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The impact of the internet of lighting on the office lighting value network

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Abstract

Lighting systems in offices are becoming an infrastructure to connect people, devices, and systems to each other and to the Internet, creating an Internet of Lighting (IoL). This can bring advantages to stakeholders involved, and is expected to have a disruptive impact on the value chain. This study investigates the impact of IoL on the European office lighting value chain. A qualitative stakeholder study indicates four perspectives with corresponding drivers of change: IP to the end node, standardisation, sharing data, and light as a service. Potential impacts on value have been formulated for each driver, and are operationalised towards stakeholders using the layered value network model. The validity of the model is shown by populating it with the European office lighting value chain. The work concludes with insights in the impact of IoL on stakeholders, and recommendations about the user of the model for synthesis of new stakeholder networks.

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1. Introduction

The Internet of Lighting (IoL) is a trend that becomes evident in office lighting. Advancements in the world of smart buildings show that the Internet of Things (IoT) paradigm [7] is brought closer to office lighting than ever before, due to a combination of recent developments in (solid-state) lighting: LED technology, advanced digital lighting controls, and network technology. The lighting system inside a building becomes an infrastructure to connect people, devices, and systems to each other and to the Internet. This provides opportunities for better lighting, that supports the activities of users in the building and increases comfort and productivity, as well as providing new services related to lighting, i.e. for Facility Management (FM), energy consumption, or security. Office workers will be able to personalise their lighting environment for comfort, and remote building management becomes possible, with smart energy solutions to decrease carbon footprint.

IoL is an example innovation that illustrates the societal paradigm shift from an experience economy towards a knowledge economy [3]. In the knowledge economy, the connection between devices allows for the exchange of information and the contextualisation of services and applications that facilitate individual empowerment. Open source tools allow new stakeholders and service providers to participate in the new value propositions. New networks of stakeholders propose new value propositions. Stakeholders are no longer just producing and delivering a product, but will rather provide a service during the usage period of a system. Moreover, working-in-the-cloud and mobile computing allow people to work from anywhere. People no longer work solely in office buildings, which calls for flexible use of office space over time. Open plan office floors allow workers to occupy and use space flexibly. This new-way-of-working [9] is changing the way office buildings are managed. The workplace of the future will be “far more agile, the presence of technology is ultra predominant and human beings are highly reliant on it” [21]. This development affects the way value is created by the organisations involved.

As office buildings are changing, the organisations involved with the business of office lighting need to reconsider their value propositions. IoL can bring many advantages to all stakeholders involved, but then again it will have a disruptive impact on the office lighting value chain. Office lighting is integrated in the building value chain. In this chain, many stakeholders are involved during the design, development, installation, maintenance, and use of offices and their lighting systems. The stakeholders can be modelled in a linear value chain [20], in which the product (office lighting) is developed and produced in industry, a lighting system is designed by lighting designer, installed by a contractor, configured by a commissioner, sold to the building owner and then maintained by the
facility manager (see Table 1). IoT, however, transforms lighting systems from a product to a service, and the traditional value chain does no longer suffice. Instead, the business environment should be approached as a network of stakeholders that deliver value to the end-users of the lighting system. New stakeholders will be introduced to this network, and as stakeholders deliver flexible services, they will stay involved for the entire use period and might even change role over time accordingly.

This work presents a study that maps the impact of IoT on the European office lighting value chain. The goal is to get a better understanding of how a stakeholder network is impacted by IoT – in this case IoT. For this we constructed the layered value network model, based on existing models from related literature. Analysis of interviews with stakeholders resulted in perspectives. The model was populated with the stakeholder network and impact was defined on stakeholder level, according to the perspectives. This method captures the impact on different stakeholders, and allows to identify opportunities for new value propositions and new stakeholder networks. A secondary goal is to show that this method is interesting for other application domains as well, especially within the scope of smart buildings.

The research presented in this paper is performed within the OpenAIS project [15]. The aim of this project is to create an open standard to include lighting for professional applications in the IoT, to enable the transition from closed command-oriented lighting system architecture to an open and service-oriented system architecture. The project delivers a technological innovation but also aims to at understanding the potential impact on the European office lighting value chain.

In the next section, we will discuss relevant related work. It presents an overview of methods for analysis and synthesis of stakeholder networks which are used as building blocks for the layered value network model. Next, in Section 3, we present how we approached the research on the office lighting value chain. In a systematic stakeholder study, relevant developments and future expectations are identified. This resulted in the formulation of four perspectives on IoT that are presented in Section 4. In Section 5, we describe the process of deriving the layered value network model, where several modifications to existing value models are proposed, by using the European office lighting value chain as example stakeholder network. The section concludes with a proposed method to define potential impact by approaching the stakeholder network from the four perspectives. A discussion on the results and our conclusions are described in the remainder of the paper.

