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Construction related urban disturbances: Identification and linking with an IoT-model

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ABSTRACT

While being a significant part of the urban development, construction projects disturb different stakeholders in various ways. There are three problems associated with construction disturbances: (i) most of these disturbances are not recognised by the people causing them, (ii) they are not monitored and (iii) if they are to be monitored, data is spread among stakeholders. This paper defines what a disturbance is, presents a list of disturbances, linking disturbances to stakeholders and, categorising them based on their distance from construction sites (responding to (i)). Next, a IoT domain model is developed, demonstrating how IoT in construction needs to be combined with the sensors of smart cities to capture the primitives of these disturbances (responding to (iii)). This is a first step towards enabling large-scale data-gathering of construction transport disturbances (responding to (ii)), which is a necessity to predict them and allow better construction transport planning to decrease disturbances.

1. Introduction

The world is currently in the midst of an urbanisation trend, implying that people are leaving rural areas for cities and urban areas [1]. This trend means that there is a strong demand for new houses, apartment buildings, workplaces, hospitals, schools and supportive infrastructure to be built [2]. Construction is heavily dependent on logistics activities, with 60–80% of the gross work involving the purchase of materials and services [3]. According to Guerlain et al. [4], the cost of materials represents 30–40% of the overall construction costs and in general a site receives 2–10 deliveries or 8–10 t of material per day. The construction industry has since long suffered from low productivity compared to other industries [5], and as Josephson and Saukkoriipi [6] reported, Swedish construction workers on average spend more than 49% of their time waiting for and handling materials. One of the main reasons for this is the lack of proper logistics management [7]. Furthermore, if not managed appropriately, logistics activities related to construction become a source of significant environmental harm. The impact of construction transport is significant and, according to Guerlain et al. [4], it accounts for at least 30% of urban goods transport.

Construction transport in urban areas affects several different types of stakeholders, including residents, freight transporters, municipal administrations, shop owners, businesses, and tourists. It causes disturbances such as emissions, congestion, noise, prolonged travel times and increased risk of accidents [8]. With urbanisation, the amount of construction transport, and thus disturbances, is likely to increase further [9]. Thus, there is a need to minimise the disturbances caused by construction transport, which makes it crucial to investigate which disturbances are caused by construction projects, which stakeholders they influence, what type of data is needed to monitor these disturbances and, who owns the data.

Data, collected in various ways, may present narrow aspects of the physical world, however through modelling, fusion and interpretation relevant to the application domain can become valuable information. In this paper, the information we focus on is about disturbances caused by construction projects and construction transports. To capture construction transport disturbances, two types of data are required: data on construction transport and the disturbances they generate. However, the construction industry is one of the least digitalised industries, ranked joint last with agriculture and hunting in a list of 22 industries [10]. With most information being collected, recorded, and conveyed by humans manually, the extraction of useful information is not trivial. Data-gathering in construction requires innovative actions and it is especially required to be not too time consuming or costly. The Internet of Things (IoT) has opened up new opportunities to collect data on complex and interdependent systems, such as urban transport and its

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relation to urban construction sites, in an automated way.

Summarising the above, the aim of this paper is to: (i) investigate the disturbances caused by construction transport that affect different stakeholders, and (ii) develop an IoT-inspired domain model to characterise these disturbances, identifying data needs and data sources.

The paper contributes with an improved conceptual definition of construction transport disturbances, describing the relation between project internal and external disturbances and identifying a total of 66 possible disturbances. It also contributes by modelling links between stakeholders as device owners (project internal and external), primitives (data/performance indicators), disturbances and stakeholders as disturbed (mainly project external) through the IoT domain model (see Fig. 6). The IoT domain model is a first step towards enabling large-scale data-gathering about the effects of construction transport on society. Moreover, it shows that a single device of a primitive can be involved in identifying, contributing to, or exposing, multiple disturbances.

The paper is organised as follows. Firstly, the literature that forms the foundation for the conceptual development is reviewed. Secondly, the methodology of the study is presented. Then comes the results and, finally, concluding remarks.

2. Literature review

The literature review begins with presenting earlier studies of construction transport, stakeholders and disturbances, which is the basis for investigating the disturbances caused by construction transport (the first aim). Thereafter, to respond to the second aim, the basics of IoT-A architecture are introduced.

2.1. Construction transport

The focus of construction logistics can be separated into two primary functions: the management of logistics activities on construction sites, and the transport of resources and materials to and from construction sites [11]. The focus of this paper is on the second function. Transportation is the actual physical movement of goods within the material flow. As such, transportation management includes coordination with the goods owner and available transport modes. Transport takes place between two actors, in this case either from the construction supplier/merchant to the construction site, or from the site to a waste management company or mass storage area. By definition, a construction transport event means two trips, one on the way into a construction site and one on the way out.

Transport planning in construction is dependent on the planning of construction production. The responsibility for planning and coordinating the supply chain and construction site resides with the main contractor [12]. Thus, the main contractor faces the challenge of managing a network of multiple deliveries of different materials, products and resources to the construction site [13]. The construction supply chain consists of three major flows: material, equipment and labour [14]. These flows are delivered by many types of suppliers: material suppliers, equipment suppliers, subcontractors and specialists [15], as well as different types of service providers. Furthermore, the location of suppliers in relation to the site also impacts upon the routing of transport [16] and possible transport modes other than road, with the latter being an example of transferring freight to 'greener' transport modes [17]. These transport modes can be via water or rail, which generate fewer emissions and also cause less congestion. However, they require access to ports, quays or railway tracks. The routing of transport determines the ability to influence which routes are used to and from the site and places for parking to load or unload.

According to Fredriksson et al. [16], in order to capture the impact of construction transport, the surroundings of each construction project can be divided into three zones, see Fig. 1. Zone 1 is the construction site itself and the traffic within it in the form of material being unloaded, loaded and moved around the workplace. Zone 2 is the area near the construction site, i.e. within a few hundred metres of the fence. Zone 2 is a geographical area where stakeholders experience direct disturbances from the site. Zone 3 covers the rest of the city, through which transport needs to pass in order to reach the construction site. This affects third parties indirectly.

