Lappeenranta University of Technology
School of Business and Management
Degree Program in Computer Science

Master's Thesis

Petra Helmiö

Open source in Industrial Internet of Things: A systematic literature review

Examiners: Professor Jari Porras
D.Sc. Antti Knutas

Supervisors: Professor Jari Porras

ABSTRACT

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91 pages, 12 tables, 6 figures, 3 appendices

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Keywords: open source, Internet of Things, Industrial Internet of Things, IoT, IIoT, literature review

This Master's thesis is a systematic literature review that studies the usage of open source in the Industrial Internet of Things. The amount of connected devices in the Internet of Things is expected to grow and Industrial Internet is one of the areas that has a lot of potential. This study attempts to find out how open source is used in the industrial domains of the Internet of Things, reasons for and against using open source in different industries, how the usage has changed between the years selected for this study and how the usage has developed between industries. Based on the selected search queries, 27 papers were selected for the systematic literature review. Results drawn from the study suggest that the usage of open source has evolved between different industrial domains.

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
School of Business and Management
Tietotekniikan koulutusohjelma

Petra Helmiö

Avoin lähdekoodi teollisessa esineiden Internetissä: Systemaattinen kirjallisuuskatsaus

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Hakusanat: avoin lähdekoodi, esineiden internet, teollinen internet, IoT, IIoT, kirjallisuuskatsaus

Tämä diplomityö on systemaattinen kirjallisuuskatsaus, joka tutkii avoimen lähdekoodin ohjelmistojen käyttöä esineiden internetissä teollisuudessa. Verkkoon yhdistettyjen esineiden Internetin laitteiden määrän odotetaan kasvavan ja teollinen Internet on yksi alueista, joissa on kasvupotentiaalia. Tämä työ pyrkii selvittämään miten avointa lähdekoodia käytetään teollisessa esineiden Internetissä sekä esittämään syitä avoimen lähdekoodin käyttöön ja käyttämättömyyteen. Näiden lisäksi tämä työ pyrkii tutkimaan miten avoimen lähdekoodin käyttö on muuttunut tutkimukseen valittujen vuosien aikana ja miten sen käyttö on kehittynyt teollisuudessa. Määriteltyjen hakutermien perusteella 27 tutkimusta valittiin tähän kirjallisuuskatsaukseen. Kirjallisuuskatsauksen tulokset ehdottavat, että avoimen lähdekoodin käyttö on kehittynyt eri teollisuudenalojen välillä.

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Petra Helmiö

Helsinki, 22.05.2017

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LIST OF SYMBOLS AND ABBREVIATIONS

AGPL	Affero General Public License
AI	Artificial Intelligence
Apache 2.0	Apache License 2.0
API	Application Programming Interface
BSD	Berkeley Software Distribution
CABA	Continental Automated Buildings Association
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CC	Creative Commons
CDDL	Common Development and Distribution License
CIM	Common Information Model
COMPOSE	Collaborative Open Market to Place Objects at your Service
CPS	Cyber Physical System
CPPS	Cyber Physical Production System
CSV	Comma-Separated Values
DVB	Digital Video Broadcasting
EPC	Electronic Product Code
EPCIS	Electronic Product Code Information Service
EPL	Eclipse Public License
EU	European Union
FOSS	Free and open source software
FSF	Free Software Foundation
GE	General Electric
GNU	GNU’s not Unix!
GPL	GNU General Public Licence
GPS	Global Positioning System
ICT	Information and Communication Technology
IDC	International Data Corporation
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers

IERC	European Research Cluster on the Internet of Things
IETF	Internet Engineering Task Force
IIC	Industrial Internet Consortium
IIRA	Industrial Internet Reference Architecture
IIoT	Industrial Internet of Things
Industrie 4.0	Plattform Industrie 4.0
IoE	Internet of Everything
IoT	Internet of Things
IP-rights	Intellectual Property rights
ISC	Internet Systems Consortium
IT	Information Technology
ITS	Incompatible Timesharing System
ITU	International Telecommunication Union
LGPL	GNU Lesser General Public License
MIT	Massachusetts Institute of Technology
MPL	Mozilla Public License
NFC	Near-field Communication
OFC	Open Connectivity Foundation
ONOS	Open Network Operating System
openHAB	open Home Automation Bus
openJPA	open Java Persistence API
OPN	Open Patent Non-Assertion
OS	Open source
OS	Operating System
OSGi	Open Service Gateway Initiative
OSI	Open Source Initiative
OSMC	Open Source Modelica Consortium
OSS	Open source software
PaaS	Platform-as-a-Service
PHP	PHP: Hypertext Preprocessor
PHP/FI	Personal Home Page/Forms Interpreter
RAMI 4.0	Reference Architecture Model Industrie 4.0

RFID	Radio Frequency Identification
ROS	Robot Operating System
RQ	Research Question
SLR	Systematic Literature Review
SSL	Secure Sockets Layer
SQL	Structured Query Language
TCP/IP	Transmission Control Protocol/Internet Protocol
UML	Unified Modeling Language
XML	Extensible Markup Language

1 INTRODUCTION

In 2014 the open intellectual property movement was categorized as one of the 23 innovative technologies, that has the potential to change IT (Information Technology) and industry by year 2022, along with technologies like cloud computing, Internet of Things, device and nanotechnology, big data and analytics, and networking and interconnectivity. [1] Software sharing has been a part of software development even before concepts like free software or open source were defined. The ideology of free software began to take shape in the 1970s and it drives for the freedom to use, modify and redistribute software. [2], [3]

Free software technologies such as Apache web server and Linux operating system that have been commonly used in server side and in embedded systems have helped define what the Internet is today. The Apache web server has been reported to have dominated the market share of all sites throughout the mid-90s until 2015 [4] and lately major technology forerunners such as Google and Tesla have opened some of their patent portfolio as open source [5], [6]. There are several different terms describing the basic characteristics of open source. Most commonly used terms are free software, open source and FOSS (free and open software). The differences for these terms are described later in the chapter 2. For the purposes of this paper, the term “open source” is used after chapter 2 to encapsulate the whole concept of free and open source software and not limit the search results based on principal differences between different terms and ideologies.

It is estimated that the amount connected devices will be as high as 20.4 billion by the year 2020 with cross-industry connected devices growing from the 1.5 billion in 2017 to 4.4 billion devices by 2020. [7] Industrial Internet of Things (IIoT) will take the current Internet of Things (IoT) into industrial domain and bring smart devices into manufacturing, smart cities and smart factories. There are already implementations of self-driving cars and e-health services that track the health of individuals. The potential for IoT and Industrial Internet to bring intelligent devices to help in everyday life is major. Open source is making its way into the Internet of Things for example by offering an alternative for newcomers to enter competitive markets easier [8], [S9].

The purpose of this study is to find out how open source is used in the Industrial Internet of Things and how the usage of open source has evolved throughout the years. This study attempts to distinguish the differences between open source usage in different industrial domains through a systematic literature review by Kitchenham et al. [9]. A lot of research has been done into the Internet of Things and Industrial Internet, but existing research into open source usage in different industrial domains is scarce. This literature review will attempt to answer the questions; what kind of open source tools are used, how they are used, what industries use different tools and how has the open source usage evolved between the years of 2010 and early 2017.

A literature review was selected as the research method as there are a lot of research into Internet of Things and industrial IoT. The literature review will give a cross-section of the current trends in the topic. The cross-section can be then used to draw out potential development possibilities and future trends in the IIoT and open source research.

This paper is structured as follows. Section 2 presents the background for this work. Additionally, the relevant technologies are shown in detail and existing research in similar areas is presented. In section 3 the research methodology and setting is described and initial results from the result set of the review are drawn. Section 4 answers the research questions and section 5 discusses the results in a more detailed level and gives some future research topic suggestions based on this research. Section 6 draws the conclusions for this work.

2 BACKGROUND AND RELATED WORK

In this section the background for this work and relevant technologies are presented. The contribution of this research is to provide an overview of the utilisation of open source technologies in the Industrial Internet and the Internet of Things in industrial context.

IoT and open source usage have grown rapidly in the last decade. The purpose of this research is to find out how open source is used in industrial IoT and attempt to draw out suggestions as to what kind of potential open source has in industrial setting. This chapter presents open source, IoT and industrial IoT as standalone technologies and in the context of open source, to give the reader a better view of the current state of each concept before the research for this study is presented.

2.1 Software sharing

Since the late 1990s, the open source movement has increased rapidly. Before this rapid increase of free and open software in the 1990s, a movement called the free software movement was challenging the traditional proprietary software development models. [3], [2], [10] Even before the 1970s, software developers were sharing code to develop even better programs. There were simultaneous efforts to achieve free software distribution and publishing of the source code. Many similar paths derived from Unix drove the free distribution of software, for example the BSD (Berkeley Software Distribution) movement in the 1970s and later the GNU project [3].

One of the major contributors to the ideology of shareable software was from Richard M. Stallman, who is one of the founders of Free Software Foundation (FSF) [10]. As he describes in his article "The GNU project", the first software-sharing community that he became a part of in 1971, existed in the MIT (Massachusetts Institute of Technology) Artificial Intelligence Lab. The term "free software" did not exist then, but the AI Lab's timesharing operating system ITS (Incompatible Timesharing System) was distributed freely to anyone who requested it. [2] After the software-sharing community collapsed due to being forced to use proprietary software, Stallman looked for an alternative for the sharing community. This eventually led to the concept of free software.

The concept of free software means that the user is free to run, modify, redistribute copies and distribute derivatives of the software, essentially granting the user freedoms with the software, instead of meaning “free” as in “no-price”. [2] The Free Software Foundation was founded to enable these freedoms for users. [10] FSF was created in 1985 when more people became involved in Richard Stallman’s GNU project (GNU is a recursive acronym for GNU’s not Unix!). FSF drives the rights of users for free software as well as embraces the ideology of freedoms in software development. FSF defines the term free software using four essential freedoms. These freedoms can roughly be shortened to mean that a user has “-- the freedom to run, copy, distribute, study, change and improve the software -- ”, tracing back to Richard Stallman’s definition for free software. [10]

Free software should not be considered public domain software, shareware, freeware or software being made accessible without giving access to the source code [3]. These concepts differ from free software in terms of copyright. Free software preserves the copyright and intellectual property rights of the software and adds additional terms for the distribution of the software. [11] Free software or open source is not just allowing access to the source code. It is a set of criteria that, for example software must meet to be qualified as open source. Both free software and open source definitions allow software to be freely distributed, used and modified, while preserving the intellectual property rights of the creator [11].

2.1.1 Open source vs free software

Projects, such as Python in 1990, PHP/FI (Personal Home Page/Forms Interpreter, later called PHP [PHP: Hypertext Preprocessor]) in 1994, Apache web server in 1995, mSQL (Structured Query Language) and MySQL in mid-1990s contributed to the rapid growth of the free software movement. [3] In the late 1990s a part of the free software community separated from the movement. This group took the term “open source” by Christine Peterson into use and formed the Open Source Initiative (OSI). [2], [3], [10] The Open Source Initiative uses looser terms to define open source software than what FSF uses to define free software. OSI’s definition is formed by a ten point definition, that includes criteria for free redistribution, source code, derived works, integrity of the author’s source code, discrimination against persons or groups, fields or endeavour, distribution of license, restrictions for other software, products and technologies. [12]

Both OSI and FSF offer similar terms for the software, but FSF approved licenses are more restrictive in terms of how businesses can use the software. FSF requires the free software derivatives to be also free software, initially enabling more freedoms for users and developers. OSI allows the open source to be used as part of proprietary software. For example the GNU GPL (GNU General Public License) is also approved by OSI as an open source license, but not all open source licenses are considered free software licenses. When comparing the two ideologies, the free software can be seen as more of a social movement, when open source is considered a development methodology. [13] The basic recommendations in both initiatives are the same, and the disagreement is principal. [3] Free software focuses on the ideology for the software to be free, instead of just on the concept for enabling users to redistribute and modify existing piece of code.

Other commonly used terms for free and open source software is OSS (Open source software) and FOSS (free and open source software). For the purposes of this paper, all forms of free and open source software are considered in the research. After consideration, the term “open source” was selected, to be able to also find out possible commercial derivatives used in different research and not restricting the study only on free software. This offers a wider look into the state of open source in different industries. Later in this paper the term “open source” is used to mean both “open source” and “free software” not limiting the type of software based on principal reasons.

2.1.2 Characteristics of open source

Even with the different ideologies involved in the definition of free and open source, both recognise same characteristics for open source. Usually open source projects are recognised having one person responsible for the whole project. This person is usually the creator of the code or then a volunteer that has been appointed responsible for the project.

[3], [14] The whole community is encouraged to contribute to the project, but usually the person responsible for it approves and maintains the project as a whole.

Other characteristics involve a forum for developers that contribute to the project. The forum can be a mailing list or a separate forum in the Internet, and it usually consists of bug-reports, fixes and contributions for the project. There is usually also a separate forum for the users of the project that may not contribute to the code or have a technical background. Users may look for help in this forum or report bugs that are visible for the end user. Open source projects usually have a website for the project and a place where the source code is released. [3] The website may also be the place where the source code is available, but the source can also be released on sites such as Github.com.

Open source is also characterised by short release cycles, where improvements can be released daily or weekly. The release cycle relies on the beta users or contributing developers to tackle the bugs or suggest improvements and contribute code to the project. [3] For example Linux operating system is written using this kind of fast release cycle, a "bazaar" model as Eric Raymond describes in his publication "The Cathedral and the Bazaar" (2000). These fast release cycles usually involve more than one person and everyone is given the opportunity to contribute equally. In comparison with the traditional model of software development that is more structured "ground-up" model, the open source development model may seem hazardous and unorganised. Eric Raymond calls these two models as the "cathedral" and the "bazaar", for traditional and open source methods, respectively. [14] Open source may also be built from the ground-up, especially in new projects where the groundwork for the project must be done before any kind of effective contribution based on the open source characteristics is able to start. [14]

Known examples of successful open source projects include the Python-programming language, Linux-operating system, Mozilla Firefox –browser, MySQL-database, Apache-server and OpenIoT-middleware for cloud computing. Open source does not need to be limited to applications or middleware, for example a major Internet protocol such as TCP/IP (Transmission Control Protocol/Internet Protocol) is an open standard that can be found from the official IETF (The Internet Engineering Task Force) website [15]. Open standards are not however licensed nor considered as actual OSS.

