesigned. The results are shown in Table 7. Definitions for technology capabilities can be found in Table 6.

Table 7. Digital technology capability and redesign heuristic framework.

Technology capability	Redesign heuristic	How capability enables the heuristic	Technology example	How the process was redesigned using the technology	Reference
Connectivity	Integral technology	Introducing a digital technology enables to elevate the physical constraints and exchange data digitally within a process / organization.	Bluetooth	A hospital scenario implemented a blood pressure telemonitoring solution to where Bluetooth was used to transfer data from a medical device to a smart device.	[24]
	Interfacing	Connectivity capability enables a technology to create a standardized interface with the customers and partners.	EDI	For a port to gain a standardized way to exchange documents with other participants in the supply chain, they implemented an EDI based Port Community System.	[35]
	Automation	Connectivity enables to automatically exchange information within a process/organization.	Digital Twin / IoT	To gain real-time overview of factory shopfloor status, a petrochemical factory implemented a Digital Twin / IoT solution to collect information from sensors, terminals, and other software solutions automatically without any human input.	[19]

Technology capability	Redesign heuristic	How capability enables the heuristic	Technology example	How the process was redesigned using the technology	Reference
	Buffering	Connectivity enables a technology to obtain updates from an external source.	OPC UA	A manufacturing company created a Digital Twin virtual model for the assembly process and used an OPC UA protocol to provide real-time updated information to it from sensors.	[25]
	Contact reduction	Connectivity enables a digital technology to reduce the number of physical contacts by exchanging information digitally.	Internet	A hospital scenario implemented a blood pressure telemonitoring solution to where blood pressure information from the patient was sent over the internet to the physician, without having to physically make contact.	[24]
Storage	Integral technology	Introducing a digital technology with storage capability enables to elevate the physical constraints and store data digitally within a process / organization.	Knowledge base	An agriculture group created a digital platform that includes a knowledge base using ontology of precision farming, which allowed to digitalize and formalize required knowledge for use in automatic decision-making.	[20]
			GIS	A web-based GIS platform was created to store historical aerial photographs in an interactive way.	[39]
Analytics	Integral technology	Introducing a digital technology with analytics capability enables to elevate the physical constraints and analyse data digitally within a process / organization.	Data mining	An energy company implemented a web-based enterprise information system, where they used data mining to extract comparative statistics from energy usage data and therefore providing decision making support.	[32]
	Control addition	Analytics enables to check the completeness and correctness of a process (or its components) by analysing data.	Motion Capture	A manufacturing company implemented motion capture technology to analyse the workers actions in a packing process to understand if is done ergonomically correctly.	[31]
	Automation	Analytics enables a technology to automatically extract useful information from data and act on that information.	AI	A financial institution implemented an AI-based data driven-decision-making system to automate the decision making in credit application process.	[17]

Technology capability	Redesign heuristic	How capability enables the heuristic	Technology example	How the process was redesigned using the technology	Reference
Fabrication	Integral technology	Introducing a digital technology with fabrication capability enables to elevate the physical constraints and produce physical output using digital data.	Additive manufacturing	In the process of reverse engineering and fabrication of historical artifacts, additive manufacturing was used to create a physical replica of the initial artifact.	[28]
Visualisation	Integral technology	Introducing a digital technology with visualisation capability enables to elevate the physical constraints and make information visually available using digital data.	Dashboard	A government agency built a dashboard to visualise open data about city management in order to envision information in a simpler and more efficient manner.	[23]
	Control addition	Visualisation enables to check the completeness and correctness of a process (or its components) by visualising digital data.	BIM / AR	To carry out quality management a construction company implement a BIM-AR solution, where building models were taken from BIM and superimposed at real construction site using AR to identify if something is built wrong.	[36]
Interactivity	Integral technology	Introducing a digital technology with interactivity capability enables to elevate the physical constraints and make it possible to interact with digital data, i.e. simultaneously create and use data.	Digital Twin / DCS	A petrochemical factory implemented a Digital Twin solution of shopfloor production line and used DCS to provide information to operators and allow them to control mechanisms.	[19]
H2M interface	Integral technology	Introducing a digital technology with H2M interface capability enables to elevate the physical constraints and make it possible to capture digital data from humans.	Digital form	In a hospital a digital form was created to transition from a paper to a digital checklist in the process of carrying out a trauma resuscitation.	[21]
			Eye tracking	In the process of product usability assessment eye-tracking technology was used to capture the eye movements of test participants.	[22]
Sensing	Integral technology	Introducing a digital technology with sensing capability enables to elevate the physical constraints and make it possible to capture digital data from the presence or changes in something.	ODK Scan	A hospital implemented an ODK Scan solution which consisted of a special physical form from where digital information can be captured simply by taking a picture.	[27]
			Photogrammetry	In the process of reverse engineering and fabrication of historical artifacts, photogrammetry was used to capture a 3D representation of the artifact.	[28]