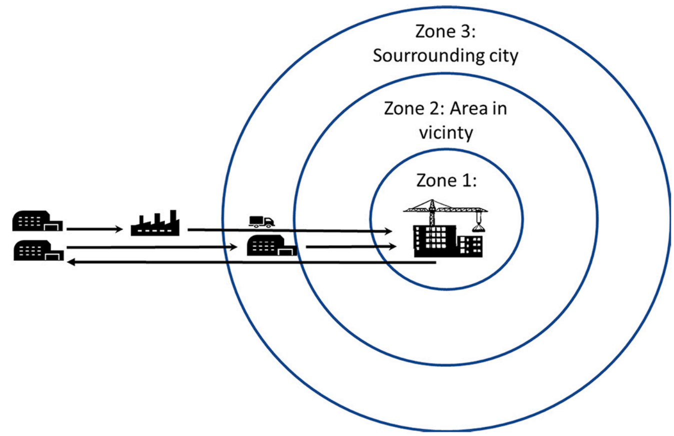

Fig. 1. The three zones of construction logistics, based on Fredriksson et al. [16].

2.2. Disturbances caused by construction transport

Construction transport causes disturbances to different stakeholders. Stakeholders can be defined as individuals or groups of individuals who can influence the objectives of an organisation or be influenced by these objectives [18]. In urban logistics, typically five stakeholder groups can be identified: the shipper, the receiver, the logistics service provider, the (local) government (which sets the rules) and society (which is impacted) [19]. Construction stakeholders can be internal or external to the project, with internal stakeholders being those who are directly involved in construction projects and external stakeholders those who are significantly affected by construction activities (e.g. neighbours, road users, local authorities), but are not part of the project.

In previous studies, disturbances have been referred to as negative impacts, annoyances, social costs and adverse impacts. These include traffic, economic activities, air and water pollution and damage to the physical environment [20]. These disturbances impact upon the urban environment at the social, economic and ecological levels, and are generally referred to as external costs, or externalities [21]. There have been studies calculating the external costs for construction traffic for Brussels, London and The Netherlands, among others [21]. However, these external cost calculations have been made at an overarching level and have not tried to capture the disturbances for different types of stakeholders.

In this paper, we define a disturbance as a negative experience due to a construction project and its transport activities (see Table 1, summarizing the disturbances mentioned in previous studies). Issues such as emissions, congestion, noise and accidents are frequently attributed to urban transport in general, and urban goods transport in particular [22–25]. Gilchrist and Allouche [20] group the impacts and social cost indicators of construction projects into four categories:

(i) Traffic (prolonged closure of road space, detours, utility cuts, loss of parking space, additional fuel consumption, travel delays, increased traffic accident rates, accelerated deterioration of roads and road rage). Here, construction transport increases the risk of accidents when it uses roads with low load capacity or by using grassy areas and cycle lanes for parking, forcing cyclists and pedestrians to merge with the motorised traffic. Furthermore, according to the Deloison et al. [9], the limiting factor for urban

Table 1
Summary of disturbances caused by construction transports.

Category	Disturbances	Reference
Traffic	Prolonged closure of road space	[20]
	Detours	[20]
	Utility cuts	[20]
	Loss of parking space	[20]
	Additional fuel consumption	[20,22]
	Travel delay	[20]
	Increased traffic accident rate	[20–22]
	Accelerated deterioration of roads	[20,21]
	Road rage	[20]
	Congestion	[21–23]
Economic	Loss of income	[20]
	Productivity reduction	[20,22]
	Loss of tax revenues	[20]
	Property damage	[20]
Environmental	Noise	[20–22]
	Dust	[20]
	Vibration	[20]
	Air/water pollution	[20–24]
	GHG emissions	[21–24,26–28]
	Surface/subsurface disruption	[20]
	Damage to recreational facilities	[20,22]
	Climate change costs	[21]
	Restoration cost	[20]
Social and health	Treating compromised physical/mental health	[20]
	Reduced quality of life	[20,22,23]
	Visual intrusion	[22]

mobility in the future will not be transport modes, but space. This is a significant problem because the present infrastructure in cities is designed for regular traffic, excluding construction transport and other type of temporary traffic. Therefore, construction transport vehicles cause congestion and prolonged travel times by competing with other types of transport for the limited urban infrastructure space and time.

(ii) Economic activities (loss of income, productivity reduction, loss of tax revenues and property damage). Shops that cannot be reached because of closed roads or blocked parking spaces lose sales, and cafés close to construction sites where the customers are disturbed by noise or dust during their visits will not be frequented.

(iii) Pollution (noise, dust, vibration and air/water pollution), and

(iv) Ecological/social/health (surface/subsurface disruption, damage to recreational facilities, treating compromised physical/mental health, reduced quality of life and restoration costs). Existing research shows that emissions from construction transport vehicles are large; according to Seo et al. [26], construction transport accounts for 2.4% to 5.5% of CO_2 emissions from construction projects, while Dimoula et al. [27] and Sezer and Fredriksson [28] conclude that it accounts for almost 10% of total CO_2 emissions.

2.3. IoT in construction

IoT is a network of interconnected things (the T in IoT). These things are usually sensors or sensor-equipped devices [29]. The use of sensors in monitoring of activities is not a new phenomenon. For decades different types of sensors have been used for monitoring, decision making, and controlling physical systems [29]. Examples of sensors in the construction industry include proximity, humidity, depth, passive and active RFID [30] as well as temperature and dust. These sensors gather a variety of data associated with project elements, personnel and environment. Though, a little over a decade ago the proliferation of broadband wireless communication, the advent of sensor networking, and the vision of pervasive computing introduced the I to the IoT concept [31]. With wireless communication, sensors could be coupled on remote physical systems and provide cost-effective and safe solutions for monitoring and thereby relieving humans from the tedious, costly, and the potentially hazardous task of obtaining sensor data [32], with the added value of the data freshness [33]. Thus, IoT support decision making by collecting data from several units and store it in a central unit, increasing the cost effectiveness of data gathering compared to manually visiting each device to download data [29]. Yet another key development in IoT and thus a key feature of the IoT concept is the potential for operating IoT services to the Cloud. This allows disconnection between sensor location and data storage and have opened for the development of Big Data as data from several sensors now can be combined in the same analysis. For construction sites, volatile by nature, this becomes an extremely appealing solution for data storage and data portability across construction projects [29]. The central storage also decreases the risk of losing data if one unit is destroyed or stolen, but in temporary organisations, such as construction, it also helps in transferring data from one project to another [29].