2.1.3 Licenses

Distributing software as free and open source preserves the copyright of the creator. “Copyleft” is a term initially suggested by Don Hopkins in a saying “Copyleft – all rights reversed” [2]. It was defined suitable for the use of free software, as the copyleft method initially uses the copyright law, but reverses some of the key points to enable more freedoms for the users. [2] The copyleft method has since evolved to be called copyleft licenses that preserve initially the same freedoms depending on the initiative that is using the term. Nowadays most of the free and open source licenses are copyleft licenses. [12] [10]

The licenses ensure freedom for the users to use and distribute the software, without giving away the intellectual property rights. The free software licenses ensure that the code will always stay available. [3] There are also other types of software licenses for free and open source software. A license can also be called “permissive” license. Permissive license grants the freedom to use, distribute, modify and also create proprietary derivatives of the open source work licensed under it. [12] The legal implications of using open source and licensing has awoken discussion through the history of open source. Works such as [16] and [11] focus on the copyright and intellectual property rights of open source software

Some popular licenses include the GNU General Public Licence (GPL), GNU Lesser General Public License (LGPL), Apache License 2.0 (Apache 2.0), BSD License (Berkeley Software Distribution License, either 2-clause or 3-clause), MIT (Massachusetts Institute of Technology) License, EPL (Eclipse Public License) and Mozilla Public License (MPL) 2.0. Each of these licenses has varying terms, but all of them follow the general definitions for free or open source. Some licenses are better suited for organisation and corporate usage, some for academic and scholarly studies [17]. Licenses vary and might not be compatible with each other. For example the GNU GPL-license is not compatible with the definition of open source by OSI, but it is still one of the most popular open source licenses there is. For example the Linux-operating system is licensed under GNU

GPL-license.

Selecting the correct license for a derivative or initial work requires getting familiar with the different licenses, their requirements, limitations and compatibility. Some licenses (those approved by the OSI) may allow the usage of the original work to be distributed as part of proprietary, “closed source” software. This does not mean that the open source component would somehow stop being open source. The source code of the component is still available as it was originally intended by the creator and intellectual property owner. Even with some degree of variation between different open source communities and licenses, it is agreed that the open source licenses “provide a mechanism for enforcing norms”, as described by McGowan (2001) in his work [16], in an environment that would otherwise lack structure.

Similar free approaches for usage of software or artistic works are shareware, public domain and Creative Commons (CC). These are not considered free software (by the definition of free software based on FSF) or open source, even though they grant permissions to use the work. If a work is released under public domain, it does not have to fill conditions and terms unlike open source software licensed under open source licenses. Public domain licensed work can be used as a part of copyrighted derivative or be sold separately from the original work. Creative Commons is a non-profit organisation that offers the right to share and distribute the work using different CC-licenses that grant different rights [18]. Creative Commons -licenses are rarely used in software products.

2.1.4 Open source and industry

IT and software industries have traditionally been the forerunners of utilising open source in their products and processes, compared to other, more traditional industries like manufacturing. [19] Companies such as Google, Salesforce.com and Amazon are known to utilise open source in their products [17] and since the early 2000s, the open source movement has gained more momentum. In 2013 Google announced its Open Patent Non-Assertion (OPN) Pledge, contributing some of its patent portfolio to the pledge [5]. The contribution to the open source community is not big, but it is a step towards a more open

Internet. In 2014 another major technology-leader, Tesla, released its electric vehicle patents as open source [6].

Healthcare is an example of an industry domain that has shown interest in open source earlier than others. A paper by Fitzgerald [17] from 2006 mentions a case of healthcare domain sharing an application as open source. This is suggested as being the first step towards open source spreading across different industries. Another research into health and OS was done by Murray et al. [20], focusing on healthcare in Europe.

Benefits from using open source software include financial savings, full control of the source code and freeing the organisations from having to purchase products only from specific vendors [21]. Open source community is strong and open. There are help, future development and bug-fixes available fast in the community. A downside to these is the sporadic nature in which open source projects are developed or maintained. Some projects are more active than others. There can be even several years without updates to projects. By the time a long forgotten project gains momentum, it may have already driven away potential users. The users of open source may argue the opposite; that the nature and characteristics of the “bazaar” open source model speeds up the development process in a way that cannot be replicated with traditional model without great development costs [14].

As a growing number of companies and organisations embrace open source usage, there are still a lot of areas in which open source might be seen as a not viable option compared to proprietary software and products. Open source is not seen as secure or reliable as traditional closed source, especially in industries such as manufacturing and construction [S12]. The lack of support system and vendor responsibility is an issue to big organisations and even the government [21]. However, the founder of the FSF argues the opposite, that by using software that has released the source code for all to see, the possible threats and errors can be spotted and fixed than in proprietary software, where issues might go unseen until they are exploited. [2]

Other issues for open source include for example the legal issues of using open source licenses and the lack of knowledge regarding the open source licences, the lack of sustainability or further development of open source projects and the missing functionality of the software [20]. In addition, many industry domains require provenance and accountability, protection of intellectual property data and heightened security with private data [22]. On the other hand open source is also seen as enabler for low-cost applications that compete with the traditional industrial systems such as computer-aided design (CAD) and computer-aided manufacturing (CAM) [S18]. Open source can bring the costs of the development of competing systems for traditional proprietary systems down and provide rapid growth in fields such as robotics, architecture and environmental sensing. [S18] With the growth of certain application domains, industries using proprietary tools can benefit from the development of new processes, tools and projects.

Some research into open source for industry domains is presented in [20] (healthcare), [S18] (smart buildings, heritage) and [19] (economy). Research in [22] takes a look into security and privacy issues in the Industrial Internet and industrial applications. When looking at some recent major open source vulnerabilities, such as the Heartbleed-bug in OpenSSL-library (Open Secure Sockets Layer), the research at [22] raises a valid point of critical manufacturing systems tolerance for security and privacy issues. These critical systems are even more vulnerable to exploits as the effects of critical systems, such as power grid and power plants [22], have major impact on the infrastructure and safety of people.

2.2 Internet of Things

The International Telecommunication Union (ITU) writes that “the IoT can be viewed as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies (ICT).” [23] Based on this definition, the Internet of Thing consists of interconnected and interoperable physical and virtual devices, so called “things” that are aware of their surroundings and can communicate through the network. This will make the devices around us initially smarter than what they are now.

IoT as a concept acts as a bridge between the physical world (the devices) and the virtual world (the connectivity and the data that is displayed collected via the physical devices). It enables users to gather information from sources that were previously inaccessible. The terms “interoperability” and “interconnected" refer to the devices’ abilities to connect to any device and share information. [S24] A “thing” can be a wireless sensor network, RFID (Radio Frequency Identification), actuator, sensor or for example a mobile device that is capable of acquiring information from the physical and virtual world and sharing this information with other devices or users [24].

The concept of ubiquitous computing and devices that are commonly used but not visible for the user was first introduced by Mark Weiser in the beginning of 1990s [25]. Nowadays the concept of Internet of Things is described in a similar manner. The term “Internet of Things” was populated by the Auto-ID Center of MIT (Massachusetts Institute of Technology) in late 1990s with research of Radio Frequency Identification, better known as RFID. [26], [27] The RFID technology can be seen as the foundation for Internet of Things. As IoT research developed, more technologies, such as sensors, GPS (Global Positioning System) and mobile devices, became connected to the concept of IoT.

International Data Corporation (IDC) forecast predicts that by 2020 more than 30 billion autonomous devices are connected [28] and over 70% of organisations and enterprises are overseen by a smart executable [29]. Gartner on the other hand gives slightly smaller figures for the connected devices, saying that the connected devices will reach 20.4 billion by 2020. For 2017 the figure is expected to be 8.4 billion, which is a 31% rise from the 2016 figure. [7] This indicates a drastic rise in the amount of devices and IoT applications after 2017.

2.2.1 Smart “things”

Smart “things” reduce the gap between the physical and the virtual world. Internet has already made the world smaller in a sense that everything is reachable just in a few seconds over a network. Connecting smart everyday objects to this network will bridge the gap between distances even more. IoT connects devices in an intelligent manner, making the physical devices “-- capable of being sensed, actuated and connected --” [27], essentially making things smart by combining item identification, sensor and wireless sensor networks, embedded systems and nanotechnology into one system. [27] IoT does not require the device to be actually connected over Internet.

The drive to connect and make everything smarter will eventually lead to a “systems of systems” [29] and the Internet of Everything (IoE), where smaller systems become a part of bigger and more complex systems. [23], [27] At minimum, these devices need to have communication capabilities, so they need to be able to connect over some network or communicate with the surroundings. ITU defines the fundamental characteristics of IoT as interconnectivity, things-related services, heterogeneity, dynamic changes and enormous scale [23]. This means that anything can be interconnected and be able to dynamically adjust to changes, for example on a networking scale. IoT is usually divided into separate layers that consist of different components that work in unison to achieve the common goal. According to ITU, the four layers of IoT are: application layer, service support and application support layer, network layer and device layer. [23] From the perspective of this research, any of the IoT layers can be open source or have open source components. Open source is not limited just to the layers of IoT, but also the surroundings of how the IoT is used or researched.

IoT applications are positioned in the application layer. The service support and application support layer is for processing data and storage. These are common capabilities that can be used by the application and without them the applications would not work. Network layer consists of networking capabilities, interconnectivity control, access and transport resources, as well as control, authentication and authorisation. At the device layer the devices are connected through different kind of wireless and wired technologies, so that the devices are not required to use the networking layer to collect and share information. [23]

2.2.2 IoT applications

Smart phones and smart systems are already here. Plans and designs to improve the quality of life are researched, and steps taken towards connecting different devices over networks. IoT applications are generally seen as consumer devices that are connected over wireless network. Wireless technologies, like RFID and the popular NFC (Near-field Communication) enable devices to share information about objects over short distances. [24] Especially in terms of IoT, this connectivity without wires brings a lot of possibilities for different applications.

Internet of Things is not just for consumer devices or devices steered by humans. Devices that require little or no interaction with a controlling human-party are increasing in numbers. The IoT ecosystem includes also devices, such as Cyber Physical Systems that are capable of functioning autonomously and adjusting automatically to dynamic changes. Cyber Physical Systems (CPS) are devices that combine virtual and physical aspects into one. CPS is usually equipped with sensors to observe the physical world around it. [30]

Devices that have previously been inaccessible or have not had the possibility, or resources for an interface, benefit from wireless connection and bring the devices for everyday use to the consumer [26]. Smart phones are already used as a way to access information all around us. NFC enables ways for smartphones to connect to each other, allowing mobile pay and sharing data. Most of the people are already carrying a smart device around everywhere they go. The paper by Mattern and Floerkemeier [26] suggests that mobile phones could essentially become a browser to this augmented reality that is IoT. Expectations for intelligent applications include the intelligence in applications to become smarter as they are now. The increased use of AI (Artificial Intelligence) and AI-powered processes has the ability to transform the everyday life to enable devices to help in the common everyday tasks [31].

With all the benefits that IoT could bring, there have been some downsides and concerns presented for connecting all the essential devices to the same network. One of these concerns is for privacy and security. Devices are already tracking the location of the user and gathering massive amounts of information. Issues like who has access to the information and what happens when interconnected devices are hacked or contaminated, with for example a virus, are presented in more detail in [26]. Mobile phones tracking the usage and pinging for connections wherever they move are easy targets for malicious parties. Mobile phones are constantly aware of their surroundings and even though they might not act upon found connections and networks, they are still visible for everyone with the right access to see. IoT interoperability and application development for IoT devices present more challenges for IoT. The drive to make the devices smaller will lead to issues like storage and battery. This also presents issues with interconnectivity, like described in [S24]. On the other hand the study in [S11] approaches the challenges of interoperability and application development for EPC (Electronic Product Code) networks through the use of blueprints using the web technologies.

2.2.3 Open source and IoT

Open source has gained hold in software development in recent decades. Operating systems such as Linux and open source programming languages like Python, Perl and Node.js are commonly used everywhere. According to IoT Developer Survey 2017 by the Eclipse IoT Working Group, IEEE (Institute of Electrical and Electronics Engineers), Agile-IoT EU (European Union) and the IoT Council, the top operating system for IoT is Linux (distributions like Ubuntu and Raspbian), with other open source operating systems like ContikiOS (BSD License), MBed (Apache License 2.0) and RIOT (LGPLv2) gaining popularity. Based on the same survey results, open source languages, such as Python and Node.js are commonly used in IoT development. [32]

A cross-industry study about open source IoT projects conducted by Amyx+McKinsey lists several open source solutions for different purposes in the IoT context. The same study suggests that open source is a good enabler for rapid innovation and development of IoT through some of the advantages that open source presents. For example interoperability for IoT can be tackled through open source implementations that can reduce costs for new players to enter the IoT markets. [8] Research paper in [S9] presents similar results. The open source projects found in the [8] include the previously mentioned operating systems such as Raspbian, MBed, ContikiOS and RIOT, as well as middleware IoTSyS, OpenIoT and Kaa and editors and tools such as Node-RED, Freeboard.io and ThingSpeak.

2.3 Industrial Internet of Things

As consumer things are becoming smarter, similar development is expected in industry. Some applications for industry include smart grid, e-health, self-driving cars and drones. Manufacturing plants could track their energy usage and tools, making the manufacturing process faster and save resources. Smart homes could be capable of tracking the energy usage and feed the unused energy back to the power grid [29]. This will mark the change towards smarter industry and Industrial Internet, where industrial devices are interconnected. Embedded devices and sensors are already being used in different industry application domains, so the step to fully intelligent devices does not seem unrealistic.

Industrial IoT devices face different challenges than those devices meant for consumer use. Older industrial applications and hardware is initially "dumber" than devices designed for IoT. This means that industrial IoT devices need to be capable of handling hardwired devices that may be running on legacy systems designed before the Internet was a thing to consider. Legacy systems and new devices need to be able to function seamlessly and the interconnectivity is a big challenge for IIoT. Industrial IoT needs to be capable of keeping track of millions, if not billions, devices running on multiple platforms from different eras. [29] Different surveys, reports and forecasts, such as [7], [32] and [33] from commercial, public and research communities around the Internet suggest that artificial intelligence, shift towards platforms and the industrial domains interest in IoT are the major trends for IoT in 2017.