2. Related work

Many efforts have been made to understand value chains, innovation design, and impact of trends on different levels of our society. This section presents an overview of related methods and models that aim to analyse value chain and stakeholder networks.

One of the most widely applied methods to analyse impact on a value chain is the Value Chain Analysis method (VCA), introduced by Porter [20] and further develop in management accounting literature [11,22,23]. The goal of the VCA method is to break up the chain of activities between raw materials and the end-user or a product or system, to “understand costs and sources of differentiation” [23]. However, in literature and practice, this method is mostly used to increase efficiency from an intra-firm perspective, rather than rethinking value across the entire value chain [6].

While VCA focuses on a value chain, Innovation Design presents an approach for meaningful innovations on networks of stakeholders within a societal context [17]. This method uses the Value Framework as a synthesis tool to support the process of creating shared value for multiple stakeholders [18]. The core idea of the framework is that meaningful innovations need to create shared stakeholder value across four societal levels: user, organisations, ecosystem and society. The user level focuses on experience and improving quality of life of end-users. On the organisations level, different stakeholders are bringing a value proposition to the users. The ecosystem level focuses on values for non-profit organisations, and companies in the same line of business that together form a community that sustains innovation, while the society level encompasses value for society as a whole and includes stakeholders like financial organisations and governments. The framework also provides four perspectives on value: economy, psychology, sociology and ecology. These allow for definition of value for stakeholders at different levels. An innovation is considered meaningful if it addresses the four levels from all four perspectives. Next to the framework, Den Ouden presents the Value Flow model [19]. This is a tool to ideate and visualize transactions (flows of value) between stakeholders in a network, by means of goods & services, money & credits, information and intangible value. The innovation design methods have not yet been applied to the societal challenges that come with innovations like Internet of Light.

The office lighting value chain is closely related with the office building value chain. The design and installation of a lighting system is often part of a building design project, as it is installed by subcontractors during the construction of the building. Therefore, it is worthwhile to investigate typical building delivery methods. The Design-bid-build method (DBB) is a traditional method for project delivery, but it has had much critique in construction economics literature [10,14]. The method presents three sequential phases (design, bid and build phase), which can be used to define when, and how long, stakeholders are involved within the different phases. As this method focusses on construction, the timeline stops at the handover of the building to the client, and thus lacks a description of the phase for the actual use and maintenance of the lighting system in a building.

3. Approach

The OpenAIS consortium put considerable effort into gathering perspectives from professionals across the European office lighting value chain, on office lighting in the future [16]. 28 Interviews were conducted in Austria, Belgium, France, Germany, Italy, Netherlands, Spain, Switzerland and the UK. The interviewees were specialized in building management (6), building automation (4), lighting manufacturing (4), lighting controls (3), real estate (3), IT (3), lighting design (3), lighting installation (1), sustainability (1). The result is an extensive list of 629 scenarios of qualitative remarks about current activities of different stakeholders across the value chain and how they expect their business to change in the future, given the prospects of IoT. This rich list provides insights in impact from the individual stakeholders’ point of view. But this work needs a broader perspective, including impact across stakeholders. Therefore, this list was used in a thematic analysis [4].
First, initial open clustering determined the base structure and defined the selection of scenarios. This was performed by the first author of this paper. Scenarios describing everyday practical problems were excluded from the clustering activity. Second, the remaining scenarios were fitted in the existing themes. 381 Scenarios were clustered in four themes describing change or impact. Recurring patterns were defined, resulting in 39 subthemes across the themes. Finally, these subthemes were reproduced partially in plenary sessions of the OpenAIS consortium, which sharpened the phrasing of themes and subthemes.

Table 2 displays the resulting drivers of change (themes and subthemes). *IP to the end-node* describes impact by the conversion to an all-IP building systems, including changing integration workflows, possibilities for remote access, and potential security issues. The standardisation theme describes impact of a standard of protocols and components for building networks, including the impact of interoperability of components, possibilities of an open communication standard, new stakeholders that might be needed and partnerships that can emerge. The data theme is illustrated by the impact of the generation of data in buildings, including potential energy savings, the value of data to multiple building systems, and the impact of data on new installations. The final theme, *light as a service*, includes impact on the end-users of the system. The subthemes are grouped in impact for the office worker – including the growing number of phone applications, personal control, and enhanced comfort – and impact for installation & maintenance – including ease of installation, energy saving and reconfiguration of building systems. The miscellaneous theme includes relevant scenarios, that were incidental and therefore not fitting any of the themes. In a subsequent refinement, the drivers of change derived from the clustering activity were defined as perspectives on IoL: Technology, Economy, Information and End-user perspective. These perspectives provide a high-level overview that aids the synthesis of a new value network model to define the impact on stakeholders. These perspectives are further elaborated in section 4.