The IoT approach differentiates between the real world and the virtual world [34]. For the IoT, the real, physical world can be modelled by- or twinned into- a virtual, cyber world. The real world comprises: (i) ICT-enabled (smart) objects, namely sensors, actuators, and devices used for application access and (ii) non-ICT physical objects. The virtual world is an ICT-representation of the real world in an abstraction layer, or model, in which all the real-world objects are abstracted into digitized representations, such as databases, or 3D models. Digitization is, in essence, the process of throwing a bridge between the real and the virtual world.

Even though construction is among the least digitalised industries [5], both the real-world ICT objects, i.e. the sensors forming an IoT network [35], and the virtual world, i.e. the building information model (BIM) model [36] do exist. The IoT in construction, as well as in other industries, has progressed from point solutions to integrating data from many different sources [35]. This allows innovative companies taking advantage of new data sources to transform their decision-making onto a new level [29]. The data gathered can be used for two purposes: 1) real-time data for immediate decision-making, or 2) for forecasting the impact of future decisions [29,35]. However, according to Woodhead et al. [35], the ability to organise and use existing data within new applications is missing in construction today, and we remain dependent on vertical, stand-alone, solutions.

Thus, in many cases, the processes required to transform the available data into information remain unclear [37]. So far, the data provided by sensors have been mostly used to monitor the productivity of the construction industry [29,35], and the structural health monitoring of the infrastructure [38,39]. For example, Louis and Dunston [29] provide a structure for automating the operational decision-making in construction based on real-time data. However, using this data to handle the disturbances caused by construction transport outside the construction site has not been considered in previous research. The issues related to these disturbances have instead been a part of the Smart Cities realm [40]. However, according to Belli et al. [41], the smart-city concept has often been accused of being too technology-centric, mainly driven by technological companies' own goals, while failing to pay real attention to the needs of municipalities or public. Furthermore, the focus has been on the mobility of people [40] not the disturbances caused by freight transport. To our knowledge, no one has considered integrating the data available within the construction industry with the data available within the smart-cities realm, even though this is precisely what is needed to capture the full picture of the disturbances due to construction transport, in other words, combining the data from all three zones of Fig. 1. However, to accomplish this, we lack a generic description of how data from sensors, both within the city and within the construction industry, can be transformed into information about disturbances. An IoT modelling methodology described here is useful to accomplish this.

2.3.1. The IoT-A architecture derivation and the role of the Domain Model

The IoT-A methodology presents a structure for building up the architecture of an IoT-based software system. Here, we begin by outlining the IoT-A methodology, and refer the reader to the relevant publications [42,43]. Based on the seminal 4 + 1 Views Model of Software Architectures [44], the IoT-A project defines a detailed methodology for deriving IoT architectures using six views, which are: (i) the Physical Entity view, which focuses on the physical objects relevant to the system users and its applications, (ii) the Deployment view, which is, in essence, the topology of ICT components required (iii) the Operational view, which together with the previous view, provide the complete set of capabilities of the system, with respect to delivering the envisioned applications (iv) the IoT Context view (containing the Domain Model), which expands the "traditional" context view of a system's relationship with its surroundings, by also including the entities within the system and setting each of these entities in relation to outside entities, while the IoT Domain Model, on the other hand, provides a semantic and ontological overlay for the context view providing guidance on which entities make up an IoT system and how they relate to each other, (v) the Functional view containing the runtime functional components, with responsibilities, default functions, interfaces, and interactions, and (vi) the Information view, which provides an overview on the system static information structure and dynamic information flow.

In a nutshell, the architecture derivation methodology of IoT-A is shown in Fig. 2. The first target is to design the Physical Entity view, which illustrates the physical objects that are important for the users and the applications. These physical objects must be attached to, or in the vicinity of, the devices that will obtain the data to be sensed. After identifying the physical entities, the requirements for the system architecture are extracted by designing the IoT Context view, which includes the IoT Domain Model. The requirement process receives inputs from the Physical Entity view, the IoT Context view and the business goals of the system, and is used for deriving the other architectural views, namely the Functional view, the Information view and the Operational and Deployment view.

Within IoT-A, it has been argued that, of the six proposed views, three are key architectural views: the Context view (Domain Model), the Functional view and the Deployment view. Moreover, previous experience with research projects RERUM [45] and SOrBet [34] has shown that the Physical Entity view can collapse into the Context view, describing the entities in the Domain Model. For this reason, in this paper we describe only the Domain Model for construction transport, since it proved to suffice in establishing a common language amongst the broad span of stakeholders of construction transport.

The Domain Model introduces the core concepts of the IoT system, including Devices, Services and Entities (physical and virtual), and reveals the relations between these concepts. The abstraction level of an IoT Domain Model is typically chosen in such a way that the captured concepts are independent of specific technologies. A key factor is that the domain model should separate that which does not vary (much) from that which does. For example, in the IoT domain, an abstract "Device" concept has a high probability of remaining relevant in the future, even though the *types* of devices used will change over time and/or vary depending on the application context.

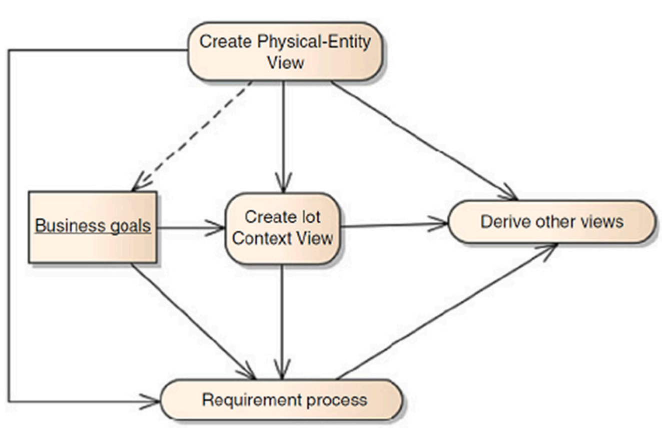

Fig. 2. The process generating IoT Architectures according to the IoT-A methodology [43].