Technology players such as Cisco, AT&T, Fujitsu, Google, SAP, Siemens, Oracle, IBM and Intel, to mention a few, have invested early in IoT. [27] The amount of data gathered from factories and industrial engines drives the development of smarter factories and smart manufacturing. Smart manufacturing and smart factories are terms for systems that interconnect multiple Cyber Physical Systems into Cyber Physical Production Systems (CPPS) [S4]. Cyber Physical Systems are designed to be modular, interconnected and ubiquitous to monitor processes and make decentralised decisions based on the environment the device is in [S16], [S25].

Gartner forecast for 2017 expects the applications designed for specific industries to drive the use of IoT within businesses. The cross-industry connected devices amount is expected to rise from 1.1 billion in 2016 to 1.5 billion in 2017, further gaining speed in growth by 4.4 billion connected devices in 2020. [7] The interest in IoT generates opportunity for industries to build smart industrial systems that leverage the power of data and networks. Customers and users are demanding products that "-- address their specific needs --" [S25] and connect virtual and physical world unlike seen before. Industrial systems, such as manufacturing and transportation can benefit from IoT and ubiquitous interconnected devices that collect and share information.

Intelligent things are expected to leverage the power of AI also in industrial settings, such as in factory floors and medical facilities [31]. IoT is said to be the "key enabler" for the Industrial Internet [S16], especially when focusing on industrial domains such as mechatronics, Cyber Physical Systems and cloud computing that are in the core of the newest industrial revolution, the Industrial Internet or Industry 4.0 [S25]. Along with smart manufacturing, it is said that by 2025 more than 60% of world population will live in cities [29]. The current infrastructure development is already shifting towards IoT solutions, so smart city research will one of the driving forces of IIoT with manufacturing. [33]

Industrial Internet or Industrial Internet of Things (IIoT) is built for bigger "things" than smartphones and wireless devices. It aims at connecting industrial assets, like engines, power grids and sensor to cloud over a network. Imagine a world where industrial engines could tell their health condition and order repairs based on gathered data before the machines become unusable due to malfunctions. The engines would be smart enough to share the workload with other engines while waiting for the repairs and not causing more delay or additional costs from broken machinery.

Industrial Internet, sometimes called Industry 4.0 or Industrial Internet of Things, is a concept that leverages virtualisation across industrial domains [34]. Industry 4.0 consists of components such as Cyber Physical Systems, Internet of Things, Internet of Services and Smart Factories [34]. Industry 4.0 and IIoT, are not however exactly the same thing, even though the terms may be used in similar context in academia and industry. Industry 4.0 is a term launched by German Federal Minister of Education and Research initiative called

Plattform Industrie 4.0. By the Plattform Industrie 4.0 definition, Industry 4.0, or Industrie 4.0, focuses mainly on the manufacturing level and related functions. [35] Another widely used term, Industrial Internet of Things, is defined by Industrial Internet Consortium (IIC). IIC is an initiative formed by tech-companies like GE, IBM, Cisco and Intel, and it has a more cross-domain approach to the Industrial Internet than the Industry 4.0. [36]

Both initiatives have defined extensive architectural models for the Industrial Internet. Industrial Internet Consortium’s model is called the Industrial Internet Reference Architecture (IIRA) and it focuses on cross-domain and interoperability in IIoT, especially in industrial domains such as energy, healthcare, manufacturing, public domain and transportation [36]. The Industrie 4.0 architecture, the Reference Architecture Model Industrie 4.0 (RAMI 4.0) focuses on the manufacturing domain in depth. It includes four viewpoints of business, usage, functional and implementation for the manufacturing industry. [35] The architectures RAMI 4.0 and IIRA are complementary, which in 2016 led to an announcement that the two organisations would collaborate in certain areas of Industrial Internet, such as the alignment of the reference architecture and different testbeds. The RAMI 4.0 can be seen as an in-depth manufacturing level in the interoperability between IIRA and RAMI 4.0 architectures as described in the architecture model definitions. [3], [35], [36]

There is a growing demand for industrial application leveraging IoT opportunities and possibilities. A research in [37] aims at finding out the current status and future research opportunities for Industrial IoT. It also describes the industrial IoT application domains and presents challenges and technological trade-offs in industrial applications. IoT has a lot of potential for improving traditional manufacturing systems. A research in [S25] takes a look at this potential and suggests that IoT will be transforming the future of manufacturing. Rapidly growing adaptation of cyber physical systems in industries presents security concerns especially for critical industrial systems [22], such as power grids. Similar research focusing on a real-life biosecurity laboratory with an example of building automation is presented in [S19]. The research also briefly describes some security concerns for building automation systems. A paper [30] investigates security issues of cyber physical systems without the industrial context.

2.3.1 Industrial application domains

Industrial Internet of Things can be identified as different application domains based on the domain of the industry. Specific industry domains focus on improving some part of the industry, such as healthcare or smart manufacturing. IIoT can be divided into different application domains, and there exists several different application domain specifications to this date. The approaches to the domains include the cross-domain approach to Industrial Internet by IIC, European Research Cluster on the Internet of Things (IERC) approach based on surveys and research and many other definitions. The few major definitions are presented here.

IIC defines the industry domains as energy, healthcare, manufacturing, public domain (smart cities) and transportation [36]. The European Research Cluster on the Internet of Things identifies the industrial application domains as transportation, building, city, lifestyle, retail, agriculture, factory, supply chain, emergency, health care, user interaction, culture and tourism, environmental and energy [29]. Another approach by Intel, one of the founding companies of IIC divides the industrial domains as automotive, energy, healthcare, smart manufacturing, retail, smart buildings, smart homes, smart transportation, aerospace and defence [38]. The research into Internet of Things from industrial perspective in [37] presents industrial applications in fields of environmental monitoring, healthcare service, inventory and production management, food supply chain, transportation, workplace and home support, security and surveillance. It also describes the trade-offs that have to be made to achieve industrial applications that have a balance of cost and benefits [38].

There is no one clear definition for IIoT domains as there are hundreds of different industrial domains outside the Internet of Things. For the purposes of this study the Industrial Internet Consortium approach was selected to be used with additional general category for those industrial papers that do not fall into the IIC defined categories. In this paper the used industrial application domains are energy, healthcare, manufacturing, transportation, smart cities and general.

2.3.2 Open source and IIoT

In the rise of Industrial Internet of Thigs, more resources have been directed towards open source usage in industry. Industry consortiums, such as The Eclipse Foundation and Open Connectivity Foundation (OFC) promote open source usage especially in the industry context. OFC has partnered with industrial associations such as the Industrial Internet Consortium, CABA (Continental Automated Buildings Association) and DVB (Digital Video Broadcasting) to accelerate industry innovation and help developers and companies to utilise open source more frequently [39]. The Eclipse Foundation is a community for open source software. Originally Eclipse started as the Eclipse Project, which was created by IBM in 2001. The independent non-profit Eclipse Foundation was created a few years later, in 2004. Eclipse focuses on building open development platforms. Eclipse is known for its IDE (Integrated Development Environment), but it has also an IoT project that focuses on open source and IoT. [40]

Existing open source applications for Industrial Internet of Things include Kaa, a middleware platform for the Industrial Internet of Things [41], OpenIoT platform that can be used for example in a Smart City solution [42], IoTSyS integration middleware for IoT, aimed at home and building automation systems [43], and Contiki, an operating system for IoT [44]. The research in [27] mentions some early IoT products that have emerged in industry, such as ZeroG Wireless Wi-Fi chips for embedded systems and Arduino, the open source platform for electronics. The purpose of this study is to find out more information about the current state of open source and Industrial Internet of Things through systematic literature review.

In summary the relevant technologies were presented in this chapter. Open source was described in a detailed level to show the variations between different possibilities for free and open software. Internet of Things and Industrial Internet of Things were presented as own concepts, as well as in the context of open source. Some existing research into IoT, open source and IIoT was presented and a direction for this research set.

3 RESEARCH METHODOLOGY

The goal of this research is to find out the current state of open source usage in IoT using industrial domains. A systematic literature review (SLR) was selected as the research method and conducted in April 2017. The systematic literature review was carried out as described in Kitchenham et al. [9].

Many open source and IoT related research papers demonstrate open source tools outside the actual case or research studies. This research offers a contribution to this area, by attempting to find out how open source is used in different industry domains in Internet of Things context. The aim is to have a thorough look on the existing research and attempt to draw out conclusions and reasons about open source usage in IIoT. A systematic literature review was chosen as the research method for this study because it offers unbiased and thorough cross-section into the current state and history of research in the chosen area. Especially for Internet of Things and Industrial Internet of Things this method is suitable as the research into IoT and the popularity of IoT is growing and trends in the research can be found through the literature review.

3.1 Planning the review

After the systematic literature review by Kitchenham et al. was selected as the research method, a research protocol was developed for the study. Research questions and the research process were developed and evaluated. Experimental searches were carried out to find out the most relevant keywords and digital libraries to be used in the study. The context of Internet of Things, real case studies and selected application domains were defined.

Real case studies were selected for this study to limit and focus the direction of the research to real use cases in industry domains. This aims at finding the current level of usage of open source in IoT applications in industry. IoT research is growing and industries are starting to focus on the switch from traditional industry methods to leveraging networks and Cyber Physical Systems instead of more traditional embedded systems [22]. By selecting real case studies to be reviewed in the study, we can more definitively find out the kind of use cases and industry domains that use open source. The aim is to find out how open source is or could potentially be used. To find out reasons for not using open source, case studies mentioning open source solutions were included in this research.

The research process and research questions were defined before the pilot study was conducted. After the experimental searches were performed, a search strategy was defined and relevant data to be extracted from each study laid out. Then the actual study was conducted using the selected digital libraries. A full list of included and excluded studies was maintained throughout the review process. In the end the results were analysed and described in this study.

3.2 Specifying research questions

The purpose of the research is to look for actual case studies conducted using open source (in any form) and does some specific industry domain have stronger relation to open source compared to other industry domains. The research aims to answer the following questions (RQ):

- **RQ1:** How is open source used within the Internet of Things paradigm in industrial domains?
  - **RQ1.1:** Which open source platforms, tools, protocols, processes are used?
  - **RQ1.2:** How is open source used to solve problems?
  - **RQ1.3:** What are the reasons for using open source?
  - **RQ1.4:** What are the reasons for not using open source?
- **RQ2:** Is the use of open source related to specific industry domain or does it vary across different domains (manufacturing vs. energy for example)?
  - **RQ2.1:** What industry domains use open source?
- **RQ3:** Based on the found set of research papers, how does the open source usage change over the years?
  - **RQ3.1:** How does the usage of open source “evolve” in different industry domains?

A systematic literature review study is used to answer these research questions. Data from the study is extracted manually by hand and a complete list of all the data collected is kept up to date through the research process.

3.3 Search strategy and databases

Pilot queries were carried out in March 2017 attempting to find out those electronic databases that produced the most relevant results. Keywords like “Internet of Things”, “Industrial”, “open source” and “case” were used in the pilot queries. The research questions were used as a base to form the final search query. The main keywords “Internet of Things” AND “industrial” AND “open source” were selected and the results limited to research papers that included a real case study (AND “case study”). A popular synonym IoT for the Internet of Things was linked to the query using OR. Related words for “industrial”, for example “Industrie 4.0” and IIoT were left out of the query to achieve wider result from all over the world and not limiting the papers to specific countries or regions (as “Industrie 4.0” is a term generally used in Europe and especially in Germany [45]).

The selected query was “-- adapted to suit the specific requirements of the different data bases --” as described in Kitchenham et al. [9]. The query structure was altered to suit each database and correct queries found by evaluating the results against the search query manually. The final search queries used for each selected library are described in table 1. Following digital libraries were selected to be used in the systematic literature review in this study; Science Direct, IEEEXplore and ACM Digital library. Libraries that were also included in the pilot study, but not selected for the review, were Citeseer, EI Compendex and Web of Knowledge. These libraries were not included in the study for the purposes of finding the most matches to the selected search queries to produce definitive result in the study.

Table 1. The search queries for each database.

Library	Search query
ACM Digital library	content.ftsec:(+industrial +"open source" +"case study") AND ("internet of things" iot)
IEEEXplore	(("internet of things" OR iot) AND (industrial) AND ("case study") AND ("open source"))
Science Direct	(("internet of things" OR iot) AND industrial AND "case study" AND "open source")

Further search filters were applied outside the context of inclusion and exclusion criteria. The papers were selected between years 2010 and 2017 and a content type filter applied limiting the results to conference publications, journals, magazines and articles. Content type was limited to publications, journals, magazines and articles as these provided the best available results in digital format. For example searching for books presented only less than 10 results of which none were available digitally. Limiting the years researched to 2010-2017 was done for the purposes of finding the relevant growth curve for IoT. The popularity of IoT was found to increase in 2014, so the year 2010 was selected as the starting point to see the early stages of the growth.

3.4 Primary study

Studies included in this review were selected matching additional inclusion and exclusion criteria. Practical issues like language and year of study were considered as described in [9] and the criteria readjusted to filter out not fully available research papers.

3.4.1 Inclusion and exclusion criteria

First the search was conducted on the selected libraries and title, author, abstract, year of publication and keywords gathered from each result. The abstract, title and keywords were read of each result and the titles ordered into a list based on relevance. All titles were listed and a matrix with columns for title, year and source, content type and relevant keywords (columns for IoT, industrial, open source and case study) filled based on the relevance of the publications. If the abstract and keywords seemed relevant to the study, the whole publication was selected for further evaluation by downloading the complete publication. The matrix columns were then updated based on the complete publication text.

Following inclusion criteria were selected for the research papers:

- Context of Internet of Things or IoT
- Industry domain
- Open source tools, platforms, processes were considered or used in the paper or case
- Includes a real case study or a use case
- Type of the research is some of the following:
    - Conference publication (C)
    - Journal (J)
    - Article (A)

Publications were excluded from the systematic literature review with following exclusion criteria:

- Publication does not match all relevant keywords
- No real case study or use case included
- Not in industry domain
- Not fully available
- Not a full publication
- Research in progress or conclusions not available in the paper
- Duplicate paper

The results were evaluated and publications selected for the literature review based on the criteria above. Only full conference publications, journals and articles were included, as the search also produced keynote speeches (1), abstract-only papers (8) and literature listings (3), to mention a few results that were not selected for the study.