Technology capability	Redesign heuristic	How capability enables the heuristic	Technology example	How the process was redesigned using the technology	Reference
	Automation	Sensing enables to automatically capture digital information within a process/organization	Digital Twin / IoT / sensors	To gain real-time overview of factory shop-floor status, a petrochemical factory implemented an IoT solution to collect information from sensors, terminals, and other software solutions automatically without any human input.	[19]
Real-time	Integral technology	Introducing a digital technology with real-time capability enables to elevate the physical constraints and achieve something in a digital form real-time.	Videoconferencing	A university used videoconferencing to give a lecture in real-time digitally to students.	[34]
	Buffering	Real-time enables the technology to have information available and updated in near real-time.	Digital Twin	A manufacturing company created a Digital Twin virtual model for the assembly process and assembled part and updated it with real-time operational data.	[25]
	Control addition	Real-time enables the technology to check completeness and correctness of a process (or its components) in near real-time.	Digital Twin / IoT / DCS	A petrochemical factory implemented a Digital Twin solution to control shop-floor production line in real-time through implementing a complex IoT solution, that gathers and analyses information in real-time and gives feedback to operator via DCS allowing them to check completeness and correctness at all times.	[19]
Virtualisation	Integral technology	Introducing a digital technology with virtualisation capability enables to elevate the physical constraints and make it possible to create a virtual version of a real entity with digital data.	Simulation	In a hospital a virtual system based on event modelling enabled to understand and test the effects of system change without actually carrying it out.	[18]
			BIM / AR	A construction company implemented a BIM-AR solution in quality management process, where BIM enabled to create a virtual version of the construction site and AR was used to superimpose the virtual version to real life.	[36]
			CAD	In the process of reverse engineering and fabrication of historical artifacts, CAD software used to represent a 3D representation of the artifact.	[28]

Technology capability	Redesign heuristic	How capability enables the heuristic	Technology example	How the process was redesigned using the technology	Reference
	Control addition	Virtualisation enables the technology to check completeness and correctness of a process (or its components) in a virtual form.	Digital Twin / Simulation	In a petrochemical factory a virtual Digital Twin of production line was created using simulating systems (APC, RTO) to compare with real production line data and check for completeness and correctness.	[19]
Coordination	Integral technology	Introducing a digital technology with coordination capability enables to elevate the physical constraints and support the coordination of a system using digital data.	BIM	BIM was implemented during the construction of a complex airport and it was used to coordinate quality control and assurance activities, materials delivery, jobsite planning and logistics, crew tracking, and safety monitoring.	[37]
	Automation	Coordination enables a technology to automate the coordination of a system.	Digital platform	An agriculture group created a digital platform that employs digital agents to automatically carry out agriculture coordination tasks instead of farmers, e.g. forming, coordinating, and monitoring plan for crop processing.	[20]
Mobility	Integral technology	Introducing a digital technology with mobility capability enables to elevate the physical constraints and makes it possible to be easily moved between physical locations.	Smart device	An agriculture group created a digital platform and introduced tablets and smartphones to provide access to farmers while they are moving around.	[20]
Ubiquitous access	Integral technology	Introducing a digital technology with ubiquitous access capability enables to elevate the physical constraints and makes it possible to be easily accessed from anywhere.	GIS / Web app	A government organisation created a web-based Geographical information system to provide its citizens access to various information.	[29]
			Web app	A church created a web app to enable to reach the religious workers anywhere and enabled to give prayers from afar	[30]
	Contact reduction	Ubiquitous access capability enables a digital technology to reduce the number of contacts with a customer or a third party by making a service/product available everywhere.	Chatbot / Social media	A financial institution implemented a chatbot in Facebook to accept their credit applications without direct contact.	[17]