3. Methodology

This research is an analytical conceptual study (see Wacker [46]), which aims to generate new insights into a common problem (disturbances within the urban environment due to construction transport) through logical relationship building. Jaakkola [47] describes four approaches to designing conceptual research: theory synthesis, theory adaptation, typology, and model. Among these, the research process takes a stance in existing relevant theory of construction systems, transportation systems and IoT, using the theory synthesis approach, in seeking to build a new concept based on existing ones, and later a model approach, in developing the domain model.

The theory included were selected by the researchers based on their accuracy in reflecting various parts of the problem to be addressed from the perspectives of the research areas: construction logistics, IoT and traffic modelling. The incorporation of tacit knowledge and experience into the development of conceptual models is key to their underpinning, credibility and usefulness [47]. Such tacit knowledge resides among the researchers, but also – to a great extent – among practitioners. For this reason, the research process leading up to the conceptual models includes numerous iterations and interactions with various research disciplines and practitioners in the construction industry including transport providers and public authorities.

Fig. 3 presents the study design, which includes two parallel flows, following the dual aims of the paper. These two parallel flows were needed in order to capture the different conceptual relationships studied. The first workflow focuses on the individuals in the system and elaborates the relationship between the stakeholders, the construction project and the disturbances at an individual project level. The second workflow focuses on the architecture of an IoT-based software system to enable a generalised description of the data-gathering and handling in relation to construction projects at a city level, i.e. the relationship between the project, the stakeholders and the disturbances at a general city level.

The first workflow was based on conceptual reasoning in order to develop conceptual definitions for the constructs used in the research [48]. It is essential to establish the exact meaning of constructs in order to identify relationship between them and provide valid examples [48]. The conceptual reasoning was used to answer: What constitutes disturbance and how does it depend on the number of transport vehicles to and from the construction projects? The result presenting a structure explaining the relation between stakeholders, disturbances and their geographical relation to the construction sites.

Providing examples of the constructs was necessary to populate the concept with content using the following the questions: What is a construction-related disturbance? Who experiences a disturbance? This was done with the help of tacit knowledge from stakeholders [47]. A workshop was organised, involving stakeholders from different disciplines. In total, there were 17 participants, including traffic planners ($n = 2$), city planners ($n = 4$), construction logistics consultants ($n = 5$), developer/contractors (n = 5) and IoT developer ($n = 1$). The disciplines were identified based on their impact on construction traffic and that they should represent the zones of Fig. 1, where traffic and city planners represent zone 3, construction logistics consultants and developer/contractors represent zone 2 and 1. The IoT developer was included in order to provide insight on possible IoT solutions available. The other participants were selected based on their interest in the subject and experiences of working with the issues related to construction traffic

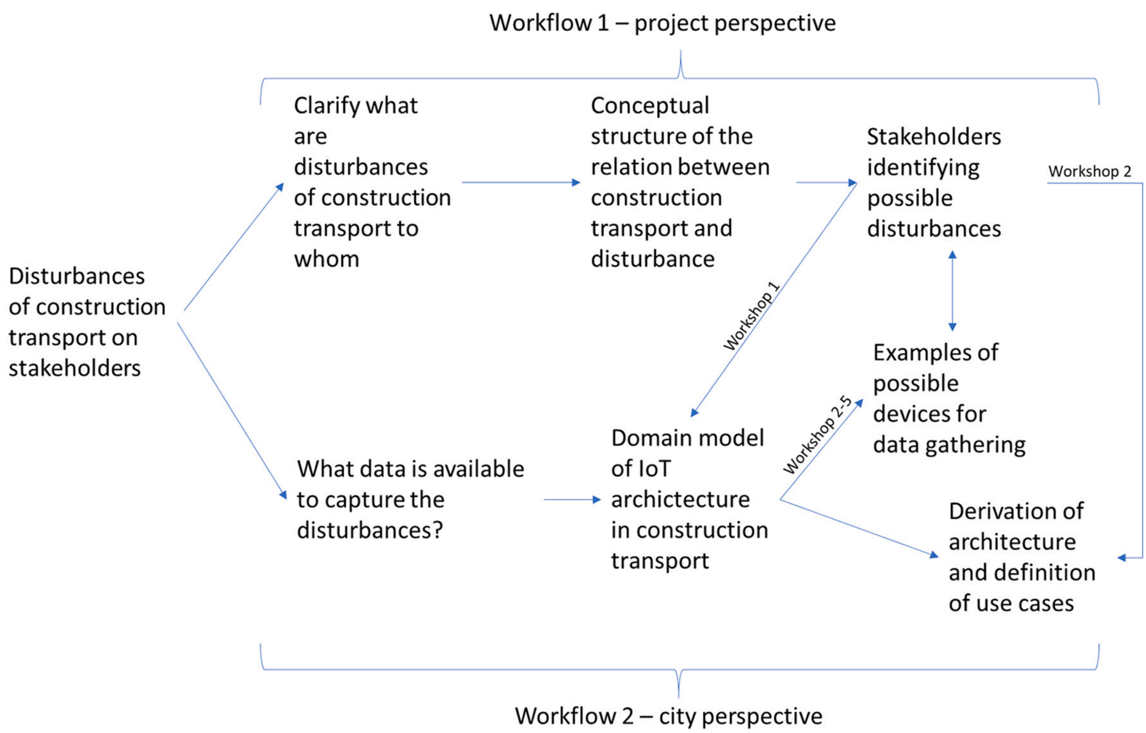

Fig. 3. Study design.

disturbances.