Industrial Internet Consortium's definition for industrial application domains was used to categorise the industrial domains into areas that can be compared in the study. The application domains by IIC are; energy, healthcare, manufacturing, smart cities and transportation. If a publication did not match any of the application domains above (such as retail), it was listed in the “general” domain. Table 2 shows list of the gathered industrial domains found in the research papers and the corresponding categorisation used for this study (based on the IIC industrial domains). A full list of the selected papers, and the industrial domains the papers are focused on, can be found in the appendix 2.

Table 2. Industrial domains and corresponding categories.

Industrial domain in the paper	**Domain category**
Energy	Energy
Power grid	
Maritime	General
Retail, supply chain	
Maritime, warfare	
Healthcare	Healthcare
Manufacturing	Manufacturing
War, manufacturing, agriculture	
Farming, manufacturing	
Construction industry, manufacturing	
Manufacturing and service businesses	
Smart offices, smart buildings	Smart city
Smart city, firefighters	
Smart home, smart building	
Smart city	
Smart city, traffic monitoring	
Building, infrastructure	
Tourism, smart room	
Bicycles, manufacturing	Transportation
Traffic, automobile	

Internet of Things context inclusion criteria was applied to each of the publications and for example titles specified only for cloud computing without the IoT context were excluded. Publications in energy, power grid, manufacturing, traffic and construction were selected for the study if the papers included a real case or a use case. If publications were in the context of Internet of Things and researched cloud computing, the titles were selected for further evaluation in this study. Papers including smart devices or smart systems were read more carefully to find out whether the context of the paper was in IoT. If the paper was for smart homes or smart grids for industrial context, it was selected for the study. Other industrial domains that were in the Internet of Things context and described an industrial setting or a case were maritime, warfare, healthcare, infrastructure and retail. Some of the domains described in the actual research paper had a direct relation to some application domain used in this research, but others were divided into the domains based on the context of the paper. The complete list of research papers and their corresponding industry application domains can be found in the appendix 2. The table above depicts how the research papers were divided into the domain categorisation based on the industrial domain they represent. The completed matrix of titles found in the search with the filled matrix with inclusion and exclusion criteria can be requested from the author and it is available on the Internet.

3.5 Conducting the study

The final search was performed in 15. April 2017. The same queries were applied in March 2017 in pilot studies, but final results were defined in mid-April. The date is defined clearly, as new publications were published after March and between the search date and writing this review. A total of 396 publications were found in the search in the date of the search. Table 3 describes the total papers found per each selected library.

Table 3. Publications found using selected search queries.

Source library	**Total papers found**
ACM Digital library	32
IEEEXplore	230
Science Direct	134

After screening and reviewing the publication abstracts, and when necessary the contents and conclusions for the paper, 27 papers in total were selected for the systematic literature review. The number of selected publications per source library can be seen in table 4.

Table 4. Selected publications for the study.

Source library	**Total papers selected**
ACM Digital library	3
IEEEXplore	13
Science Direct	11

Most of the selected papers were journal entries (12). In addition there were 9 conference papers or conference proceedings and 6 articles. Out of the 27 total papers, most (23) were written in the past four (4) years. The research into Industrial Interned has increased after 2010, so the increase in research papers in the recent years corresponds to the IoT and IIoT trends described earlier in this work. The figure 1 shows how the selected papers divide into publishing years. All of the selected papers deal with open source in some level, so the research into open source, especially in industrial context, has increased in recent years.

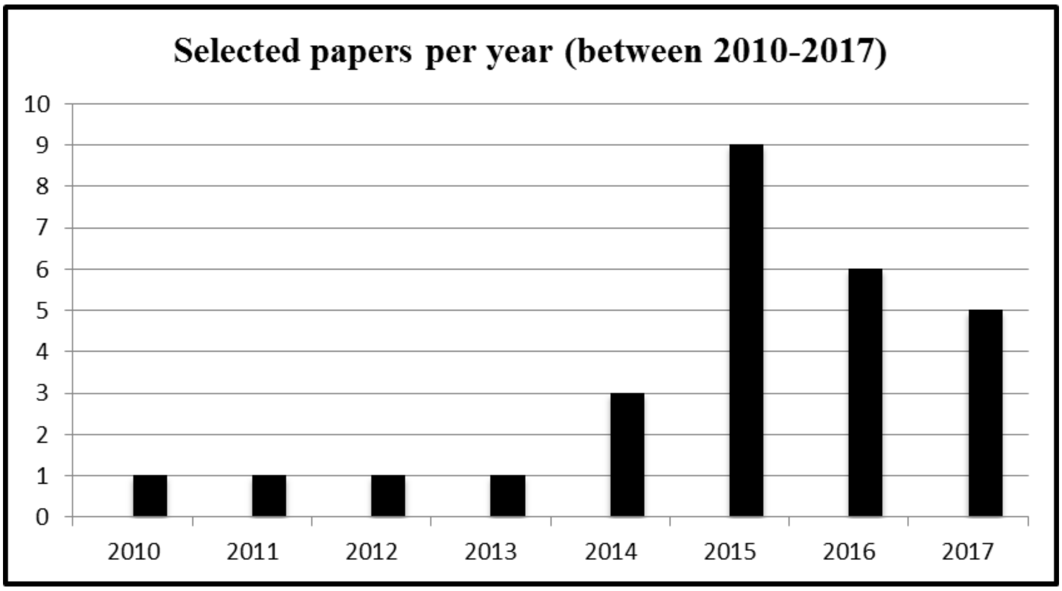

Figure 1. Selected papers published per year.

After the initial review process, the 27 selected papers were read more carefully, and a matrix of the topics and relevant information based on the research questions was filled.

This matrix can be found in the appendix 3. The relevant information based on the research questions were:

- open source used, or mentioned in the research
- reasons for using open source
- reasons for not using open source
- case study description
- other relevant info (for example more detailed description of the OS tools)
- research gaps or future research

The initial keyword matrix corresponding to the search keywords such as IoT, open source, industry context and case study was updated again at this point for the selected papers. The only changes that were made were to the open source –column based on whether the research used open source or open source –based tools or not. The updated matrix can be found in appendix 2. The open source-column legend is as follows:

- open source used in the study (X)
- open source mentioned in the study (O)

Out of the 27 total papers, majority (74%) used open source solutions in some form in the research. Eight (8) papers mentioned open source solutions as examples for similar solutions (6) or mentioned reasons why open source was not a good solution to be used in the case study (2). Total of 20 papers used open source.

The increase in open source research in Industrial Internet and industrial context is demonstrated in figure 2, which shows the numbers for open source used per year. The curve in the figure is similar to figure 1. This indicates that open source research in IIoT follows similar trend as the IIoT research as a whole. Reasons for using or not using open source were not defined in every paper. 11 papers mentioned reasons for using open source tools and four (4) papers listed reasons for not using open source. Total of two (2) papers had both the reasons for using open source and reasons for not using open source. The reasoning behind the paper OS use is described in more detail in the results-chapter.

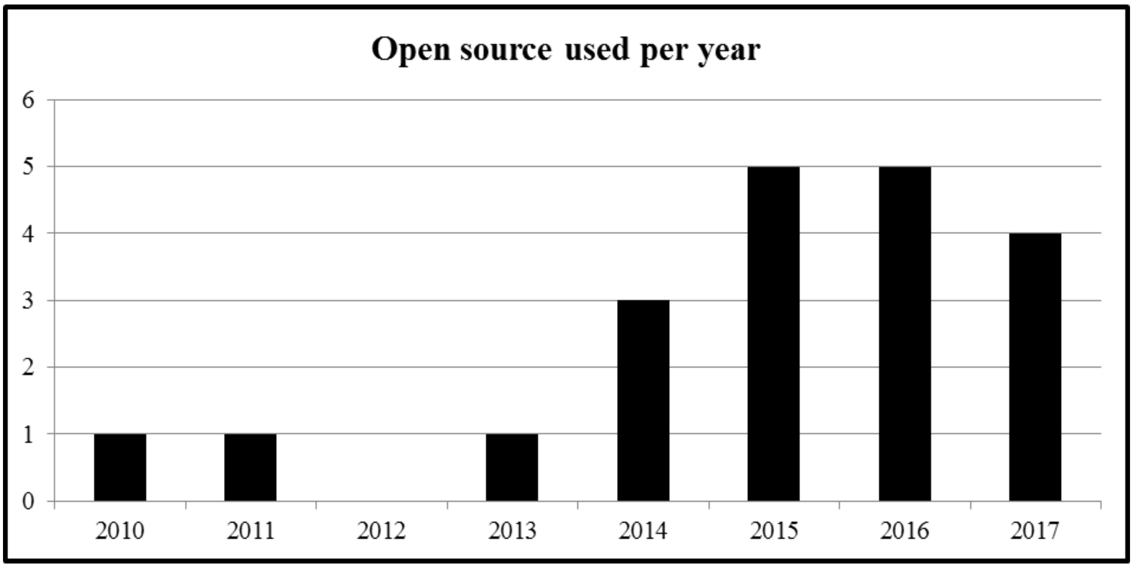

Figure 2. Open source solutions per year.

Cases described in the selected papers were done in industrial setting or described a solution for industry domains. Based on the industry categorisation done earlier in this chapter, the selected papers were divided into categories. All of the categories had at least two (2) papers. The domains and how the papers are divided into the domains, is described in more detail in the results-chapter. The used cases in the papers varied from simulation and prototyping cases such as mobile cognitive machines [S9], limb tracking systems [S7] and city fire response scenarios [S8] to actual case setups like smart buildings [S18], [S21], [S22] and manufacturing [S4], [S13].

3.6 Limitations of the study

While the study was performed thoroughly following the guidelines and steps described in [9] and publication bias attempted to being avoided with careful research and transparent review process, there are some limitations to this study. The research and data extraction was performed by one researcher and the categorisation of different industrial application domains selected based a known consortium that is formed by some of the biggest technological companies working with IoT.

Open source was selected as the point of view in this study because of the researcher's existing participation in the open source community. The open source related information may have been presented in a favourable light due to this reason. Also the digital libraries used in the literature review may not have produced all the results as only three of the libraries producing the widest result set were chosen for this study. Despite these limitations and due to following the research process carefully, this study produces a thorough conclusion into the research area.

4 RESULTS

This chapter answers the research questions and discusses the results in more detail. Open source has been defined earlier in the chapter 2. This study does not limit the open source resources to specific tools, such as platforms or software, but investigates the use of open source as a whole. In the review the different tools were divided into for better comparison of what kind of tools are used and how they are used in different industrial domains. The sub-chapter 4.1 answers to RQ1 and sub-chapters 4.2 and 4.3 answer the research questions RQ2 and RQ3.

4.1 Open source in industrial context

This sub-chapter answers to the questions how open source is used within the Internet of Things paradigm in industrial domains. This chapter will also answer which open source tools are used, how open source is used to solve problems, what are the reasons behind using open source and what are the reasons behind not using open source.

In this research 27 papers were selected for the review. 20 of these papers used open source solutions in the research and the remaining seven (7) presented open source solutions as examples for related tools researched or used in the papers. Table 5 lists the 27 papers selected for this study. The list of papers and the filled matrix based on the review in previous chapter can be found in appendix 2.

Table 5. Publication titles found using selected search queries.

Research title [ref]
A fog computing-based framework for process monitoring and prognosis in cyber-manufacturing [S1]
A framework for the integration of the conviviality concept in the design process [S2]
A full end-to-end platform as a service for smart city applications [S3]
A knowledge-based tool for designing cyber physical production systems [S4]
A lightweight and extensible Complex Event Processing system for sense and respond applications [S5]

A Service-Oriented Architecture for Web Applications in e-Mental Health: Two Case Studies [S6]
Addressing the Smart Systems design challenge: The SMAC platform, Microprocessors and Microsystems [S7]
An Application of SMC to continuous validation of heterogeneous systems [S8]
An edge operating system enabling anything-as -a-service [S9]
An IoT Service Framework for Smart Home: Case Study on HEM [S10]
Cloud computing, REST and Mashups to simplify RFID application development and deployment [S11]
Data-source interoperability service for heterogeneous information integration in ubiquitous enterprises [S12]
Defining the Stack for Service Delivery Models and Interoperability in the Internet of Things: A Practical Case With OpenIoT-VDK [S13]
Efficient naming, addressing and profile services in Internet-of-Things sensory environments [S14]
Integrated visualization and analysis of threats for marine and coastal regions via a Web-based GIS [S15]
Knowledge management of eco-industrial park for efficient energy utilization through ontology-based approach [S16]
Oliot EPCIS: New EPC information service and challenges towards the Internet of Things [S17]
Open-source digital technologies for low-cost monitoring of historical constructions [S18]
Secure RTOS Architecture for Building Automation [S19]
Semantic Model for IoT-Enabled Electric Vehicle Services: Puzzling with Ontologies [S20]
SensorAct: A Decentralized and Scriptable Middleware for Smart Energy Buildings [S21]
Supporting development and management of smart office applications: A DYAMAND case study [S22]
Towards CIM based control centers [S23]
Towards Data Interoperability: Turning Domain Specific Knowledge to Agnostic across the Data Lifecycle [S24]
UML4IoT—A UML-based approach to exploit IoT in cyber-physical manufacturing systems [S25]
Virtual shared workspace for smart spaces and M3-based case study [S26]
Visual Management System to Manage Manufacturing Resources [S27]

Different open source tools were found represented in the review. The tools varied from programming languages and microkernels to higher level software applications and complete systems. Open standards, such as XML (Extensible Markup Language), UML (Unified Modeling Language), CSV (Comma-Separated Values) and open data was mentioned in studies like [S17] and [S23]. However, these are not considered as open source in this research as open standards are not licensed under open source licenses.

Several open source tools were represented in the reviewed research papers. The tools mentioned in the research are listed in appendix 1. Table 6 lists the types of the tools and the names of the tools found in the research. The same data is represented also in figure 3, which shows how many different tools were found in which tool type. The tools were divided into types using the descriptions provided by the research authors and the tools' websites. Based on this, it should be noted that some tools can represent multiple types in reality. For example the "tool" type could be also listed as "software" and "operating system" type as "system". In this research each OSS tool is listed only in one type. Environments, such as Node.js [S3], are commonly used as programming language, and the Arduino ([S1], [S18]) board can be considered as hardware and software, depending on which component of the Arduino was used. To avoid confusion, the whole list of used tools and their corresponding open source licenses can be found from appendix 1.