We propose a new, layered value network model. Three assumptions have been made for the construction of this model: (1) We expect that a value network will occur, (2) that stakeholders will focus on delivering services and thus stay involved during the lifetime of installations, and (3) that new stakeholders will be introduced to the network. This model is based on related work from literature as presented in the previous section: The most important aspects we adopted are the notion of four levels of value (User, Organisation, Ecosystem, and Society) from the value framework [18] and the notion of value flows between stakeholders from the Value Flow model [19]. Next to this, we propose to enrich said model with a timeline based on the DBB model, with an additional fourth phase: The Use phase. This phase emphasises the actual usage of the lighting system after its installation. The timeline is made circular to illustrate that an office lighting system can be refurbished, renovated, or upgraded throughout its lifetime. Fig. 1 shows the basic structure of the layered value network model. The model has been formulated in an iterative process, allowing us to redefine the model while shaping the stakeholder network. The layered value network model is described in Section 5, by a detailed description of populating it with a realistic stakeholder network for the office lighting sector. Stakeholders are positioned in the model according to their involvement in time and to the value they bring within the network. Input from the OpenAIS consortium members’ expertise and the scenarios from the stakeholder interviews were used for this. New stakeholders are added to fill potential gaps within the network. Section 5 also shows that the model can be used to identify and describe potential points of impact on a stakeholder level. The process of defining the layered value network model is illustrated in Fig. 2.

4. Perspectives on the Internet of Lighting

This section presents the four perspectives on impact of IoL on the European office lighting value chain. For each perspective, four potential impacts on value have been formulated. These values are introduced in subsequent subsections, illustrated by examples. Fig. 3 illustrates the four perspectives, including their key drivers of change (centre of each perspective) and four potential impacts of IoL on the office lighting value chain. Next to this, it shows a relation between the perspectives with arrows. The technological

### Table 2

Quotes from the stakeholder interviews clustered in four main themes.

<table>
<thead>
<tr>
<th>Main theme</th>
<th>#quotes</th>
<th>Sub-themes (#quotes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP to the end node</td>
<td>38</td>
<td>Integration (19); (Remote) Access (6); Security (5); Costs (2); Management Information Base (2); Other (4)</td>
</tr>
<tr>
<td>Standardisation</td>
<td>73</td>
<td>Interoperability (19); Open standard (13); New Skills Needed (8); Application Programming Interface (5); Acceptance time (4); Component Integration (3); Partnerships (3); Renovation (2); Other (16)</td>
</tr>
<tr>
<td>Data (in the cloud)</td>
<td>42</td>
<td>Energy Saving (8); Occupancy data (7); Diagnostics (5); Security (3); Share Systems (3); Share data between stakeholders (2); Sensors (2); Building Management System (2); inform New Install (5); Other (5)</td>
</tr>
<tr>
<td>Light as service</td>
<td>189</td>
<td>Office worker (32); Applications (21); Personal Control (20); Comfort &amp; Well-being (18); Social Environment (9); Natural Light (7); Reducing Costs per m² (6); Presence Detection (3); Other (28)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>39</td>
<td>Installation &amp; maintenance (76); Easy Installation &amp; Commissioning (12); Maintenance (11); Energy saving (11); Handover (9); (re)Configuration (7); Compatibility of Components (5); Diagnostics tools (2); Other (19)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Failures of Technology (7); Building Information Model (1); Information about activities of stakeholders (31)</td>
</tr>
</tbody>
</table>

Fig. 1. The layered value network model, an office goes through four phases (Design, Bid, Build, Use) and stakeholders add value on four levels (User, Organisation, Ecosystem and Society).
Innovation of IP to the end node makes standardisation of building systems possible and allows for sharing data between systems and stakeholders. In turn, these two drivers allow stakeholders to bring light as a service to the end-users of the system. The classification, the high-level overview, and the insights that these potential impacts offer can be operationalised towards stakeholders using the levelled value network model that will be introduced in the next section.

4.1. Technology perspective

At first, we take a technology perspective, and look at the implications of applying the concept of **IP to the end node**, which focuses on integration of IP communication for each end node of a lighting system (luminaire, control objects, switches, etc.). This makes it possible for individual lighting nodes as well as (integrated) sensors to communicate directly with each other and with other IP enabled building systems, without any protocol translation being required.

4.1.1. Shared IT network for building systems

The IP to the end node innovation closely integrates the lighting network in the IT network. Traditionally FM is responsible for systems connected to the Building Management System (BMS). However, now that systems are starting to integrate with the IT network, the line between FM and IT is blurring. This means that lighting stakeholders will have to rely on the IT network and staff, and IT stakeholders might have to deal with lighting aspects, not only during installation of the lighting system, but especially during operation.