Before the workshop, two response canvases were developed and the participants were divided into four groups. The division aimed to include a wide representation of different stakeholders within each group and each group was given one example of each response canvas. In the groups, there was also a researcher who acted as a moderator. Starting the workshop, the groups were given canvas 1, presenting actors and zones, and asked to list actors first and then identify disturbances for these actors in the zones. Next, the participants were given canvas 2 and asked to note decisions that can impact on the disturbances identified in the first step that the different actors identified can influence. The workshop was organised so that it started with discussions in small groups and thereafter the results were discussed in a plenary session. In the plenary session it was seen that the four groups provided similar inputs to the canvases and therefore we considered saturation in number of participants. The workshop results have been summed up and iteratively clustered to identify the main areas of disturbances to different stakeholders and their geographical relation to the construction site (different zones in Fig. 1), using the following structure: *disturbances, effects on whom, type of disturbance, source of disturbance and source responsible*.

The second workflow focused on developing a domain model, following the well-documented and widely accepted IoT-A methodology. It was developed based on logical reasoning combining interdisciplinary knowledge from the areas of the co-authors: construction logistics, IoT and traffic modelling. In line with the work done by Dale et al. [49], co-authors were invited to discuss the issues raised and in total, four workshops (Workshops 2–5 in Fig. 3) were organised. Each workshop was organised with one of the co-authors presenting the views from his or her research area on transport disturbances, construction transport and IoT and thereafter the domain model was brought up on a whiteboard and the terms and connections within the model were discussed. This enabled understanding of the meaning of different vocabulary used within the research areas and helped bridging different disciplines. After the workshops were conducted a draft review of the paper was circulated among the co-authors, requesting input into literature review and commentary to conceptual reasoning.

Next, to populate the domain model and gather knowledge about the available data, purposive sampling within existing research projects was used to represent scenarios. The sampling was identified based on a meta-analysis of our own previous and ongoing research projects and was complemented with interviews with representatives of four local municipalities in Sweden, as well as six interviews with employees from different companies in the construction industry. In line with Lacoste and Johnsen [50], we have thus used 'tacit knowledge' gained through longitudinal immersion in the field [51] to achieve this part.

4. Conceptual relationships identified in the two workflows

Firstly, we present the results of the first workflow, i.e. the relationship between disturbances, stakeholders and the construction project, and the actual disturbances identified. Secondly, we present the results of the second workflow, the domain model, its main content and examples of data sources.

4.1. Conceptual relationships between disturbances and stakeholders

Different stakeholders experience different disturbances. Following the reasoning of Freeman [18] and Lindholm [52], we identify external stakeholders as those who are not planning or executing work at construction sites, i.e. who are unable to affect the work at site or the transport flow, and internal stakeholders as those who can (see Fig. 4). Internal stakeholders (those who execute and plan work on-site, i.e. main contractors, developers and subcontractors) have projects (active construction sites) in a city, which cause disturbances. Disturbances have four directions: (1) disturbances caused by internal stakeholders influencing external stakeholders, (2) disturbances caused by external stakeholders influencing internal stakeholders, (3) disturbances caused by internal stakeholders influencing internal stakeholders and (4) disturbances caused by external stakeholders influencing external stakeholders.

We do not exclude project-inward disturbances (direction 2 in Fig. 4): i.e. disturbances that external stakeholders can cause to the project. However, to internal stakeholders, only actions/activities

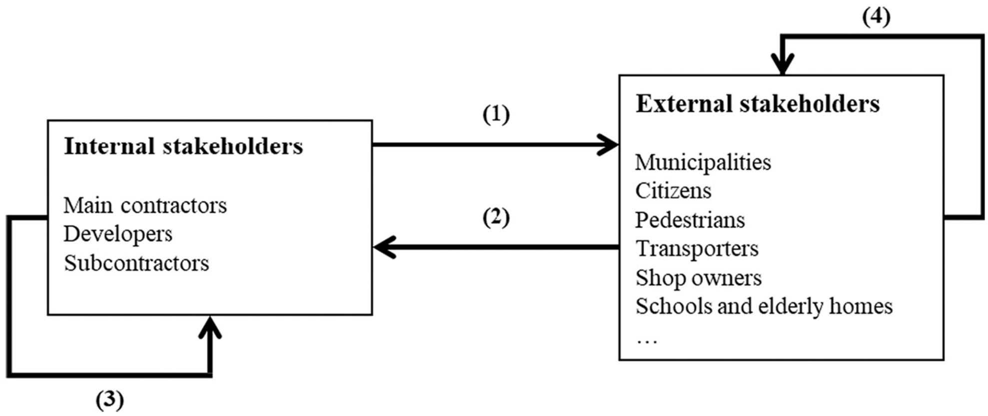

Fig. 4. The relationship between stakeholders and disturbances.

outside the control of the project are disturbances, the rest are seen as part of the natural workflow at the site. Consider, for example, the municipality deciding to pedestrianize a road near a construction site during working hours, or citizens taking actions, i.e. changing their habits or working processes because of the construction project, such that they create a disturbance to the construction project. For example,