Most commonly used or mentioned types of tools were open source software (6) and open source frameworks (6). Open source operating systems, such as Ubuntu and the Robot Operating System (ROS) were mentioned in five (5) research papers. Open source platforms were mentioned four (4) times as "platform" and two (2) times as Platform-as-a-Service (PaaS) –types, which in total makes six (6) times for different platforms.

All in all the tools represented in this review were found to represent the following items: application server, environment, EPCIS (Electronic Product Code Information Service) repository, framework, language, library, microkernel, middleware, module, operating system, PaaS, platform, software, system and tool.

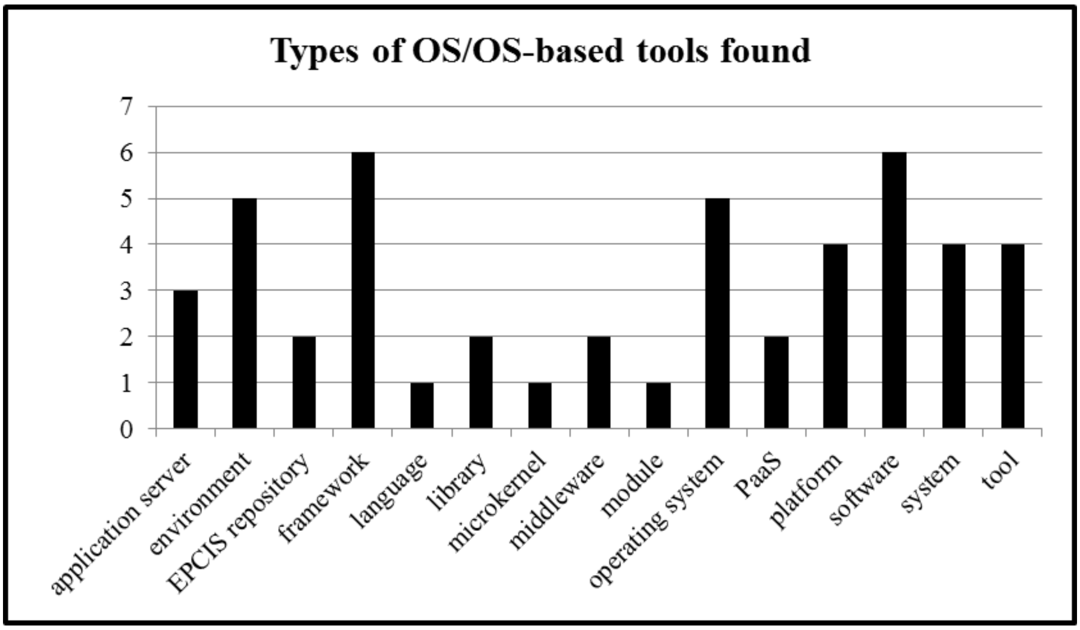

Figure 3. The amount of different open source tools by the type of the tool.

Based on this literature review, open source tools in Industrial Internet of Things are usually platforms, environments or components, which are used to create and develop complete entities that act as a framework for the devices. Open source solutions are used to tackle the interconnectivity and availability issues of IIoT devices, such as autonomous machines and smart buildings. Manzalini and Crespi [S9] suggest that remote controlled devices can have a big impact on the future of Industry 4.0.

Open source is also used in Industrial Interned to provide tools for developers ([S11], [S14]) or to simulate real data in a case study about limb tracking [S7] and a case study for emergency fire-response scenario [S8]. Case study in [S27] uses open source Freeboard.io as the representational dashboard as the case is built on online tools. Open source is also used in cases through application servers and databases, like GlassFish [S4], GeoServer [S15], MySQL [S11], [S23] and MongoDB [S17].

Table 6. The types of the tools collected from the papers.

Type of the tool	**Tool name**	**Mentioned in**
application server	Apache Tomcat	[S11], [S14]
application server	GeoServer	[S15]
application server	GlassFish	[S4]

environment	CLIPS	[S4]
environment	Eclipse IDE	[S11], [S14]
environment	Node.js	[S3]
environment	OpenModelica	[S8]
environment	Papyrus	[S25]
EPCIS repository	Fosstrack EPCIS	[S11], [S17]
EPCIS repository	Oliot EPCIS	[S17]
framework	AllJoyn	[S10]
framework	Apache Hadoop	[S1]
framework	Apache Spark	[S1]
framework	Protégé Ontology Editor	[S16], [S24]
framework	Ruby-on-Rails	[S6]
framework	Sesame	[S20]
language	Python	[S23]
library	jQuery	[S11]
library	OpenLayers	[S15]
microkernel	Muen Separation Kernel	[S19]
middleware	OpenIoT	[S13], [S24]
middleware	SensorAct	[S21]
module	EPCIS Webadapter	[S11]
operating system	Contiki OS	[S11], [S25]
operating system	Linux OS (Ubuntu), Ubuntu Public Cloud	[S11]
operating system	ONOS	[S9]
operating system	OpenStack	[S9]
operating system	Robot Operating System (ROS)	[S9]
PaaS	COMPOSE	[S3]
PaaS	Predix (OS-based)	[S1]
platform	Arduino boards	[S1], [S18]
platform	Geo2Tag	[S26]
platform	Predix Machine (OS-based)	[S1]

platform	servIoTicy	[S3]
software	Apache openJPA	[S14]
software	Esper	[S5]
software	Freeboard.io	[S27]
software	openHAB	[S22]
software	OpenSim	[S7]
software	Processing	[S18]
system	MongoDB	[S17]
system	MySQL	[S11], [S23]
system	Smart-M3	[S26]
system	SmartRoom	[S26]
tool	Apache JMeter	[S14]
tool	Apache Maven	[S11]
tool	Node-RED	[S3]
tool	Oracle VirtualBox	[S11], [S13]

The cases where open source was used, varied between different domains of industry. A digital factory tool for designers was created in [S4] to replace tools such as CAD (Computer-Aided Design) and CAM (Computer-Aided Manufacturing), and smart building and smart city cases were presented in [S14] and [S21]. Some other cases include air traffic control and weather data monitoring case in [S24] and case study of migration of a legacy utility to a CIM (Common Information Model) utility in [S23].

Some similarities exist between the selected tools in the industrial IoT. Two tools listed as the “platform” type are built on open source solutions, instead of being fully open source themselves. These tools are Predix, General Electric’s (GE) industrial cloud based PaaS, and Predix Machine, an Industrial Internet software by GE [S1]. Predix is built on open source Cloud Fondry cloud platform and Predix Machine is built using the open source Java-framework OSGi (Open Service Gateway Initiative) and it acts as a container for the OSGi.

The open source Fosstrack EPCIS repository and specification was used on two occasions [S11], [S17] with two different cases (healthcare and retail, supply chain). The open source cloud solution OpenIoT was also used on two occasions, in traffic monitoring case [S24] and in manufacturing plant scenario [S13]. Both cases focused on monitoring the surroundings through IoT sensors, which is one of the areas the OpenIoT middleware is designed for [42]. More similarities between open source used in the cases come from the COMPOSE (Collaborative Open Market to Place Objects at your Service) open source platform and Predix, PaaS based on open source. These PaaS-solutions are both based on the same open source cloud platform Cloud Fondry. The platform does not have limitations as to what industry the platform is most suitable for, and the cases that it is used for are data-driven machine health and process monitoring in cyber-manufacturing [S1] (manufacturing) and minimising the use of cars and decreasing traffic [S3] (smart city).

Along with the similarities in different platform solutions, the framework OSGi was mentioned in two (2) research papers. The openHAB (open Home Automation Bus) and Predix Machine are both built on the open source OSGi framework. From the table 5 other similarities between used tools can be also noted. The popularity of certain frameworks and platforms can be explained through the industrial setting. These tools are designed for the Industrial Internet of Things and the study focuses especially on the open source tools, it is reasonable to expect some overlap between the used OS-tools in the cases.

4.1.1 Why open source?

Out of the reviewed publications (27), 11 mentioned reasons for using open source. Four (4) papers mentioned reasons for why open source was not used. The full list of which papers were for and which were against can be seen in appendix 2, especially the column “+/- OS”. The legend for the column is as follows:

- reasons for open source usage (+)
- reasons against open source usage (-)
- no reasons mentioned (*)

The analysis of the data why open source is used is done manually by the research author.

Table 7 lists the reasons that were mentioned in the research papers that were for (+) open source usage. Open source community (5), flexibility and easy development of functionalities (4), and promoting open innovation and accelerate development (4) were given as reasons for using open source more often than for example convenience (1) or reusable components (1).

Table 7. Reasons for using open source in the review.

Reason	**Mentioned in**
Accessible up-to-date information	[S15]
Availability and usability of OS software (no need for third party software or hardware)	[S9], [S15]
Bring new players into growing field of telecommunication through the usage of open source	[S9]
Convenience (available as part of some existing solution used in the research)	[S14]
Involvement of different stakeholders (customers, developers, industry, community, any interested party)	[S2], [S18]
Easily scalable	[S3], [S17]
Existing, well established OS solution	[S3], [S13]
Flexibility, easy development of more functionalities, additional programs (multi-program) and inclusion of additional data sources	[S10], [S13], [S15], [S17]
Free software or tools	[S13], [S27]
Open source community	[S2], [S3], [S15], [S18], [S21]
Reduce costs	[S9], [S13], [S18]
Reusable components	[S10]
Sharing of the research product	[S13], [S17], [S21]
To promote open innovation and accelerate development, potential for growth	[S3], [S9], [S10], [S18]

When investigating the reasons for open source usage, it can be noted that each of the given reasons represents one or more freedom or definition of open source. For example open source must be freely accessible without discrimination or limiting the source code to a specific platform, product of technology [12], which combines reasons like availability and usability of OS software (no need for third party hardware or software), free software or tools and flexibility, easy development of more functionalities and additional data sources. Based on the table 7 and open source definitions presented in chapter 2, open source is used for those reasons that make open source what it is today.

From a business point of view, open source can be used to reduce costs and time spent on developing the tools using existing solutions. From a technological point of view, open source can be used to drive innovation and development of the frameworks in a growing IoT. When the source is freely available for anyone to use, it makes the development of new products faster and easier as new players in the technology field do not need to start from the beginning, but they can leverage existing solutions. As [S9] mentions, open source will lower the threshold for new players to enter for example the telecommunications markets that have been previously dominated by only a few players. Similarly [S10] noted that even though the AllJoyn open source –framework by the AllSeen Alliance was not used in the research itself, the framework offers reusable components, possibility to easily add more programs and functions to the framework and to enable and accelerate the development of interoperable peer connectivity and communications, that are in the core of IIoT and IoT research.

To promote open innovation and accelerate technology development is a positive thing from the IoT point of view. IoT research is growing and based on this research open source research seems to follow the trend. Easily scalable and reusable open source components can be integrated as part of the IIoT and in the end also the Internet of Everything, or System of Systems. The existing open source IoT tools have already provided good examples how open source can be used to develop tools that promote openness and interconnectivity.

4.1.2 Reasons for not using open source

There are fewer reasons listed in the reviewed studies for not using open source in comparison to the reasons why open source was used. It can be assumed that those industrial papers that choose not to use open source, will not mention open source tools in the research. This means that using the “open source” as a keyword in the systematic literature review limits the found papers to a result set that mentions open source in some form. All of the reasons found for not using (-) open source are listed in table 8.

Table 8. Reasons for not using open source based on the review.

Reason	Mentioned in	Domain
May require contracted third party support in the product life-cycle to be usable in production environments for commercial, industrial, financial and public domains	[S9]	manufacturing
Open source licenses not being practical	[S12]	manufacturing
Tools not suitable for use based on cost-effective analysis	[S12]	manufacturing
Security and practical reasons	[S12]	manufacturing
OS not used because it was in early development stages and not usable for embedded system with real-time requirements	[S19]	smart city
OS was not used because it failed an initial test of configuration easiness	[S22]	smart city

Despite the flexibility of open source and the growing support and community behind open source solutions, there are valid reasons for not using open source in industrial projects. Manzalini and Crespi [S9] mention that most open source tools may eventually need a third party support provider if a system is to be taken into use in production environments, especially in commercial, industrial, financial and public domains. This is because production environments often have to have support functionalities that are available throughout the day in case of system crashes or malfunctions. Production system malfunctions that are not fixed in a quick manner cost money and resources for the company suffering from them. Especially the public domain may aim for a full vendor support to consider using open source [21].

Open source community is vast, but it does not have the resources to fully offer online support for all of the open source tools available. Open source requests for fixes and functionalities may be scattered around different forums [17], [21]. Most of the time open source is a contribution from one or more developers. This can be seen from how the open source community works; for example Github.com-software development platform workflow includes so called “Pull requests”. This means that anyone is free to contribute to the system, but they have to make a pull request that gets verified by the original authors before the additional code is added to the resource. This improves quality but may slow down the overall process of additional functionalities and bug-fixes.

Other reasons for not using open source software are mentioned in Pang et al. [S12]. They concern the security, privacy and practicality reasons, as well as the cost-effective analysis for open source. Based on the study, especially in manufacturing industry, licences such as GPL and LGPL are not suitable to be used [S12] “-- given the cost-effective analysis --”. Licences such as GPL and LGPL require the derivative software to be licensed under the same license as the original work, so making a profit out of this derivative may prove too difficult for organisations to take interest [21]. A work outside this literature review [22] argues in a similar manner about the security and privacy concerns for industry domains. For construction industry, to which the study in [S12] is focused on, one of the reasons for not using open source tools may be the fact, that the industry relies heavily on more older and traditional methods for information, such as telephone, fax, printed paper sheets and emails [S12].

The reasons mentioned in [S19] and [S22] do not concern the open source as a whole, but the specific reasons why that open source solution was not used in the project. Wang et al. [S19] discusses the maturity of the reviewed open source project and suggests that early research concept phase is not suitable for embedded system with real-time requirements.

Nelis et al. [S22] on the other hand does not utilise open source because the open source tool failed the initial test of being easily configurable. The case in [S22] was to monitor office environment and one of the requirements was the system to be easily configurable. Other papers in this literature review did not mention reasons for not using open source solutions even if they mentioned such open source projects as similar projects to proprietary software, such as Lab of Things [S10] by Microsoft.