4.1.2. Enable indoor IoT innovation

IP to the end node will act as an enabler for development of new services that smart buildings will bring in the future. As lighting is everywhere, an IoT-compatible lighting installation could well serve as an infrastructural access to the web for self-powered IoT applications, leveraging the innovation and development power of a worldwide IP community.

4.1.3. Stimulate network security

Security is essential to allow for safe communication between end nodes. In literature, we find multiple studies describing security challenges that IP to the end node can bring [1,8]. And secure communication between end nodes in a lighting system is essential, as the lighting system will be accessed and controlled by different devices and people inside and outside the building, with different levels of authorisation. One can think of full access for a commissioning agent, regrouping luminaires, or an office worker accessing control of a single lamp on his desk. Unauthorised control over the light can be a major concern if the architecture is not secured properly. The push of IoT can potentially act as catalyst for security providers. These stakeholders will play an important role in the future lighting value network, and other smart building value networks. The guarantee for a safe communication protocol can result in a faster acceptance of connected systems overall, catalysing indoor IoT innovation even more.

4.1.4. Low-voltage building systems

Finally, a combination of IP to the end node and Power over Ethernet (PoE), can stimulate the adoption of fully integrated low-voltage, DC powered lighting systems. The adoption of PoE for lighting can potentially save energy, which is highly dependent on the number of ports that are used, and the amount and speed of data transferred [12]. A centralised building AC-DC power conversion can drive LED lighting more efficiently, reducing power consumption and lengthening luminaire life-cycle. Next to this, low-voltage systems are safer and cheaper to install and maintain than traditional high-voltage systems.

4.2. Economy perspective

With this second perspective, we broaden our scope and investigate the economic aspects of **standardisation** of lighting components and communication. A standard unified protocol, that is vendor and manufacturer independent, can make luminaires, controls, sensors and drivers interoperable within the one architecture. This allows for a competitive multi-supplier ecosystem, with shorter and more frequent renovation cycles.

4.2.1. Interoperability of components

An open standard for lighting (communication) is a first essential step for interoperability of components. This can be valuable to lighting designers as it allows them to use components of different manufacturers and vendors in one design. Next to this, contractors and building owners no longer have to choose a specific vendor-dependent lighting control system before installation, which means...
that they are free to use any component or software from other vendors during the use of the lighting system. Even for maintenance this can be a benefit as it becomes possible to replace a defective luminaire with one from any different brand.

4.2.2. Stimulate competition
Creating a standard that is widely accepted, can open up the market and can be an enabler for competitive stakeholder environments. Manufacturers can incorporate the standard in their components, and third-parties can develop new applications and software to control these components without having to be exclusive to one specific brand. Small start-ups can have a big impact on the lighting value network. It might also influence selection criteria. For instance, during a build a combination of local vendors might be preferred over multinational vendors.

4.2.3. Allow flexible lighting setups
A lighting system is a relative big investment for building owners. During the design, building owners try to find a lighting solution that fulfils the need of the building occupants for the upcoming 15 years. Most of the time, this leads to a vendor specific solution, which is generally not easy to change, or expand. IoL can potentially make this more flexible. In this way, building owners can an initial investment and install a basic system. Later, during the use of the building, it is possible to make lighting controls more advanced, easily add or remove components (luminaires, sensors), and add services by means of purchasing software. In turn, this can decrease costs and labour for recommissioning the lighting system, which might imply that small changes to the system will happen more often. In practice this can reduce initial investment costs during the build, or CAPEX (Capital expenditure), and allows for smaller investments during operation, or OPEX (operating expenditure).

4.2.4. Increase market acceptance
An early involvement of the lighting value network in IT architectures will act as a catalyst for IoT adoption by consumers, and

Fig. 3. Four perspectives on impact of IoL, their key drivers and potential impacts.
will create a market for related applications, leading to additional employment in the European lighting and IT industry. This can lead to faster adoption by building owners, because of multiple vendors delivering modules, software stacks, devices, etc., all being part of the open architecture.

4.3. Information perspective

With the third perspective, we look at the effect of collecting, sharing and exploiting data that connected building systems can facilitate. As more and more devices get connected, more data is generated, processed and shared.

4.3.1. Building-wide ecosystem

The systems in a building are often connected through a BMS. Conversion of data is needed, which complicates the sharing of data between systems. Systems that generate data in a unified format can make this integration easier and might even share and process data locally. In this way, for example, an HVAC system can control climate locally by using data from a presence sensor integrated in luminaires. It is expected that all low-voltage systems will be integrated in one building-wide ecosystem. This de-siloing of systems is expected to decrease integration effort and increase operation efficiency, thus potentially saving operation costs.