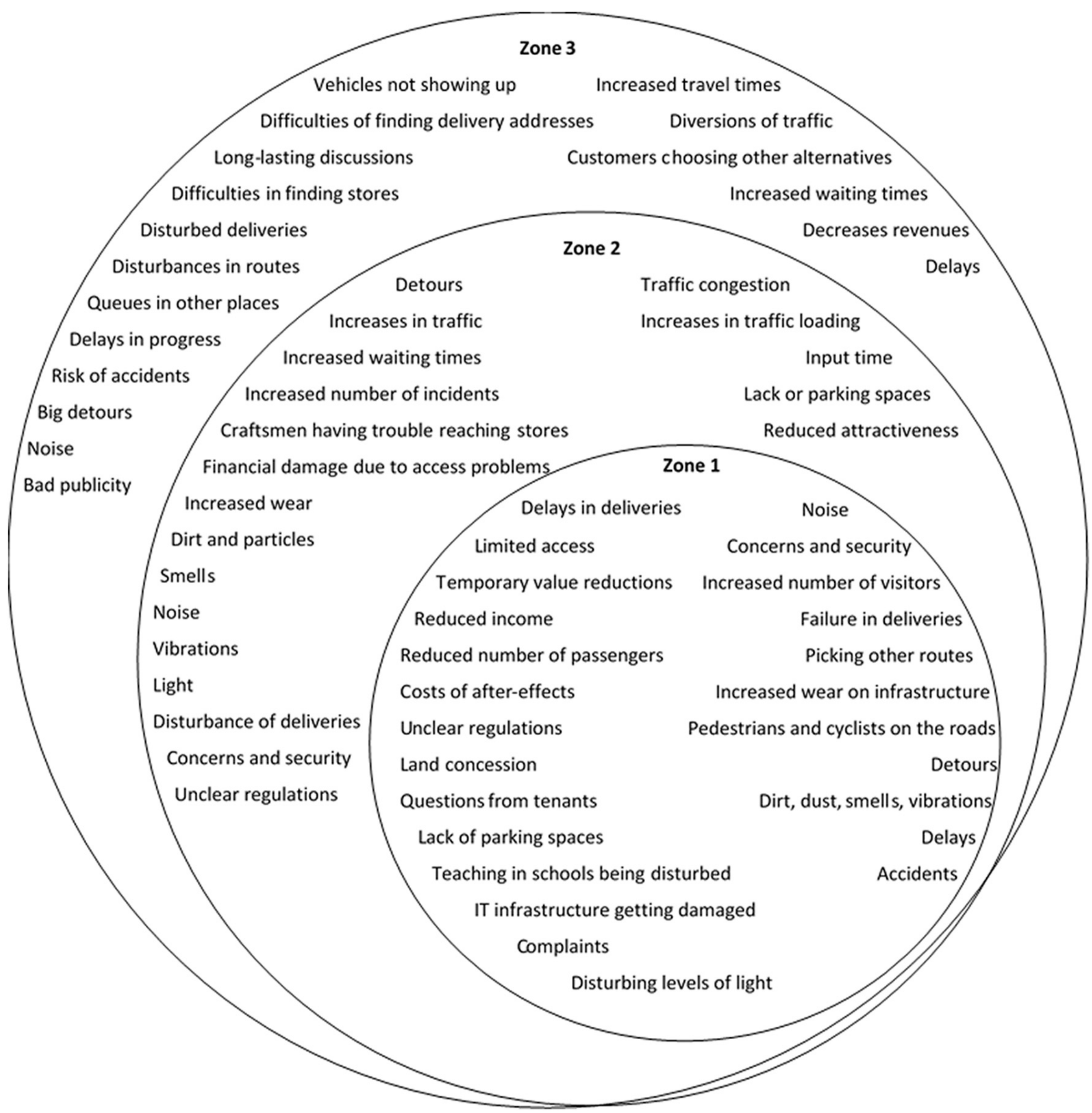

Fig. 5. Disturbances identified by stakeholders for different zones.

changes to travel routes can create congestion in new places in the urban areas that causes delays to construction transport and thus delays deliveries to the project. Furthermore, the lack of coordination among internal stakeholders in construction may generate disturbances to each other (direction 3 in Fig. 4).

4.2. Identification of actual disturbances by stakeholders

Based on the first workshop, both disturbances and sources of disturbances were identified for three zones (see Fig. 5). To be able to relate these disturbances to the arrows in Fig. 4, we divided them into the zones depicted in Fig. 1. There are different disturbances for each zone, and some of these were mentioned for more than one zone, mainly for zones 1 and 2, with noise being the only disturbance reported in all three zones. Compared to zones 2 and 3, the number of disturbances reported in zone 1 was large, with 39 disturbances in total.

4.3. The construction disturbances domain model

The IoT-based model developed here, essentially is an IoT Domain Model which aims to capture the context of a city that needs to identify disturbances caused by one or more construction projects. In that regard, we formed the model in Fig. 6, where IoT operational services are currently only implied, at best. Thus, the IoT Domain Model developed here is only a structure linking disturbances to data sources and thereby enabling characterization and interpretation. We note that this model represents a significant departure from the domain model of the IoT ARM.

The model is based on UML notation. UML is a standard language for specifying, visualising, constructing and documenting the artifacts of software systems. The UML base models on three different concepts: entities, intangibles and data.

- Entities corresponds to tangible objects (physical object)
- Intangibles corresponds to a concept (non-physical). This concept can be a performance indicator such as disturbance or complaint/alarm or a result of a non-physical process such as schedule and task.
- Data in this case is represented by primitives. Primitives are quantifiable key performance indicator values characterizing the disturbance. Typically, primitives would only be implied in a classical domain model, as they undergo clarification in the information model. However, given the need here for clarifying the importance of data, we have introduced them explicitly into the domain model. Therefore, primitives are a key abstraction novelty that we have introduced into the domain model.

In the domain model we have a triplet of key abstractions: the Project and Stakeholder entities and the notion of the Disturbance. An abstraction is a dependency relationship between two named elements or sets of named elements representing the same concepts but from different viewpoints. Our modelling begins from the premise that Stakeholders (here instances of construction companies) have Projects (active construction sites) in a city, which cause Disturbances. If these disturbances are project-outward (Fig. 4), i.e. disturbances caused by the project to the city, are they in turn, experienced by other Stakeholders present in the city (citizen groups, mass transport companies, shop owners, etc.). Next a Disturbance may not only be composed of one or several measurable Primitives. The later issues is important to notice, i.e. a disturbance in this model can be composed of a set of observed values and conditions. Therefore, Primitives form a modelling "bridge", allowing us to create composite disturbances from several Primitives. Such composite disturbances, if project-outward, can be caused either by multiple tasks running concurrently on one or multiple construction projects, or by combinations of different primitives (e.g. noise values in different sensitivity areas or at different times).

Projects' entities are composed from tasks, which in turn are defined by a schedule (project plan, delivery plan or daily task scheduling). This allows us to link the effects of project planning directly to the disturbances generated. The scheduling allows us to show the combined effect of different tasks potentially taking place simultaneously in a more efficient way. These simultaneous tasks can jointly affect the primitives in the vicinity and give rise to specific unforeseen disturbances as it is easier to foresee disturbances with a one to one relationship between primitive and task.