Cases where open source was not used varied from construction industry (manufacturing) in [S12] to prototype of a biocontainment laboratory monitoring scenario [S19] and an office environment monitoring application [S22]. Other cases that did not use open source but only mentioned some open source resources, such as Esper, were dangerous goods monitoring during maritime transport case study in [S5] and a smart home energy monitoring case in [S10].

4.2 Open source in different application domains

This sub-chapter answers the research question; is the use of open source related to specific industry domain or does it vary across different domains. This sub-chapter will also answer what industry domains actually use open source tools.

The selected industrial domains for this study were divided into following categories based on the Industrial Internet Consortium's definition for industrial application domains: energy, general, healthcare, manufacturing, smart city and transportation. The process how the industrial domains were selected for which category can be found earlier in table 2. Appendix 2 shows the complete list of selected studies and their industrial domains based on each study. Open source usage is mainly focused to the manufacturing (6) and smart city (6) domains. Healthcare studies (3) use open source more than transportation (2), general (2) or energy (1). Figure 4 shows how open source is divided into the domain categories. The amount of used tools is not taken into consideration in this figure, only the amount of research papers per domain using open source solutions.

In general there is a trend for industrial domains to use low-level open source solutions, such as environments, operating systems and platforms. Table 8 lists the tools used in each domain category. Manufacturing and smart city domains, that have the highest open source utilisation number based on this literature review, use mostly environment (4), operating system (4) and platform (5) or PaaS (2) open source. Some manufacturing domain cases, like [S16] and [S27] use open source for displaying (Freeboard.io) or editing (Protégé Ontology Editor) the data from the IoT solutions.

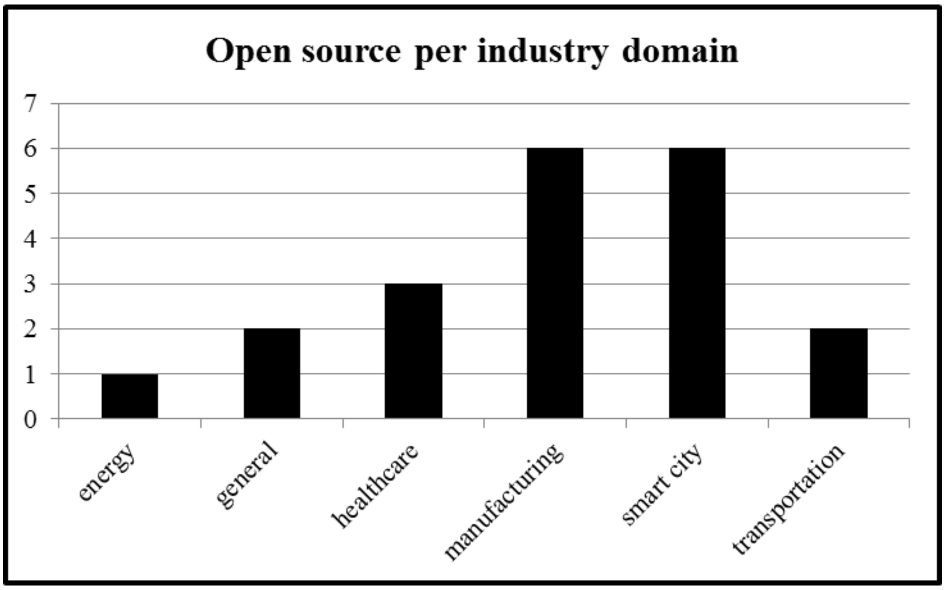

Figure 4. Studies using open source divided into industry domain categories.

Energy, general, healthcare and transportation domains use open source for testing and to achieve tasks that have an effect on the user experience. These domains use open source as systems (3), application servers (2), libraries (2) and frameworks (2) as well as the EPCIS repository open source solutions (3). There is also one (1) environment used in [S11] in the form of the Eclipse IDE Galileo 3.5.0 for performance testing. The frameworks used are Ruby-on-rails in [S6] and Sesame in [S20]. Figure 5 visualises the data from table 9 and it is clearly visible here that manufacturing and smart city uses different open source tools more often than the other domains.

Table 9. Open source tools used in each industry domain.

Domain	Tool	Used	Year	Tool name
energy	language	1	2013	Python
	system	1	2013	MySQL
general	application server	2	2011 2011	GeoServer Apache Tomcat
	environment	1	2011	Eclipse IDE
	EPCIS repository	1	2011	Fosstrack EPCIS
	library	2	2010 2011	OpenLayers jQuery
	operating system	1	2011	Ubuntu
	system	1	2011	MySQL
	tool	1	2011	Apache Maven
healthcare	EPCIS repository	2	2015 2015	Fosstrack EPCIS Oliot EPCIS
	framework	1	2015	Ruby-on-rails
	software	1	2015	OpenSim
	system	1	2015	MongoDB
manufacturing	environment	1	2016	Papyrus
	framework	3	2017 2017 2017	Apache Hadoop Apache Spark Protégé
	middleware	1	2015	OpenIoT
	operating system	4	2016 2016 2016 2017	ROS ONOS OpenStak Contiki OS
	PaaS	1	2017	Predix
	platform	2	2017 2017	Arduino Predix Machine
	software	1	2017	Freeboard.io
	tool	1	2015	Oracle Virtualbox

smart city	application server	1	2014	Apache Tomcat
	environment	3	2014 2014 2016	Node.js Eclipse IDE OpenModelica
	middleware	1	2015	SensorAct
	PaaS	1	2014	COMPOSE
	platform	3	2014 2014 2016	servIoTicy Geo2Tag Arduino
	software	2	2014 2016	Apache openJPA Processing
	system	2	2014 2014	Smart-M3 SmartRoom
	tool	2	2014 2014	NodeRED Apache JMeter
transportation	framework	1	2016	Sesame

All of the industry domains in this research had at least one (1) paper that used open source in the research. Open source is used in all of the domains, but the research into open source and using OS-tools is focused on certain industry domains such as manufacturing and smart city.

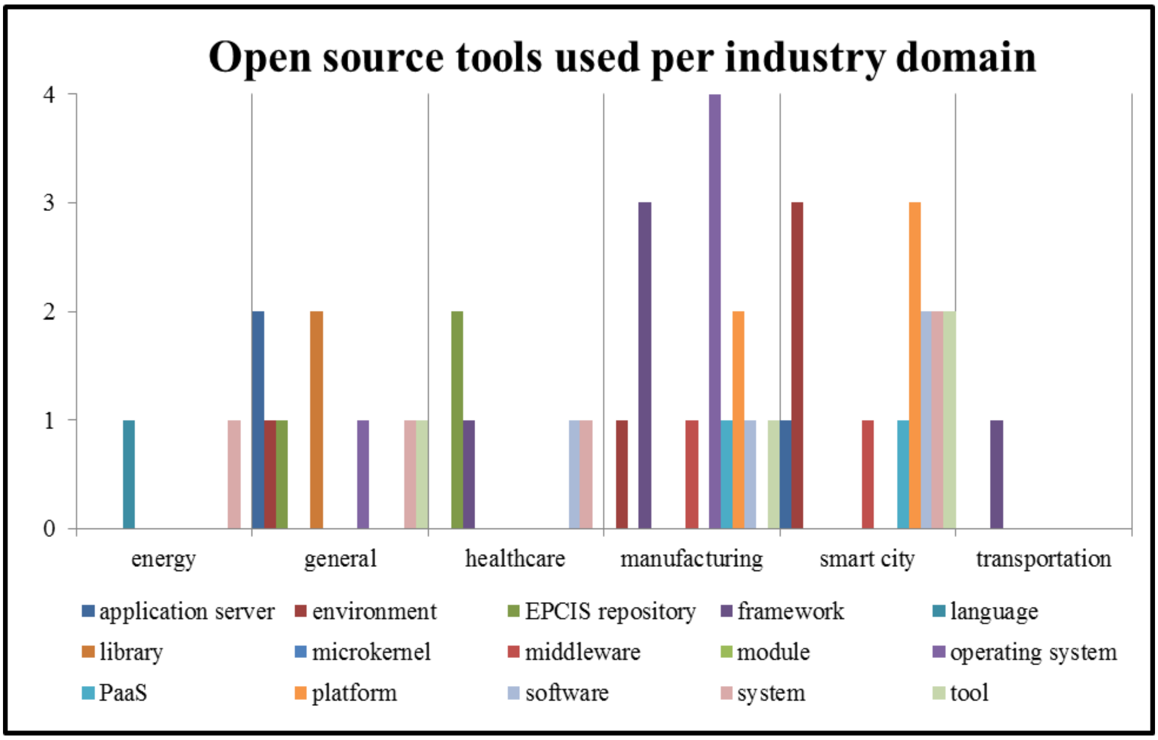

Figure 5. Open source tools in different domain categories based on table 9.

4.3 Open source yearly

This sub-chapter answers the research question RQ3; based on the found set of research papers, how does the open source usage change over the years? This chapter answers also how the usage of open source "evolves" in different industry domains. The third research question investigates how the open source usage develops through the years. Figure 6 represents the years selected to be investigated in this research (from 2010 to early 2017). The year in this literature study means the year when the research paper was published.

Previous chapters have defined that the research into IoT and IIoT has grown in recent years. Based on the figure 2, research into open source or using open source –solutions has increased during the same timeframe. As open source usage has increased outside the industrial domains, it is logical that also industrial application domains start to invest and research open source as there is a lot of potential in it. Figure 6 shows how open source usage has divided into different open source domains during different years.

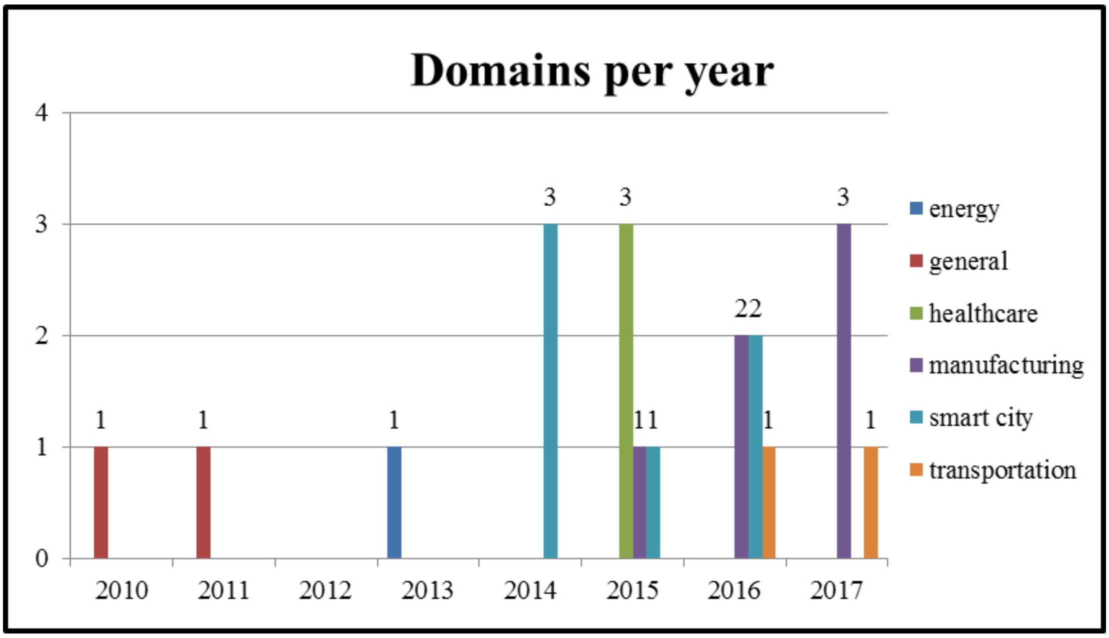

Figure 6. Open source usage per domain per year.

The trend for open source stays small until 2014, when there is a surge in open source tools used in industrial research. Before 2014 there are three (3) papers, [S15] from 2010, [S11] from 2011 and [S23] from 2013 that use open source. The domains for these papers are general (two papers) and energy respectively. The research in [S15] aims at creating a support tool for marine environment monitoring and sensing. The research from 2011 on the other hand creates a store supply tracking chain leveraging the use of RFID-tags and open source [S11]. 2013 research aims at migrating legacy utility to open source CIM-utility [S23]. As the research into IoT and IIoT has increased in a similar manner to the research into open source, it can be expected that industrial domains such as manufacturing and smart cities start to focus on IoT and open source research after the development of concepts such as the Internet of Everything and the System of Systems. It should be also mentioned that there is one research from 2012 that mentions open source tools, but does not use them in the research [S5].

In 2014 the open source research focused on the smart city domain. The three (3) studies that use open source are [S3], [S14] and [S26]. Open source was not mentioned in other papers from 2014. The cases mentioned in these research papers focus on smart homes and smart buildings [S26], monitoring and minimising the use of traffic [S3], and the naming conventions for smart home sensors and actuators connected to the same system [S14].

2015 was the most prolific year for research in IIoT and open source. Total of five (5) papers used open source ([S6], [S7], [S21], [S13] and [S17]) across different domains such as healthcare (3), manufacturing (1) and smart city (1). In 2015 also four (4) papers ([S12], [S19], [S10] and [S22]) from domains of energy (1), manufacturing (1) and smart city (2) mentioned open source, but did not use open source solutions in the research or cases. In 2016 the research into IIoT and open source continued in the same level as in 2015, with total of five (5) research papers ([S8], [S9], [S18], [S20] and [S25]) from smart city (2), manufacturing (2) and transportation (1) domains. A study that only mentions open source in 2016 is [S24] in general domain.

In 2017 research to open source in the industrial context is already close to the same levels as in the previous years (2015 and 2016). To the date of this systematic literature review, there were four (4) papers ([S1], [S2], [S16] and [S27]) from manufacturing (3) and transportation (1) domains. One (1) paper [S4] from manufacturing industry mentioned open source, but did not use it. It can be expected that the research into IIoT and open source grows at the same level as it has in the previous years. The table 10 shows the amount of used open source and the amount of mentioned open source per year. This same data was described in detail earlier in this chapter. The numbers list the amount of papers mentioning or using open source and not the amount of tools used or mentioned (this data is described in figure 5 and table 9).

Table 10. Open source used and mentioned (in the reviewed papers) per years.