4.3.2. Share data across buildings

It is expected that data from inside buildings will be shared with the outside world as well. This enables organisations to source management and operation to remote organisations. These remote data managers can add value to the network by securely transferring, collecting and storing data. By combining and analysing data from multiple buildings, high-level information can be generated that is valuable for other stakeholders as well. For example, logistics and energy efficiency can be optimised based on real-time data gathered from other locations. Another example is the efficient redistribution of power over a smart grid based on prognoses for energy need per building or per area.

4.3.3. Catalyse data security and data ownership

An important aspect of the information perspective is the need for secure data to facilitate privacy. The data gathered by building systems can contain privacy sensitive information and should therefore be shared and stored securely, especially when shared outside the building (and stored in the cloud). Data handling and the ownership of (valuable) data, is a societal concern, and it is likely that both commercial parties as well as regulatory organisations will be involved.

4.3.4. Inform new design

The data generated by buildings can be valuable for different stakeholders outside the building. A new opportunity arises when data from lighting systems can be used by manufacturers and lighting designers. In this way, data generated from currently used buildings can inform renovation plans for that building, or it can even inform new building designs.

4.4. End-user perspective

With the end-user perspective, we envision how sharing data and standardisation can facilitate new services that add to the quality of life and work of building occupants (office employees, facility managers, maintenance, cleaners, security guards, receptionists, etc.), as well as installers and commissioning agents. The light as a service approach brings third-party application developers to the stakeholder network. New applications and services will be the vehicle to bring the potential value of IoL to the end-users of the lighting system and building.

4.4.1. Full control for office workers

Human-centric lighting is about going beyond illumination. Lighting systems will no longer only bring enough light, but will bring comfort, control and well-being to office workers. The new lighting system will allow numerous applications that make the building more comfortable and efficient to work in. Office workers will be able to create their perfect work environment through new user interfaces (applications on their personal devices or dedicated physical controllers in the building). Research shows that control over one’s environment improves the appraisal of the work environment [2]. Connected building systems can provide these qualities and will play an important role in attracting people to work in office buildings, rather than at home.

4.4.2. Facilitating building management

Because office space is expensive, there is a need for more efficient use of space. The sensor network within a lighting system can collect occupancy data and provide accurate information about how space is used over time. This information can aid FM to optimally allocate tenants to work space and calculate rent for each tenant.

Energy usage is accurately measured by each endpoint (and devices connected to it) and collected by the system, allowing for immediate and accurate energy performance reports. Through third-party applications FM can exploit this data to the fullest. When Smart Grid signalling is available via the energy provider, or when the main utility meter has a threshold driven by contract limit, FM can reduce energy demand easily if needed.

4.4.3. Optimise building facilities

IoL can also bring benefits for maintenance. It can play an important role in calculating mean time between failures (MTBF) of devices more accurately. This can result in a better understanding of needed replacement of components, thus decrease downtime. The ease of installation and (re)configuration reduces downtime of the system even more.

IoL can be interesting for a variety of other facility services in buildings as well. Cleaners can use occupancy information to direct cleaning effort; Receptionists could create light paths for visitors to guide them where they need to be; Security can use presence data to monitor the building outside office hours.

4.4.4. Services for installation

Finally, applications and services for installation and commissioning will bring value as well. Think for example of apps for reconfiguration of the lighting system [13]. This make it easier to install and can potentially even allow for automatic commissioning. Next to this, in the future it can make commissioning so easy that building managers can do it in-house when needed.

5. The office lighting levelled value network model

This section explains the levelled value network model, illustrated with the European office lighting value chain as example. First, we explain how the office lighting stakeholders network is constructed in the model, followed by a description of how the four perspectives of IoL were used in combination with the levelled value network model to define potential stakeholder impact.

5.1. Constructing the value network

We used four steps to construct the value network. The steps were not taken in a fixed order, but rather used iteratively to define new stakeholders and value flows in the network. First, we identify stakeholders and their roles, then we position them in the model in two dimensions: the stakeholder role is positioned
in the fitting level of value and then the role is positioned in the phase that they are involved in. Finally, the value flows are identified and visualised. These four steps and the resulting model give a detailed overview of the stakeholder network, including their involvement over time and relationships in the form of transactions. Fig. 4 shows the resulting levelled value network for office lighting.