Technology capability	Redesign heuristic	How capability enables the heuristic	Technology example	How the process was redesigned using the technology	Reference
Collaboration	Integral technology	Introducing a digital technology with collaboration capability enables to elevate the physical constraints and makes it possible to work together in an environment based on digital data.	BIM	BIM was implemented during the construction of a complex airport and it was used to for all participants in the construction value chain to work in the same environment, ensuring quick and error-free information exchange between parties.	[37]
	Integration	Collaboration capability enables a digital technology to integrate a customer or a supplier into a business process.	Digital Platform	A port created a digital platform called "Port Community System" where supply chain participants were able to submit documents by themselves and access information relevant to themselves.	[35]
Automatic identification	Integral technology	Introducing a digital technology with automatic identification enables to elevate the physical constraints and makes it possible to identify an entity based on digital data.	Barcode	In the context of implementing an IoT solution in manufacturing, barcode scanners were used to identify products and therefore, provide information about status of orders.	[33]
	Control addition	A digital technology with automatic identification enables to check completeness and correctness of a process (or its components) via entity identification.	RFID	A hospital introduced RFID by attaching chips to surgical equipment to ensure real-time overview of instruments and to avoid accidentally leaving one in a patient.	[26]
	Automation	A digital technology with automatic identification enables to automate entity identification.	RFID	A construction company a solution for automatic truck-watering and used RFID to uniquely identify a watering truck and capture the arrival and leaving times.	[40]
Location tracking	Integral technology	Introducing a digital technology with location tracking capability enables to elevate the physical constraints and capture the location of a physical entity using digital data.	GPS	During the mining process, GPS allows to import "as drilled" or "as designed" hole coordinates into blast design software.	[41]
	Control addition	A digital technology with location tracking enables to check completeness and correctness of a process (or its components) via location tracking.	GPS / GIS	A construction company during the building of a dam used GPS to identify truck's location and display it in a GIS app to ensure process was carried out correctly.	[40]

6. Discussion

This section discusses the results of the conducted study, explains the usefulness and describes further research areas.

Introducing a digital technology to a business context can have all kinds of positive effects on business processes. They can be used to reduce time spent, increase quality, enhance flexibility, or decrease costs. Usually not all of these aspects can be improved with a single change. For example, automating a process helps save time, money and increase quality, but results in less flexibility in the process, as automation requires standardisation. Introducing a technology can also increase flexibility, as digitizing data makes handling it much more flexible, but turning data digital takes an extra effort and might result in additional costs and time spent. Another example, how digital technologies can increase flexibility is introducing additive manufacturing as it enables to easily switch between creating different products and therefore also save time [80], but usually is more expensive than traditional manufacturing methods.

Business processes can be redesigned in numerous ways, but Process Redesign Heuristics [6] are a good way to capture the essence of it, as it provides a finite set of heuristics. These heuristics also provide a good way to investigate the correlation between the digital technologies and business process redesign effects. Out of the 29 total heuristics, 7 were identified to be directly enabled by digital technologies.

Digital technologies are often abstract concepts that are made up from other enabling technologies. For example, a Digital Twin usually consists of simulation and an IoT solution and an IoT solution usually consists of sensors, a network, a storage solution, and a software application [19][25][75]. Also, in real life applications, digital technologies are almost never in isolation and are used along with other technologies to provide business value.