Year	Used in (times)	Mentioned in (times)
2010	1	0
2011	1	0
2012	0	1
2013	1	0
2014	3	0
2015	5	4
2016	5	1
2017	4	1

The reviewed papers focused on providing solutions to specific issues. Most of the papers did not suggest any research gaps or future research in the area. The mentioned research gaps and future work suggestions focused on building more predictive models that can be integrated on existing systems and leverage the usage of AI and machine learning. [S1], [S4] The conclusion in [S1] suggests that significant advancements are needed especially in predictive analysis, software portability, computing scalability, infrastructure flexibility and cyber security. [S22] describes similar research issues in interoperability, requesting the issues be tackled on a bigger scale than only locally. Remote services are suggested to be needed to monitor and manage the system. Future research to leverage the scalability of cloud solutions is described in [S11] as well as the aim to get around network delays with real-time system. [S26] described a lack of practical platforms for smart spaces, but suggested that in the future this will be improved.

The research into Industrial Internet and open source has shifted from general and energy domains more towards manufacturing, smart city and transportation domains. This is due to the rise of the interest in the Industrial Internet of Things and initiatives like The Eclipse Foundation and OFC that promote open source in industry and aim to accelerate open source development in IoT as well as IIoT. In this chapter the results from the systematic literature review were presented and research questions answered based on the review. In the next chapter the results are discussed in more detail.

5 DISCUSSION AND FUTURE WORK

This chapter analyses and discusses the results presented from the systematic literature study in previous chapter. Reasons for occurrences of certain tools or the differences in open source usage between different industrial domains are studied and initial conclusions defined.

Open source does not limit what the OSS or platform can do, it is a means of contributing to the community through sharing of the source code. Open source was found to be used in many different ways based on this review. The tools vary from platforms and operating systems to libraries (jQuery, one of the most common JavaScript libraries used nowadays) and modules (such as EPCIS Webadapter) that extend frameworks. Libraries and modules are components that enable functionalities in bigger systems. These bigger systems can be platforms or operating systems that have additional functionalities through the usage of a library or a module.

In the industrial domain the commonly used OSS are framework, software and platform (platform and PaaS). Some of the use cases for open source included testing framework, simulators for prototyping (like in a city fire response situation and a human simulator prototype), programming languages and platforms that were used to create working ecosystems, for example in a smart office situation monitoring the usage of office space. Specific similarities between cases and the usage of certain open source tools in the review were not found, but some generalisations from the used tools can be drawn for industrial domains.

There are similarities between the used tools, such as the OSGi framework and Cloud Fondry cloud platform. This can be explained through the use of the industrial domain context. There is a limited amount of finalised open source solutions that are suitable for industrial use. Based on this it is reasonable to expect some overlap in the usage of different tools or how some tools are built. Further analysis on the tools that were used in the research papers (and not just mentioned as an example) verifies that industry domains use mostly frameworks, software and platforms. In addition, systems and operating systems were used more frequently. This further suggests that the open source used for industrial domains is used to build complete systems or ecosystems for the IoT sensors and actuators to connect and function in.

5.1 Usage development

Energy and general domains are found to be those industrial domains that started using open source before other domains. As the figure 6 in earlier chapter 4 describes, between years 2010 and 2013, the industrial domains that used open source were general and energy. Between years 2010 and 2013 the open source is focused mainly in tools such as libraries (jQuery), systems (MySQL), application servers (Apache Tomcat, GeoServer) and languages (Python). The open source tools used between 2010 and 2013 are listed in table 11 below.

Table 11. Open source tools between 2010 and 2013.

Domain	Tool	Used	Year	Tool name
energy	language	1	2013	Python
	system	1	2013	MySQL
general	application server	2	2011 2011	GeoServer Apache Tomcat
	environment	1	2011	Eclipse IDE
	EPCIS repository	1	2011	Fosstrack EPCIS
	library	2	2010 2011	OpenLayers jQuery
	operating system	1	2011	Ubuntu
	system	1	2011	MySQL
	tool	1	2011	Apache Maven

After the year 2013 the focus has been in domains such as manufacturing and smart city and the tools used has shifted more towards platforms (Arduino, Predix, COMPOSE), frameworks (Apache Hadoop, Apache Spark, Ruby-on-rails) and operating systems (ROS, ONOS, Ubuntu). Table 12 below shows the used open source tools between 2014 and 2017. There is a direct correlation between the development in the use of tools and in the using industry domain. As the types of open source changed towards complete ecosystems that can be used to create complex solutions for IoT, the industry where open source was used changed from general and energy, towards manufacturing and smart city. IoT was first defined in the 1990s, but the research to IoT has gained momentum only during the recent years (and especially in the 2014 as defined earlier in this study). Similar curve can be seen in the research papers selected for this literature review. The seemingly sudden increase in open source usage in 2014 is explained with the increase in open source related research as well as the attention towards open source. As mentioned earlier in chapter 2, in 2014 it was suggested that open source is one of the incoming technologies by 2022.

Table 12. Open source tools between 2014 and early 2017.

Domain	**Tool**	**Used**	**Year**	**Tool name**
healthcare	EPCIS repository	2	2015 2015	Fosstrack EPCIS Oliot EPCIS
	framework	1	2015	Ruby-on-rails
	software	1	2015	OpenSim
	system	1	2015	MongoDB
manufacturing	environment	1	2016	Papyrus
	framework	3	2017 2017 2017	Apache Hadoop Apache Spark Protégé
	middleware	1	2015	OpenIoT
	operating system	4	2016 2016 2016 2017	ROS ONOS OpenStak Contiki OS
	PaaS	1	2017	Predix
	platform	2	2017 2017	Arduino Predix Machine
	software	1	2017	Freeboard.io

	tool	1	2015	Oracle Virtualbox
smart city	application server	1	2014	Apache Tomcat
	environment	3	2014 2014 2016	Node.js Eclipse IDE OpenModelica
	middleware	1	2015	SensorAct
	PaaS	1	2014	COMPOSE
	platform	3	2014 2014 2016	servIoTicy Geo2Tag Arduino
	software	2	2014 2016	Apache openJPA Processing
	system	2	2014 2014	Smart-M3 SmartRoom
	tool	2	2014 2014	NodeRED Apache JMeter
transportation	framework	1	2016	Sesame

Internet has grown extremely rapidly in the recent 20 years. With the modern trends such as IoT, IIoT and big data it is not surprising that cloud computing as a data storage was one of the new trends in the early 2000 [46]. The ever demanding data storage issues that derive from IoT sensor increase, cloud computing is more popular than ever. Different platform and storage solutions drive the development of IoT devices further as the capacity of the frameworks and platforms increases to accommodate the rapid data growth. In industrial domains this is found to be also the case, as the trends in open source shift towards platforms. In the growth of the Internet, open source has gained more visibility and popularity especially in the developer community [47], when big companies like Google, Tesla and even Microsoft open their code to the public. The increase in open source is also visible in the Industrial Internet based on this research. Open source usage has increased each year and even in the beginning of 2017 it is almost as high as in the previous year altogether.

This research found that open source was used in manufacturing and smart city domains more often than in other domains. General and energy domains were however using open source solutions earlier than manufacturing and smart city domains. In this research there are two figures, figure 2 and figure 5 earlier in chapter 4, that show the same curve in the usage of open source between industries. The figure 2 is based on the amount of research papers using open source and figure 5 in chapter 4 shows the amount of tools used in each domain. Open source is most used in manufacturing and smart city domains and also the tools selected for different purposes in these domains are open source more frequently than in other domains. Manufacturing and smart city domains represent the two (2) domains that also mentioned the most reasons for not using open source. Based on the reasons found and how they were divided into different domains, it looks as if manufacturing and smart city domains would be the least optimal candidates for using open source due to security, privacy and practicality reasons. However, the fact, that these are also the two domains that use the most open source solutions, suggests that the research into open source in IIoT is highest in manufacturing and smart city domains.

Moreover the results in this study offer similar results as in [7], [8], [31], [32] and [33], suggesting that the industries of smart cities and manufacturing and industrial automation are the focus areas for IoT development in 2017. The previously mentioned works also suggest that smart homes and IoT platforms are trends in IoT for 2017. This literature study found similar interest in IoT platforms and smart home studies. Some of the mentioned open source tools from [8] are also found represented in this study.

5.2 The characteristics as reasons

The reasons for using open source vary from cost savings to giving back to the community. Closer analysis of the results suggest that open source is used due to the exact nature of open source itself; flexibility, ease of use, availability and easy development of new functionalities. Open source community, to promote open innovation, accelerate development and the involvement of different stakeholders, are seen as important reasons for using open source. Convenience was mentioned by [S14] as a reason for using open source. This shows that open source is not a disqualifying property when the research is not focused on finding open source tools to solve the problems. In the Internet of Things context acceleration of development, promoting open innovation and the involvement of different stakeholders will drive the development of different IoT solutions even further. Increasing interest in open data and big data solutions offer a platform for IoT and open source to develop rapidly.

Less reasons are found to be presented for not using open source, than there are reasons found for using open source. Four (4) studies mentioned reasons for not using open source, whereas 11 studies were found to list reasons why they selected open source tools for the research. The reasons why open source was not used included the licenses not being practical for example for manufacturing and factory use due to limitations of what kind of derivatives from the original work can be done. Also security and practicality reasons were mentioned for dismissing open source tools, but no further explanation was offered. Most of the reasons found for not using open source were specific to the certain tools investigated in the research papers, instead of representing negative points of open source characteristics as a whole. Examples for this offered [S22] (smart city), where open source was not used because it failed the initial tests set for platforms in the selection process of the tools for the research. Similar reason was offered in another smart city domain case in [S19], where OSS was not used because the tool was in early research and prototyping phase and not ready to be used for an embedded system with real-time requirements.

5.3 The potential of open source

Open source offers a lot of potential for IoT and industrial IoT research. By opening the source code to the community, the development of new tools, platforms and processes can be faster when new players can enter the competitive market easily. Open source offers also a solution for IoT interconnectivity issues, since OSS is by nature modular. By leveraging open source in IoT the suggested rapid growth in cross-industry business sectors as well as in the customer segment can be achieved. When the open source characteristics are leveraged correctly, the faster development of systems can be achieved with lower costs than when the same manpower is used to power the development of proprietary software. More developers contributing on the same system produce better quality bug-reports and faster release cycles offering additional functionalities and fixes.

In summary this chapter presented detailed discussion for the reasons found in the results and some corresponding results from other studies. The reasons were described in more detail and conclusions from the results drawn. A clear shift towards different industries open source usage was found in the review. Based on the review manufacturing and smart city domains use the most open source solutions and focus more on IoT research with open source solutions.

Future work based on this research could include researching how industries actually use open source solutions in reality, and what kind of tools are seen as open source. Open source is a major player in IoT already with Linux distributions leading the operating systems and other open source operating systems gaining more popularity. Other future research areas include the reasons behind not using open source and do the reasons vary between different industries. It should also be investigated that are open source solutions actively taken into consideration when choosing tools for research projects and possibly why the reasons in these cases are not mentioned in the study. This study did not find conclusive reasons for not using open source between industrial domains. Improvements to address the security and privacy reasons across open source tools, research into different licenses suitable for industrial use and studies into specific industrial domains and ways for the domains to leverage open source better are also suggested for future research.

6 CONCLUSION

This study found that open source is used in different industrial domains, such as energy, general, healthcare, smart city, manufacturing and transportation. Open source found in this study included software, libraries, modules, platforms, environments and operating systems. Open source was used as data simulators, components and platforms for ecosystems. The usage of open source developed from using OS libraries, systems (MySQL, MongoDB) and programming languages (between 2010 and 2013) to using environments, frameworks and platforms to form complex ecosystems. The open source solutions that were mentioned more often were MySQL, OpenIoT, Apache Tomcat, Arduino, Contiki OS, Eclipse IDE, Fosstrack EPCIS, Protégé Ontology Editor and Oracle VirtualBox

Reasons for using open source included cost savings, the open source community, accelerating the development of open innovation, the properties of open source like flexibility, accessibility and usability of OSS, as well as the involvement of different stakeholders. The existing support of open source community was given as a reason for using open source more often than other reasons. Reasons found for not utilising open source solutions were licenses being not suitable for industry use, security and privacy issues and open source tools not being suitable for the cases the research papers were investigating. In the end open source was found to be used for the nature of open source; flexibility, openness and the community. The reasons for not using open source based on this research seem to focus on the properties of the specific tools and the tools not being suitable for a certain set of cases, instead of focusing to the characteristics of open source. One reason that mentioned open source characteristics as a whole was the possibility that in the production-phase of a system there might be requirements for a third party full-time support. However, it should be noted that not every research will include the criteria why some tool was not used in it and if the research is not inclined to utilise open source solutions in the first place, it is unlikely that the research will in this case mention open source.

Finally, the study found that the usage of open source has evolved in the researched years

(2010-early 2017). All of the industrial domains selected for this study used or mentioned open source tools in different forms. However the usage of open source was found to have evolved in and between different industries. Between 2010 and 2013 the industries found using open source were energy and general industrial domains. In 2014 the research into IoT and open source grew in comparison to the earlier years, and after 2014 the focus for open source and IoT research has been in manufacturing and smart city industry. This finding corresponds to earlier research and surveys presented in this work. Manufacturing and smart city domains were found to be the domains that also mentioned the most reasons for not using open source. It is suggested that this is because the research into manufacturing and smart city domains in IoT and open source is bigger than in the other mentioned domains.

There is still a lot of potential in the research into Industrial Internet of Things and especially in open source. Open source offers ways to approach the problems of IoT from a different view compared to more proprietary and traditional ways. Open source is already being researched and used more and it is reasonable to expect the same trend to continue in the future.

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APPENDIX 1. Open source and OS-based tools mentioned in the research.