5.1.1. Identify the stakeholders and their roles

The stakeholders involved in the office lighting value chain were listed. The data from the interviews was used to identify their roles by means of responsibilities and activities that they perform within the value chain. The stakeholder roles were defined according to a set of roles as defined in the Value Flow method [17]. Some example roles are: customers (who are using or consuming the value proposition); service providers or goods providers (who are involved in the production and sales of the value proposition); and financiers or regulators (who either influence or are affected by the new value proposition). The layered value network model shows the stakeholders roles with corresponding icons as defined by den Ouden [17]. For example, in the office lighting network the architect is the stakeholder responsible for the final design of the building and, if applicable, the tender document. Their main role is to provide a service to the customer by combining the customer's wishes and the state of the art into a building design; later in the project they oversee the construction of the building. The (future)
building owner is the customer in this case; their role is mainly to consume the value of the building.

5.1.2. Position stakeholder roles on a value level

Next, the stakeholders are positioned into the model according to the value that they add to the customer in the value network. For this, the four levels of value from the Value Framework [18] are implemented in the levelled value network model. The first (inner) level concerns value for the User. In this particular case, the buyer and the end-user are not always the same throughout the project. This level addresses the part of a value proposition that is attractive to the user. In this case, the (future) building owner can be positioned on this level. The second level addresses value for the Organisation. This level focuses on providers of products, service and information directly to the customers. The architect can be placed on this level as they work very close with the building owner. The third level of value addresses value for the Ecosystem. This level contains communities and non-profit organisations. A consortium of companies that put effort in standardizing lighting communication would fit in this level. Society is the highest level in the model. This level addresses value for society as a whole. All stakeholders are part of the Society level (including User, Organisations and Ecosystems). In this case, we can regard role of regulation bodies on a societal level, because they maintain security and safety for society.

5.1.3. Define the involvement in phases

Next, the stakeholders are positioned in the model according to time of involvement. For this step, we have added the timeline from the DBB method to the Value Framework. In addition, we added a fourth phase: The Use phase, because of our expectations that stakeholder stay involved during the use of the lighting system rather than until the handover after the Build phase.

The first phase is the Design phase. It includes all activities around the initial design of the new system. In this case, the Design phase contains the design of the building and the initial lighting design for the building. In the Design phase the client (building owner) retains an architect and a design team of consultant engineers, informed by suppliers, to (re)design a building. The design is made according to rules set by regulation bodies. In the process, a financier finances the process.

The second phase is the Bid phase. A tender is open for bids. General contractors with a team of subcontractors, informed by suppliers, specify the tender requirements and make an offer. The architect and client award the project to one of the general contractors.

The Build phase starts once the project is awarded to a contractor that leads subcontractors that perform the construction. The architect supervises the build. Generally, the light installation and further commissioning starts after construction, installation of power distribution and electrical equipment. An electrician orders components from a supplier and installs all cabling. A lighting designer orders a lighting system and delivers these to the installer who mounts and connects the luminaires to the power cabling. Then a commissioning agent commissions the system. They both use tools and platforms for this process. After the installation, other building systems like the IT system are installed. Then integration is realised by an integration specialist. The phase concludes with certification of the building and the handover to the building owner.

The final phase in the model is the Use phase. The building owner hires a facility management team to manage the operation and maintenance of the building. Then space is rent out through a real-estate agent to tenants. The building is occupied by building users; including office workers, cleaning services and security personnel. This phase can span a long period time, including (planned) changes in use, reconfiguration, and modernization. It ends with a renovation or a new build, which brings us back to the design phase.

Some stakeholders (like the building owner) stay involved throughout multiple phases and change their role, and thus level of value. In the model this is visualised by white trails over time. The width of the trail visualizes the amount of the involvement.

5.1.4. Specify the flows of value

Finally, the flows of value between stakeholders are visualised by means of transactions adopted from the Value Flow model [19]. Transactions can be activities, resources, information or items that are shared or exchanged between two actors. Arrows show the direction of the flow of the transaction between stakeholders. These transactions can be in the form of Goods & Services, Money & Credits, Information and Intangible value. In this step, it is important to capture the value that is added by the stakeholder, which we captured via the stakeholder interviews.

We can show the value flows from and to the architect during the Design phase as example. The architect discusses the wishes of the client (Information) and provides the client with a building design (Service) in exchange for Money. To inform their design, the architect uses state of the art from suppliers and vendors of components and systems (Information). The design team of consultants help the client and architect by providing them a Service in exchange for Money. Through the modern lighting system, the building owner provides comfort and well-being, which can be seen as Intangible value to the building users.

5.2. Identifying potential stakeholder impact on the value network

This section shows how potential impact on stakeholders in the network can be identified by combining the levelled value network model and the four perspectives on IoT. This process was done for each phase separately. We identified potential points of stakeholder impact (visualised by black markers) by systematically looking at the potential impacts from the four perspectives. The complete analysis of impact on all stakeholders in the four phases can be found in a report published by the OpenAIS consortium [5]. In this paper, we zoom in on the Use phase as an example. Fig. 5 shows the involved stakeholders from the previous section and includes new potential stakeholders and strategies, and potential points of stakeholder impact. Next we will describe the points of stakeholder impact according to the four perspectives.

