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# Smart Ambient Learning with Physical Artifacts Using Wearable Technologies

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## Abstract

Wearable technologies have been developing a momentum recently. However, integrated concepts for teaching and learning with wearable technologies are not available at present. In this paper, we report on a multi-contextual framework for such an integrated concept. It consists of a number of real-world use cases coming from a third-party funded project, an entrepreneurship lab course from a technical university and an open source software development strategy. Based on an exhibition scenario, we conceptualize a framework for dealing with physical artifacts that integrates community learning analytics for self-reflection. Conceptual as well as technical issues and first experiences with an open source prototype draw an optimistic picture while we outline further needs for research and development.

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## 1. Introduction

With the ever-increasing pace of innovation in businesses nowadays, the demand for life-long learning gets reinforced day by day. As an example, the construction sector has to deal with a steady flow of new tools and materials, while the budget for training of staff is ever decreasing. Nevertheless, the introduction of new tools and materials is accompanied with new knowledge that has to be learned before applying it. Besides, physical assets on construction sites are often closely linked to each other and thereby span a network of artifacts. For instance, the electrical components of a smart home, such as a heating control system with multiple digital temperature controls distributed in a building, require a complex interplay of systems. In turn, this demands model-specific expertise of construction workers and electricians to understand the particular systems and their configuration.

In these settings, traditional classroom-based learning scenarios are neither reflecting the daily pace of innovations, nor do they scale beyond demand. Commonly, moving learning situations to the workplace is considered as a solution. With the shift to informal workplace learning situations [2], new solutions have to be found for conveying learning material to learners. To succeed, they must cover a wide range of aspects. It is not enough to present a technical solution and expect workers to embed them into their practices. Instead, social aspects like friendships of workers within their profession and their trusted authorities like foremen have to be taken into consideration as well.

At the same time, developments in microelectronics and Internet protocols are advancing at a high rate. Whereas we have not yet fully understood the socio-technical consequences of the ubiquitous presence of smartphones and tablet computers especially with regard to innovative learning solutions, the next revolution is already well on its way. Wearable computers, most notably smart watches, became widely available recently with the release of the Apple Watch and similar designs based on the Android Watch operating system. These wearables allow new unobtrusive ways of passing information to and from their wearers. Already, a huge market for wearable and devices exists in the realm of personal healthcare and leisure activities, like measuring the steps taken or the distance covered in a run.

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We argue that wearable devices are ideally suited to informal learning situations at the workplace as well. Having these devices attached to the body, they are always available to the wearer right within the workplace context. Wearables can spontaneously emerge and guide the user in a critical situation or provide answers for queries. Moreover, they can solve the hands-free problem of manual workers [3]. However, the challenge is to understand the complex interplay of people on the hand and the physical artifacts on the other. We need to investigate and master the complex patterns of interactions in these new kind of information infrastructures. Our approach presented in this article combines the availability of always-on wearable devices with the notion of augmenting physical artifacts with additional information. We call this a smart ambient setting: "Smart" refers to the intelligence and interconnectedness of artifacts, while "ambient" means the seamless fusion into the working environment. Based on a number of real-world use cases we report on our technical feasibility system study that allows content producers to link digital subjects to working tools or materials. Through the means of community learning analytics, we visualize the complex network of social actors and physical artifacts for community self-reflection.

The paper is organized as follows. First, we give a motivation for using wearables for informal learning in workplace situations, including the use of advanced visual analytics [4]. Then the related work section highlights literature about systems that connect physical artifacts to digital learning content; subsequently, systems offering visual analytics for social networks are referenced. Three real-world use cases coming from a large-scale research project are presented afterwards. We then give an overview of our terminology and list underlying technological considerations. Then the concept of our smart ambient learning system is introduced, before the concrete implementation is shown. A discussion of community analytics, in particular visual analytics, gets presented as a means to get a deep understanding of the learning infrastructure. Finally, we discuss our challenges and give an outlook on possible future work in this area.