To complete a task, the schedule needs to mobilise resources. These resources are captured by the entities of personnel, equipment and materials, which are generalised as Assets. Another sub-class of asset is the City Infrastructure. Instances of city infrastructure may be stretches of road, pavement, a set of traffic lights, etc. These assets all include devices (e.g. sensors) that enable us to gather data that will allow us to say something about the primitive, and thus the disturbance. Thus, we consider that project and city assets can be monitored using Devices.

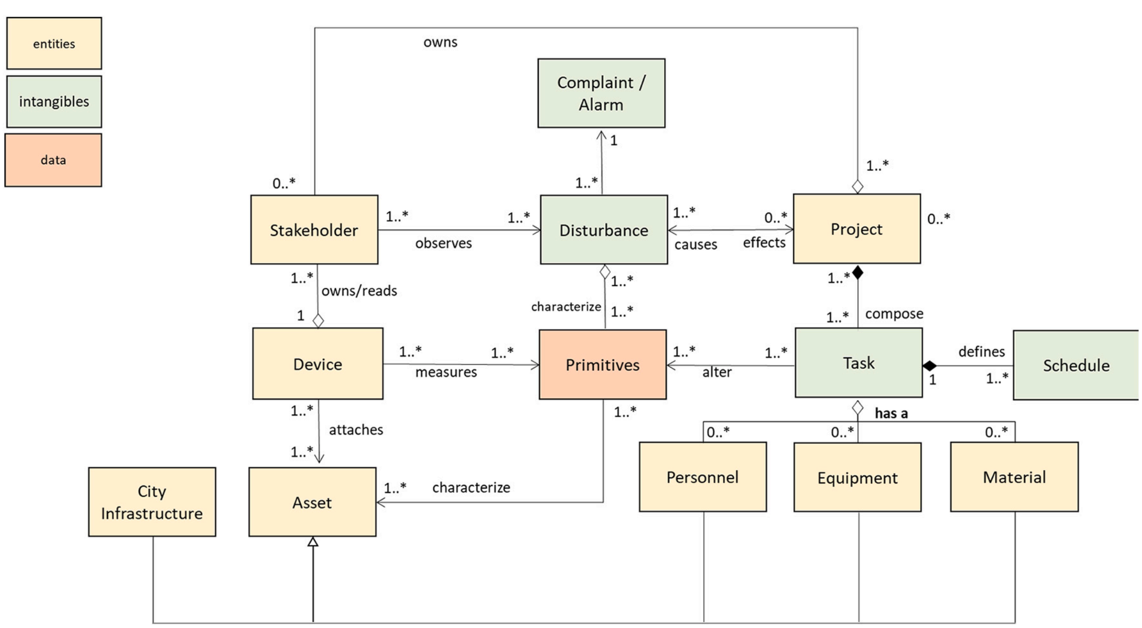

Fig. 6. The construction disturbances domain model.

These devices can be assumed to be specialised sensors, although they may consist of any form of source generating values for the monitored primitives.

Project devices can be found as part of construction machinery, fuel tanks and vehicle such as GPS or sensor boxes on site. But they can also be booking calendars and sensors at the gates controlling the traffic flow to and from the site. These type of devices are usually included in construction logistics setups (CLSs), such as checkpoints or construction consolidation centres [16].

Instances of city infrastructure devices include, for example, radar sensors, parking detection sensors, inductive loops, mobile phones, public transport tap-in systems or licence-plate recognition systems. These devices can give us data about travel patterns as well as local densities, flows and speeds. Emission models in combination with traffic data or dedicated pollution sensors can be used to monitor environment-related primitives.

Overall, each device is owned by one stakeholder in our model; however, we make no provisions, at this stage, for the data values and their storage, or ownership.

5. Applying the domain model: linking disturbances to data sources

The aim of this paper was two-folded: (i) investigate the disturbances caused by construction transport that affect different stakeholders, and (ii) develop an IoT-inspired model to characterise these disturbances, identifying data needs and data sources.

Focusing on the first aim, we have contributed by conceptually defining construction transport disturbances. Based on this definition, it was possible to gather possible disturbances in the stakeholder workshop and in total 66 disturbances distributed over three zones were identified. Compared to the 26 disturbances identified in literature (Table 1), we have contributed with 40 additional constructs to be added to the concept of construction disturbances. Furthermore, distributing the disturbances over three zones in the urban area provide a contribution to the urban planning practice, as it shows that construction related disturbances is a widespread phenomenon, impacting the whole city. By this we also provide content to the model presented by Fredriksson et al. [16] and a managerial contribution to the urban planners in their search for arguments to why construction projects need to implement construction logistics setups also controlling the transports to and from the site [53]. This is immensely important as one of the main reasons of why it is so hard to decrease the disturbances of construction transport is the lack of knowledge of it among urban municipalities in general [54].

Focusing on the second aim, the developed IoT domain model contributes to theory by providing additional linkages between stakeholders as device owners (project internal and external), primitives (data/performance indicators), disturbances and stakeholders as disturbed (mainly project external).

However, since the problem the paper tackles is the lack of ability in the construction industry to transform data into information, we need to connect the results of the two aims. In the researcher workshops, the disturbances identified during the stakeholder workshop (see Fig. 5) are linked to the primitives/data and device owners identified during the interviews. This is a theoretical contribution as according to Louis and Dunston [29], we currently lack research on how to handle the data generated and collected through the IoT infrastructure and the purpose of this linking is to illustrate how data can be collected to capture the disturbances (see Table 2). This is also a practical contribution because effective decision-making requires a deeper understanding of the concerns of different stakeholders [55] and construction transport according to the research presented here, generates a lot of different disturbances, not only on the site or in its vicinity, but also further away (in zone 3).

Table 2 exemplifies the usefulness of utilizing the IOTA methodology

Table 2
Utilizing the structure from the IoT domain model to link disturbances, primitives and device owners in construction transport.