5.2.1. Technology perspective

From the technology perspective, we know that IP to the end node can allow the lighting system to be integrated with the IT network. In this way, responsibilities of facility management (FM) and the IT management will be affected by an IP lighting network. If, for example, one luminaire is not turning on when pressing a wireless switch, a number of possible causes are possible. It is crucial for systems to be able to accurately diagnose a potential problem to clarify whether it is an IT or an FM problem. Next to this, a good structure for cooperation between IT and FM to manage and operate the lighting system (and all other integrated building systems) is needed and should be guided by top management.

As the lighting network will be operating on a low-voltage power grid, maintenance will be safer and labour costs might decrease, as professionals don’t need certification for working on high-voltage systems.

5.2.2. Economy perspective

The interoperability of components will benefit maintenance as defective devices can be quickly replaced by devices from any vendor. This can reduce downtime of the system. Nowadays, reconfiguration of space requires a specialist to re-commission lighting and
control. It is expected that smaller reconfiguration of space and light will happen more often as opposed to a complete renovation/refurbishment project. This can result in less downtime, savings in labour, materials and costs and ensuring continuation of rent payment to the building owner. Secondly, updates for the network can be installed over the air, reducing downtime even more.

Third-party application developers will be introduced to the stakeholder network and will play an important role especially during the Use phase. New apps will be developed, deployed and used by building users like office workers (to control their lighting), FM (to manage the building) and other building facilities like cleaning and security. This app developer will bring the value of IoL to the end users. This can impact traditional money flows as well as normally a tenant pays a fixed amount to rent space from a building owner, but rent for space can be calculated according to occupancy data, which allows for more flexible renting.

For the building owner, IoL can lower cost of ownership: if a wide range of non-lighting applications can be linked to the lighting platform, the number of operation platforms in buildings can be reduced. Also, because the investment into more sophisticated controls or new lighting setups can be made in the Use phase, rather than design the Design phase (moves from CAPEX to OPEX).

As lighting becomes part of the building-wide ecosystem, accurate and real-time energy and usage data can be reported back to the BMS. This allows FM to calculate energy costs accurately and forecast future energy costs. Next to this, it allows for immediate demand reduction when using too much energy. Occupancy data can give a better insight in how spaces in a building are used, which will aid in allocating space amongst tenants to utilize the building optimally.

Data from the lighting system can be interesting for stakeholders outside the office building. Privacy issues with the office workers should be minimised and therefore be strictly regulated. The role of IT providers and security providers will be important. Sharing data with the energy provider can greatly affect energy distributing on the power grid (or future smart grid). Data gathered about light- and building usage can be interesting for the wider research community as well.

Performance data from luminaires and other components of the lighting system can benefit manufacturers and light designers that were involved during the Design phase as it can inform new lighting and component designs.

5.2.4. End-user perspective

When lighting becomes a service, mainly the building occupiers will be affected. It will allow building users to create a personalised work environment through applications and user interfaces provided by app developers. This can stimulate workers to work in the office, which can result in the building being used longer. For
the building owner, this has a positive effect on the continuation of tenants renting space.

New services and applications developed by app developers can allow cleaning to optimize their work by providing insights in which spaces need cleaning. New applications will be valuable to security, providing them with alerts if movement is detected after office hours. New services can help maintenance in calculating MTBF (Mean time between failures) of devices more accurately. This can result in a better understanding of needed replacement/space components, thus decrease downtime of the lighting system.

New money flows will be generated as office workers and building facilities can pay app developers for the use of lighting control applications. To enable the building users to use third-party applications FM and/or IT need to explicitly allow users to connect to the lighting system, for example by providing login credentials.

### 6. Discussion

In the previous sections, we have presented the results of a study that was conducted to identify perspectives on the impact of IoT on office lighting value chain. We created a layered value network model that can help in identifying potential impact on stakeholders in the European office lighting value chain. In this section, we discuss the limitations of the study.

The layered value network model was constructed systematically from related methods and insights from experts. Within this work, we did not apply alternative methods for impact analysis, and applied the method on one stakeholder value chain only. Therefore, we cannot guarantee the completeness and the validity of the model.

The data gathered during the interviews are based on the viewpoints of stakeholders currently involved in the European office lighting value chain. Consequently, the four perspectives that have been formulated are the result of their point of view. Although we expect that the perspectives cover the main drivers of change and potential impacts of the Internet of Lighting, it is possible that due to the qualitative nature of the study we have missed additional perspectives or drivers.