Digital technologies have capabilities, meaning they enable the user to do something. For example, a Graphical User Interface enables the user to interact with a computer, a Digital Twin enables to create virtual replica of an actual entity, a database enables to store data, Internet enables to transfer data, RFID enables to automatically identify an entity, GPS enables to track the location of an entity. These capabilities are shared with other similar technologies. A total of 16 unique digital technology capabilities were identified, that were able to comprehensively capture the essence of 121 different digital technologies found in 71 papers. These 16 technology capabilities all can enable business process redesign. Digital technology capabilities can either be functional, meaning they describe handling of digital data or they provide distinct business value. It was observed that every digital technology exhibits at least one functional capability and complex real-life solutions usually exhibit at least one or more business value-oriented capabilities. Also, many functional capabilities of digital technologies are usually taken for granted and not discussed in the papers.

Combining the digital technology capabilities and redesign heuristics a framework was assembled, where for each capability related to redesign heuristics and examples from the real-life use case cases were given.

This framework can be a tool for business professionals to assist in carrying out digital transformation. The framework will provide them a reference point to start the digital transformation journey as it will enable them to explore the capabilities of digital technologies and how each capability can be used to redesign processes.

The framework could also theoretically be used as an input structure for the development of an AI-based recommendation tool that helps companies make better choices with digitalization.

The results could also be used in further academic research. The framework could be expanded to include the effects of other organisational and environmental factors to be able find the best fitting technology adoption, as is attempted by Ahmad [12]. Also, it could be further studied what other factors are necessary to carry out digital transformation, such as digital maturity level, required competences, transitional management practices, economic viability. Furthermore, it could be studied how digital technologies can affect other aspects of a business [10], such as business service/product design, business model/strategy design, culture, compliance, information security.

7. Conclusions

This section gives an overview of what was accomplished in the study.

The goal of the thesis was to look at digital transformation from the perspective of BPM and find answers to three research questions – what digital technologies have been used to redesign business processes, what capabilities of digital technologies have enabled business process redesign and how can digital technologies enable business process redesign.

First, the most important concepts were explained. A section was dedicated to clarifying what are business processes and digital technologies.

Then, related work was analysed to identify state-of-the-art in the world of digital technologies and their relationship to business process management.

To answer the research questions, a systematic literature review was carried out. It consisted of six distinct phases – first 4 were used to reach a list of papers, that provide information about the research questions. Phases 4 and 5 included information extraction, to answer research questions 1 and 2. Phase 6 consisted of analysing the extracted information to answer research question 3. The results of the literature review were discussed and visualised with several diagrams.

The extracted information was used to create a digital technology capability framework. Initially, a list of 16 digital technology capabilities was created along with definitions and example technologies from the identified literature, which answered the first and second research question. These capabilities were then combined with process redesign heuristics to create a framework, that explains how the capabilities enable process redesign and exemplifies it with real-life use cases, answering the third research question.

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Appendix 1. Final list of identified papers categorised by sectors

Sector	Reference
Agriculture	[20][42] [43]
Archaeology	[28][38][44][45] [46]
Architecture, Engineering, Construction	[37][47][48][49][50][51][52][53][54][55][56][57][58][59]
Archives, libraries, museums	[60][61][62]
Chemical industry	[19][63]
Education	[34][63][64]
Finance	[17]
Forensics	[65]
Government	[23][29][66]
Healthcare	[18][21][22][24][27][67][68][69][70][71][72][73][74][75]
Land surveying	[76][77][78]
Manufacturing	[25][31][33][79][80][81][82][83][84][85][86][87][88][95]
Mining	[41]
Ports	[35]
Professional services	[89]
Religion	[90]
Utilities	[32][91]

Lihtlitsents lõputöö reprodutseerimiseks ja üldsusele kättesaadavaks tegemiseks

Mina, Steven Leego,

1. annan Tartu Ülikoolile tasuta loa (lihtlitsentsi) minu loodud teose

"Uurimus digitaalsete tehnoloogiate võimekusest äriprotsesse parendada",

(lõputöö pealkiri)

mille juhendaja on Dr. Fredrik Payman Milani,

(juhendaja nimi)

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Steven Leego

15.05.2020