Disturbances	Zone	Primitives	Device owner
Reduced income	1	Accounting	Local businesses
Craftsmen having trouble reaching stores	2		
Financial damage due to access problems	2		
Customers choosing other alternatives	3		
Decreased revenues	3		
Reduced attractiveness	2		
Detours	1,2	Changes in routes	Public transportation companies
Increased wear on infrastructure	1,2	Costs of maintenance	Transport administration
Difficulties in finding stores	3	Customer feedback	Local businesses
Increased travel times for tenants and workers	3	Estimated traffic congestion based on number of projects	Municipality
Unclear regulations	1,2	Interviews	Construction projects
Diversions of traffic	3	Number of closed roads	Municipality
Big detours	3		
Questions from tenants	1	Number of complaints	Building owners
Teaching in schools being disturbed	1		Schools
Complaints	1		Transport administration
Disturbances in routes	3	Number of disturbed routes	Municipality
Accidents	1	Number of reported accidents	Police
Risk of accidents	3		
Concerns and security	1,2	Number of reported incidents	Police
Increased number of incidents	2		
Limited access	1	Phone signals	Mobile operators
Increased number of visitors	1		
Pedestrians and cyclists on the roads	1		
Picking other routes	1		
Traffic congestion	2		
Increases in traffic	2		
Increases in traffic loading	2		
Queues in other places	3		
Lack of parking spaces	1,2	Records from parking automats	Municipality
Delays in deliveries	1	Records of deliveries	Transporters and construction projects
Failure in deliveries	1		
Disturbance of deliveries	2,3		
Vehicles not showing up	3		
Delays	1	Records of deliveries/ reported delays by emergency services	Transporters/ emergency services
Difficulties in finding delivery addresses	3	Records of incidents in deliveries due to address failure	Transporters
Land concession	1	Records of land concession	Municipality
IT infrastructure getting damaged	1	Records of network troubles	Schools
Long-lasting discussions	3	Records of political discussions	Local government
Disturbing levels of light	1,2	Sensors	Construction projects
Noise	1,2,3		
Dust	1	Sensors/Tenant surveys	

(continued on next page)

Table 2 (*continued*)

Disturbances	Zone	Primitives	Device owner
Smells	1,2		Construction projects/Owners
Vibrations	1,2		
Dirt	1,2	Tenant surveys	Owners
Increased waiting times	2,3	Trends in delays	Public transportation companies
Temporary value reductions	1	Trends in market	Real estate/Stock market
Reduced number of passengers	1	Trends in ticket use	Public transportation companies
Costs of after-effects	1		
Input time	2	Travel times	Emergency services
Delays	3	Travel times	Mobile phone data
Delays in progress	3	Project schedules	Real estate owners, contractors
Bad publicity	3	Comments on social media	Public relations

and IoT modelling as a base for data gathering from different available sources (sensors and other digital sources). Some primitives allow monitoring of multiple disturbances, for example accounting data and phone signals allow capturing data for more than six disturbances in Table 2. If these primitives can be combined, they can deliver information about a disturbance experienced by another stakeholder. The spread of devices among stakeholders demonstrates the need to combine primitives/data about construction work with primitives/data from city infrastructure sensors in order to develop a better understanding of these disturbances. Thus, the construction industry and the urban municipalities need to jointly combine their forces. Issues of primitives/data being spread among different stakeholders can be resolved using the IoT domain model, based on which stakeholders can connect primitives of different device owners, project internal tasks and disturbances. It provides a practical contribution on who collects primitives/data about what, and this can lead to collaborations between different stakeholders to reduce disturbances. Some of these primitives/data are already collected, such as accounting, number of accidents and phone signals, while others can be gathered from the device owners in case of a such need.

Primitives/data being spread over various device owners is a problem, however with Table 2, it is possible to capture which disturbances to be monitored and see with which type of primitives can be used to monitor that disturbance and who owns that device. It is important to note that Table 2 is not complete and more links between disturbances, primitives and device owners are expected to be identified in future studies.

6. Concluding remarks

Construction projects are a significant part of the urban development, providing homes, schools, hospitals and roads. However, during the construction process, different stakeholders around the construction sites are disturbed in various ways due to factors such as congestion, noise, vibrations, emissions and economic losses. As part of future urban development, we need to understand how to reduce the disturbances caused by construction. In our current state of knowledge, there are several problems with reducing the disturbances: (i) most of these disturbances are not known to the people causing them because they take place far away from the construction site, (ii) they are not monitored and (iii) if they are to be monitored, data is spread among stakeholders because monitoring would be carried out by various stakeholders.

These problems are not unknown; however, they fall in between several practical areas as well as research disciplines; construction management, IoT in construction and smart cities. By combining the knowledge of researchers within construction logistics, IoT and traffic modelling this paper attempts to manage problems (i) and (iii) which is a significant input for future studies tackling the problem (ii). We have provided a practical contribution to problem (i) through identification of a wide variety of disturbances (66 in total), their relation to different stakeholders and their geographical location in relation to construction sites. This practical contribution was enabled through a conceptual contribution of an improved conceptual definition what a disturbance is and the relation between project internal and external disturbances (see Fig. 4). A second theoretical contribution is providing additional links between stakeholders as device owners (project internal and external), primitives (data/performance indicators), disturbances and stakeholders as disturbed (mainly project external) through the IoT domain model (see Fig. 6). This demonstrates how IoT in construction needs to be combined with the sensors of smart cities in order to capture the primitives of these disturbances and thereby responding to problem (iii). The IoT domain model is a first step towards enabling large-scale data-gathering about the effects of construction transport on society, a practical contribution to solve problem (ii). Another practical contribution that comes out of the IoT modelling is that it shows that a single device of a primitive can be involved in identifying, contributing to, or exposing, multiple disturbances (see Table 2).

Further research needs to dig deeper into what devices and data is needed to calculate the primitives of the different disturbances. Here, the present lack of clarity about who is responsible for construction transport disturbances leads to two major drawbacks: (i) difficulties in collecting data and (ii) difficulties in taking the necessary actions to reduce the disturbances caused by transportation. Thus, further research is needed on the managerial and legal issues of construction transport data management. We also need to deal with the issue of low digitalisation in the construction industry, where most data is still captured manually at sites, which is both time consuming and resource intensive [4,56]. Poor data quality among the available digital data in construction is also an issue [28] that can have severe impacts [57].

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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