The validity of the model is indirectly addressed because it proved to be useful as it brought interesting points of impact on the European office lighting value chain as a result, moreover we are planning to validate these points of impact during the installation of a state of the art lighting system in a real office building. Therefore, we believe that it is worthwhile to apply the generic method and layered value network model for analysing impact of IoT related trends on other application domains as well (e.g., smart buildings, smart cities, smart grids), especially for stakeholders within these domains. Compared to alternative value chain analysis methods, the method presented in this work stands out as it facilitates analysis (and synthesis) of a stakeholder network with high ecological validation.

The four perspectives and layered model presented in this work are the result of analysing the office lighting domain, and are therefore tailored to the lighting domain. We expect that the defined impact in this work will have much overlap with impact defined for other “smart” domains, as they are all impacted by the same IoT trend. For example, the IT to the end node perspective stresses the importance of a building wide ecosystem, a shared IT network for all building systems. It should be noted that this result is not specific to lighting, as this will probably also emerge when analysing impact on HVAC or building security systems. Similar to the IP to the end node, we believe that the remaining perspectives will be applicable for other domains that are impacted by IoT as well.

This study has been conducted by design researchers and lighting professionals, and it represents design thinking perspectives: The goal of this study was to identify new opportunities in the office lighting value chain, with focus on end-user experience. This influenced the choice of related work and models. It is possible that from another discipline, for example engineering or management science, other models can be appropriated to describe the impact of IoT on the office lighting value chain, leading to results with a focus on other stakeholder values.

### 7. Conclusions

With this work, we have presented four perspectives that help to get a grip on the impact of the Internet of Lighting (IoT) on the office lighting value chain. An overview can be found in Fig. 3. With the Technology perspective, we define that the technological of IP to the end node makes IoT possible and will affect interoperability, stimulate IP security, push low-voltage building systems and stimulates future IP innovation. IP to the end node allows for Standardisation, which we approach as an Economy perspective. An open standard will increase market acceptance of connected systems, will create a new competitive environment, allow for flexible building use and will guarantee interoperability of components. IP to the end node also enables Sharing data, which we approach with an Information perspective. Sharing data will be key in setting a building-wide ecosystem and makes it possible to combine data from multiple buildings. It will catalyse data security and regulations and will definitely inform new designs. The final perspective emerges from the combination of Standardisation and Sharing Data. The End-user perspective is used to investigate light as a service. IoT will allow end-users to create their ideal lighting environment, it will play an important role in building management, it will optimize building facilities and will allow for new services for installation of lighting systems. These four perspectives, although defined from expectations about IoT, can be relevant to other stakeholder networks as well. As IoT is closely related to IoT, we believe that the four perspectives can be used by other stakeholders that expect to be influenced by the IoT trend.

We have proposed a new, layered value network model that can aid in understanding the impact of IoT on a value chain. The model is constructed based on three expectations: First, stakeholders will organise themselves in a stakeholder network; Secondly, new stakeholders will be introduced to this network and thirdly, stakeholders will stay involved after handing over their product and can change their role over time. The model can be populated by positioning stakeholders according to (1) their involvement in the design, bid, build or use phase of a building, (2) the value they bring to the end-user on a user, organisation, ecosystem and society level and (3) the relations they have with other stakeholders defined as value flows. The layered value network model has been developed as an analysis tool to describe the office lighting stakeholder network and potential impact. We demonstrated how the model could be useful as a synthesis tool to ideate new stakeholder networks and new value propositions.

Finally, we demonstrated a method which combines the layered value network model with the four perspectives, and that it can be used to define a stakeholder network and describe potential points of impact on a stakeholder level, by presenting the case of the European office lighting value network. (1) At first data was gathered by conducting interviews with stakeholders in the value chain of interest; (2) impact across stakeholders is defined with high-level perspectives; (3) the layered value network model is populated with the stakeholders in the value chain, and (4) the perspectives are used to identify impact on a stakeholder level, within the model. This method proved to be helpful for value chain analysis. It allows for creation of a broad overview of a stakeholder network,
the value they bring to the end user, the relations between stakeholders and potential impact according to high-level perspectives. It’s completeness and the ecological validation distinct the method from alternatives. Although the used value network is one of many examples, we believe that this model can be beneficial for a variety of business environments that are potentially impacted by societal trends.

In this study, we have defined several potential points of impact in a qualitative way. In future work, we plan to validate the findings of this work. A state-of-the-art lighting installation system, with the OpenAIS architecture, will be installed in an office building. During the design, installation and usage of the lighting system, several points of impact will be evaluated through quantitative and qualitative methods. Before this, a selection of impacts to be validated will be made, which is dependent on the pilot site and the installation process during the installation. It is likely that this work leads to refinement of the key drivers of change of the four perspectives on IoT.

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