Tool	**License**	**Context/notes**	**Research**
AllJoyn	Previously under Apache License 2.0, some parts under BSD License. Commercial usage requires ISC (Internet Systems Consortium) license	mentioned	[S10]
Apache Hadoop	Apache License 2.0		[S1]
Apache JMeter	Apache License 2.0		[S14]
Apache Maven	Apache License 2.0		[S11]
Apache openJPA	Apache License 2.0		[S14]
Apache Spark	Apache License 2.0		[S1]
Apache Tomcat	Apache License 2.0		[S11], [S14]
Arduino boards	GPL (Java environment) and LGPL (microcontroller)		[S1], [S18]
CLIPS	public domain		[S4]
COMPOSE		license not found, based on open source CloudFondry PaaS licensed under Apache License 2.0	[S3]
Contiki OS	BSD License 2.0	mentioned	[S11], [S25]
Eclipse IDE	EPL		[S11], [S14]
EPCIS Webadapter	GPLv3		[S11]

(continues)

APPENDIX 1. Open source and OS-based tools mentioned in the research. (continues)

Tool	License	Context/notes	Research
Esper	GPLv2	mentioned	[S5]
Fosstrack EPCIS	LGPLv2.1		[S11], [S17]
Freeboard.io	MIT License		[S27]
Geo2Tag platform		license not found	[S26]
GeoServer	GPLv2		[S15]
GlassFish	dual licensed, CDDL (Common Development and Distribution License) or GPLv2 with Classpath exception, some components under Apache License 2.0 and Mozilla Public License		[S4]
jQuery	MIT License		[S11]
Linux OS (Ubuntu), Ubuntu Public Cloud	multiple licenses (mainly GPL)		[S11]
MongoDB	AGPL v3.0		[S17]
Muen Separation Kernel	GPLv3	mentioned	[S19]
MySQL	GPL		[S11], [S23]
Node.js	Node.js own license		[S3]
NodeRED	Apache License 2.0		[S3]
Oliot EPCIS	LGPLv2		[S17]
ONOS	Apache License 2.0		[S9]
openHAB	EPL	buit on OSGi framework	[S22]
OpenIoT	LGPLv3	used and mentioned	[S13], [S24]

(continues)

APPENDIX 1. Open source and OS-based tools mentioned in the research. (continues)

Tool	License	Context/notes	Research
OpenLayers	FreeBSD		[S15]
OpenModelica	OSMC Public License		[S8]
OpenSim	own license		[S7]
OpenStack	Apache License 2.0		[S9]
Oracle VirtualBox	GPL		[S11], [S13]
Papyrus	EPL	tool based on Eclipse	[S25]
Predix		built on open source CloudFondry PaaS licensed under Apache License 2.0	[S1]
Predix Machine		built on open source platform OSGi licensed under OSGi Specification License 2.0	[S1]
Processing	GPL, libraries LGPL		[S18]
Protégé Ontology Editor	FreeBSD		[S16], [S24]
Python	Python-license		[S23]
Robot Operating System (ROS)	BSD License 2.0		[S9]
Ruby-on-Rails	MIT License		[S6]
SensorAc	own license		[S21]
servIoTicy	Apache License 2.0		[S3]
Sesame	BSD License		[S20]
Smart-M3	BSD License		[S26]
SmartRoom	GPLv2	based on Smart-M3	[S26]

APPENDIX 2. Matrix of the papers selected for the literature review.

Research title	Year	Type	IoT	Case study	Industrial internet	OS	+/- OS	Digital library	Industry domain	Ref.
A fog computing-based framework for process monitoring and prognosis in cyber-manufacturing	2017	J	X	X	X	X	*	Science Direct	manufacturing	[S1]
A framework for the integration of the conviviality concept in the design process	2017	J	X	X	X	X	+	Science Direct	manufacturing, bicycles	[S2]
A full end-to-end platform as a service for smart city applications	2014	A	X	X	X	X	+	IEEEXplo re	smart city, traffic monitoring	[S3]
A knowledge-based tool for designing cyber physical production systems	2017	J	X	X	X	O	*	Science Direct	factories, manufacturing	[S4]
A lightweight and extensible Complex Event Processing system for sense and respond applications	2012	J	X	X	X	O	*	Science Direct	maritime	[S5]
A Service-Oriented Architecture for Web Applications in e-Mental Health: Two Case Studies	2015	C	X	X	X	X	*	IEEEXplo re	healthcare	[S6]
Addressing the Smart Systems design challenge: The SMAC platform, Microprocessors and Microsystems	2015	J	X	X	X	X	*	Science Direct	healthcare	[S7]

(continues)

APPENDIX 2. Matrix of the papers selected for the literature review. (continues)

Research title	Year	Type	IoT	Case study	Industrial internet	OS	+/- OS	Digital library	Industry domain	Ref.
An Application of SMC to continuous validation of heterogeneous systems	2016	J	X	X	X	X	*	ACM	smart city, firefighters	[S8]
An edge operating system enabling anything-as - a-service	2016	A	X	X	X	X	+ & -	IEEEXplore	general, war, manufacturing and agriculture	[S9]
An IoT Service Framework for Smart Home: Case Study on HEM	2015	C	X	X	X	O	+	IEEEXplore	energy	[S10]
Cloud computing, REST and Mashups to simplify RFID application development and deployment	2011	A	X	X	X	X	*	ACM	retail, supply chain	[S11]
Data-source interoperability service for heterogeneous information integration in ubiquitous enterprises	2015	J	X	X	X	O	-	Science Direct	manufacturing, construction industry	[S12]
Defining the Stack for Service Delivery Models and Interoperability in the Internet of Things: A Practical Case With OpenIoT-VDK	2015	J	X	X	X	X	+	IEEEXplore	farming, manufacturing	[S13]
Efficient naming, addressing and profile services in Internet-of-Things sensory environments	2014	J	X	X	X	X	+	Science Direct	smart home, smart building	[S14]

(continues)

APPENDIX 2. Matrix of the papers selected for the literature review. (continues)

Research title	Year	Type	IoT	Case study	Industrial internet	OS	+/- OS	Digital library	Industry domain	Ref.
Integrated visualization and analysis of threats for marine and coastal regions via a Web-based GIS	2010	A	X	X	X	X	+	IEEEXplore	maritime, warfare	[S15]
Knowledge management of eco-industrial park for efficient energy utilization through ontology-based approach	2017	J	X	X	X	X	*	Science Direct	manufacturing and service businesses	[S16]
Oliot EPCIS: New EPC information service and challenges towards the Internet of Things	2015	C	X	X	X	X	+	IEEEXplore	healthcare	[S17]
Open-source digital technologies for low-cost monitoring of historical constructions	2016	A	X	X	X	X	+	Science Direct	building, infrastructure	[S18]
Secure RTOS Architecture for Building Automation	2015	A	X	X	X	O	-	ACM	smart building	[S19]
Semantic Model for IoT-Enabled Electric Vehicle Services: Puzzling with Ontologies	2016	C	X	X	X	X	*	IEEEXplore	traffic, automobile	[S20]
SensorAct: A Decentralized and Scriptable Middleware for Smart Energy Buildings	2015	J	X	X	X	X	+	IEEEXplore	smart home	[S21]

(continues)

APPENDIX 2. Matrix of the papers selected for the literature review. (continues)

Research title	Year	Type	IoT	Case study	Industrial internet	OS	+/- OS	Digital library	Industry domain	Ref.
Supporting development and management of smart office applications: A DYAMAND case study	2015	C	X	X	X	O	-	IEEEXplore	smart offices, smart buildings	[S22]
Towards CIM based control centers	2013	C	X	X	X	X	*	IEEEXplore	power grid	[S23]
Towards Data Interoperability: Turning Domain Specific Knowledge to Agnostic across the Data Lifecycle	2016	C	X	X	X	O	*	IEEEXplore	general	[S24]
UML4IoT—A UML-based approach to exploit IoT in cyber-physical manufacturing systems	2016	J	X	X	X	X	*	Science Direct	manufacturing	[S25]
Virtual shared workspace for smart spaces and M3-based case study	2014	C	X	X	X	X	*	IEEEXplore	smart room, tourism	[S26]
Visual Management System to Manage Manufacturing Resources	2017	C	X	X	X	X	+	Science Direct	manufacturing	[S27]

APPENDIX 3. Data gathered from each of the reviewed papers.

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
A fog computing-based framework for process monitoring and prognosis in cyber-manufacturing			Predix Machine built on CloudFondry	Fog-computing based framework for data driven machine health and process monitoring in cyber-manufacturing	Building predictive models and integrate the models to online process monitoring systems. Significant advancements needed in: predictive analysis, software portability, computing scalability, infrastructure flexibility and cyber security.
A framework for the integration of the conviviality concept in the design process	Customers are involved in the development and implementation of the system, system supported by the industrial stakeholders as well as the open source community			To study the ecological aspect of the cases	

(continues)

APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
A full end-to-end platform as a service for smart city applications	Established open-source solution, community support, environment for hosting scalable applications. To boost the creation and adoption of smart city services developers need to be offered an easy to use, effective, end to end environment for the integration, development and delivery of such services		COMPOSE is based on CloudFondry PaaS	Minimise use of cars and decrease traffic	
A knowledge-based tool for designing cyber physical production systems				To create a digital factory tool for designers	Better means to model and predict product and process evolution. Enable this using machine learning and information modelling.

(continues)

APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
A lightweight and extensible Complex Event Processing system for sense and respond applications			Open source only mentioned as used in one project	Dangerous goods monitoring scenario.	Improve the detection of threats and the accuracy of the resultion situation awareness.
A Service-Oriented Architecture for Web Applications in e-Mental Health: Two Case Studies				eHealth services for tracking user mental health through questionnaires and diary.	
Addressing the Smart Systems design challenge: The SMAC platform, Microprocessors and Microsystems			Open source was used for simulating real human	Limb tracking system in lab environment using simulators	

(continues)

APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
An Application of SMC to continuous validation of heterogeneous systems				Emergency response in a city fire scenario	Improving the solution by detecting rare emergent behaviors and to automatically be able to find an architecture for the contracts.
An edge operating system enabling anything-as -a-service	Availability of open source software: open source software will fuel innovation and reduce the investment costs required to deploy the standard hardware infrastructures. Threshold for new players in telecommunications markets lowers	Most open source solutions may require third party support if used in production environments	Remotely controlled robots may have significant impact on Industry 4.0. OpenStack open source cloud platform	Optimal allocation of logical resources in mobile cognitive machine.	

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APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
An IoT Service Framework for Smart Home: Case Study on HEM	Reusable components and the possibility to easily develop more functions and additional programs (multi-program), enable widespread adoption and help accelerate the development and evolution of an interoperable peer connectivity and communications network based on AllJoyn		Mentions open-source as an option but does not use it, uses Microsoft's Lab of Things	Smart home energy management system, build a smart home service framework	Optimise the energy consumption and provide instructions based on the electricity consumption.
Cloud computing, REST and Mashups to simplify RFID application development and deployment				Store retail supply chain tracking system for tracking the stock automatically as products are sold and bought.	The accessibility issues if a reader is behind a firewall. Current Fosstrack EPCIS is not compliant with the Java Data Object; porting the EPCIS to JDA would enable better leverage of the scalability that cloud solutions offer. Getting around the network delays (real-time).

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APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps
Data-source interoperability service for heterogeneous information integration in ubiquitous enterprises		For security and practical reasons, industrial companies cannot accept GPL or LGPL licences or open source tools and commercial tools that are not suitable for industrial application developments given the cost-effective analysis.	Traditional methods, such as phone, fax, printed paper sheets and emails are widely used in construction industry		
Defining the Stack for Service Delivery Models and Interoperability in the Internet of Things: A Practical Case With OpenIoT-VDK	Results distributed to the community, offers value by reducing costs and deploying about technology and software development efforts (= ready made platform), main incentive that its free of cost for the industry and manufacturers of hardware, functionalities can be added			Manufacturing plants scenario to monitor production processes, real-time information In smart agriculture the case is to use openIoT to analyze the size, growth and performance of plants in a greenhouse or a field and report this in real-time	

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APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
Efficient naming, addressing and profile services in Internet-of-Things sensory environments	Convenience (available in the chosen IBM WAS-CE container for the application)			Naming convention case study in a smart building that has temperature sensors, humidity sensor, one alarm, one camera and all connected wirelessly by ZigBee.	
Integrated visualization and analysis of threats for marine and coastal regions via a Web-based GIS	Easily accessible and up-to date information related to a region of interest, open modular structure of the system allows for easy inclusion of different data sources, open architecture allows for easy integration of various kinds of custom data formats, easily accessible for new users without the need to install third party software or hardware requirements, software developed by the community				

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APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
Knowledge management of eco-industrial park for efficient energy utilization through ontology-based approach				Eco-industrial park ontology study	Allow the use of AI in energy management.
Oliot EPCIS: New EPC information service and challenges towards the Internet of Things	To share the research product and enhance the platform with competent researchers and entrepreneurs in the world MongoDB chosen due to its flexibility and scalability			Healthcare case, monitoring health status of people	
Open-source digital technologies for low-cost monitoring of historical constructions	Openness, low-cost, brings the source to the grasp of everyone who is interested, large community, open source offers exponential growth (such as in robotics, architecture, medicine)			Existing crack monitoring system for historical buildings replaced by open-source tools	

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APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
Secure RTOS Architecture for Building Automation		In early research concept project and its not suitable for embedded system with real-time requirement		Biocontainement laboratory scenario	Design and experiment with scheduling method.
Semantic Model for IoT-Enabled Electric Vehicle Services: Puzzling with Ontologies				Case studies for traffic measuring and electric battery lifecycle	
SensorAct: A Decentralized and Scriptable Middleware for Smart Energy Buildings	For community use			Monitoring energy usage in smart building	
Supporting development and management of smart office applications: A DYAMAND case study		Mentioned, tested but not selected for the study	OS not used because it failed an initial test of configuration easiness	Case study monitoring application for office environment; real-time feedback on meeting room usage	Solving interoperability issues need to be done in grander scale than only locally. Remote services needed to monitor and manage the system.

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APPENDIX 3. Data gathered from each of the reviewed papers. (continues)

Research title	Reasons why	Reasons why not	Other	The case	Research gaps / future research
Towards CIM based control centers				Case study of migration of a legacy utility to the CIM utility	
Towards Data Interoperability: Turning Domain Specific Knowledge to Agnostic across the Data Lifecycle				Identifying air traffic control and weather data	Enhance data representation and automate the process of data characterisation. IoT systems need models and approaches that can better facilitate data exchange across different platforms.
UML4IoT—A UML-based approach to exploit IoT in cyber-physical manufacturing systems				Liqueur plant system case study.	Port the approach to Contiki OS and other systems.
Virtual shared workspace for smart spaces and M3-based case study				SmartRoom system for eTourism, offering virtual workspaces for conferences, meetings and lectures.	Lack of practical platforms for smart spaces.
Visual Management System to Manage Manufacturing Resources	Free online tools			Visual management tool for visualising the shop floor.	