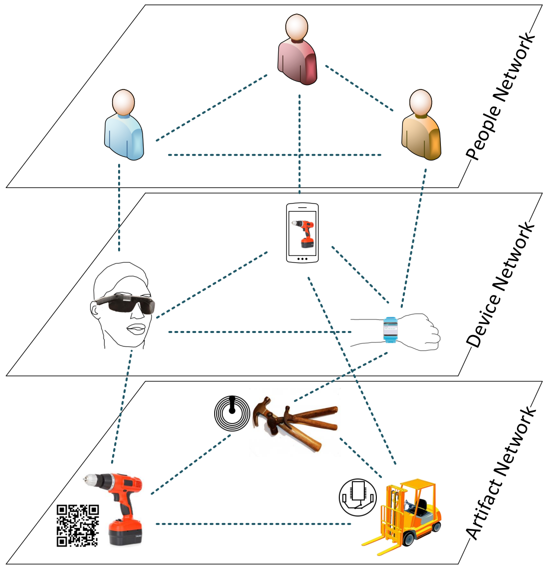


**Figure 1.** Actor-Network of Learning with Physical Artifacts

## 2. Complex Interactions of Actors, and Their Analytics

A wearable computer is defined as an "intelligent assistant that augments memory, intellect, creativity, communication, and physical senses and abilities" [5] with components "small and light enough to be worn on a user's body for convenient operation" [6]. The term 'smartphone' usually represents a different form factor, yet the principles are considered to be the same [7]. As always present body-worn devices, wearables are ideally suited to informal learning in the workplace. But learning with the help of wearables also introduces some challenges. First of all, continuous notifications may disrupt the user's workflow [8]. Besides learning-related notifications, workers may also be interrupted by non-work related messages. Overall, permanently available wearable devices have the potential to offer more integrated learning experiences as opposed to purely classroom-based scenarios. The workplace setting allows context-dependent solutions that embed directly into the work practices. However, the introduction of multiple new devices for learning in the workplace leads to a complex interplay of devices, services and people. It is particularly difficult to find out if and when learning happens, and whether it is successful.

Learning analytics aims to collect, manage, analyze and exploit data from learners and instructors to facilitate the actual learning process [1]. Community learning analytics takes a step further and strives to provide a deep understanding of interactions between learners and other entities in learning processes. As such, we consider learning with physical artifacts using wearable technologies as an ideal use case for community learning analytics. Conceptually, we regard all participants of our sociotechnical system as actors in terms of the *Actor-Network Theory (ANT)* [9]. According to the Actor–Network Theory, both human and non-human actors are part of the society. Actors always have to be understood within a network of other agents or resources that define the identity and properties of the actor. Moreover, complex networks themselves are considered actors in another, higher-level network. This becomes particularly apparent in Figure 1 that shows the different actors in the learning network that includes physical artifacts.

In this article, we discuss three scenarios for use of wearables in informal learning scenarios that are motivated from use cases in the third-party funded project Learning Layers[1]. We then present our technical feasibility study of augmenting workplace tools or other physical materials with digital content. Out of these three scenarios we chose to develop prototypes for an example scenario covering a *construction exhibition*. In fact, the sustainable construction exhibition that initiated the conceptualization and development of our system was opened in the summer of 2015 at our partner NZNB[2]. It is itself located in a building that was built using straw bales. Straw bale building is an environmentally friendly construction technique that is becoming increasingly popular and is hence an ideal testbed for trying out innovative learning solutions.

We implemented a Web-based framework for connecting digital content to physical artifacts by virtually enriching items. The development work was initiated in an entrepreneurship lab course at our technical university and was then continued within our research group. In the lab course which we have conducted for more than 15 years now, students work on software solutions for external partners from the high-tech startup sector. For the startups, the university lab represents a unique opportunity to follow and try out innovative ideas aside from their core businesses. The students gain first-hand contacts in entrepreneurial environments and are trained in new technologies, agile development practices and presentation techniques. The emerging field of wearable technologies provided a highly innovative entrepreneurial setting for a student project, giving ample opportunities for new business ideas.

Our framework consists of a backend in the cloud and frontend components for desktop, mobile and wearable devices, to demonstrate the utility of a solution that spans various user-facing endpoints. The inherent event-based character of a visit to the learning exhibition provides three phases: before, during and after the visit. From an outside perspective, we first face the challenge of detecting the three phases. Further, it is hard to analyze when and how learning takes place, whether it is already happening when planning the visit or only during reflection on the gained knowledge. From the visitor's perspective, it is essential to get an orientation of the exhibition itself and the additionally provided material. To provide him/her with suitable recommendations, his/her intentions must be clearly detected. Community learning analytics aims to answer these core questions. In particular, visual analytics focusses on drawing conclusions out of complex data sets. We are specially interested in the complex interplay of people and the physical and virtual exhibits.

For the technical realization, we borrowed concepts from social Web 2.0 applications, instant messaging and the *Internet of Things (IoT)*. Beyond facilitating the design of the system, recombining different approaches of typical Web 2.0 applications significantly helped streamlining the implementation by being able to reuse existing components like the open source WordPress[3] publishing software. We assembled a testbed as an initial configurable infrastructure for trying out different wearable-enhanced learning cases in the future. More components that may emerge in future co-design activities with users can be embedded into our architecture via open *Application Program Interfaces (APIs)*.

To allow for building upon our results, the development work is available under a permissive open source license on our GitHub page[4]. We see a huge potential in extending our prototypes to also address challenges such as personalized, localized and otherwise adapted digital content to take into account users' prior knowledge, experience, context of use and performance levels. In the next section, we review related work.

## 3. Related Work

In this section we give an overview on related work: firstly in the field of learning with wearables in general, secondly in using wearables in museum settings. Then, systems that support visual analytics for instant messaging networks are referenced. Finally, we highlight some of our recent work on community learning analytics that have led to this research.

### 3.1. Learning Using Wearables

Despite only being widely available for the past few years, research on wearable technologies in general has intensified since the early 2000s. In [10] and [5], Thad Starner, one of the pioneers of wearable technology research, gives an overview about form factors and challenges of early wearable computer prototypes.

Zeagler et al. tell the history of wearable computing, including various research prototypes and the history of the development of Google Glass [11] . Because of its rather easy availability, Google Glass has been studied by multiple researchers in various fields. Although the "Glass Explorer" program which allowed individuals to purchase one of the devices in a public beta has

[1] http://learning-layers.eu

[2] Norddeutsches Zentrum für Nachhaltiges Bauen, english: North German Association for Sustainable Construction

[3] https://wordpress.org

[4] https://github.com/learning-layers/CaptusBackend

subsequently been closed, multiple similar devices are already available, so that the gained experiences with Google Glass can be transferred to those new products in the future. Guo et al. compared methods for helping workers in a warehouse to pick up goods from a shelf: by using head-up displays or cart-mounted displays, or by light indicators on the shelves [12]. Their results show that the error rate was significantly lower with head-up notifications, compared to no technical aid; even cart-mounted indicators improved the performance.

The hands-free character of Google Glass and its usage for context-based learning is used by Suarez et al. in GPIM, a Google Glass based prototype for inquiry-based learning [13]. Their Glassware (the term for a native Glass application) allows users to plan and follow their own learning path to build and organize their knowledge. Therefore, learners can set up a hypothesis and then take pictures, record videos or create notes for their inquiry. All inquiries are displayed on a backend component where teachers can answer the questions.

## 3.2. Wearables in Museums

Leue et al. describe a qualitative study with museum visitors in Manchester using Google Glass [14]. In their Google Glass application called "Museum Zoom" image recognition is used to detect and identify the currently viewed painting. Visitors get to see further information to each painting and can follow links to other artwork. The authors argue that the hands-free experience of their application was considered vital as opposed to existing audio guide systems where the number of each exhibit usually needs to be entered manually. Except of sharing the items via social networks, no interaction between visitors is fostered.

The domain of museums and exhibitions is an especially rewarding community for innovative systems with wearable computing elements. Museums usually display exhibits in a dedicated area like a building that is available to the public. Attracting people to their exhibitions is of high interest for museum operators. Making exhibitions more interactive raises the competitiveness of museums as a leisure and entertainment place, competing with cinemas or theme parks. Therefore, operators of museums strive to digitalize their collections and introduce other means to make the visitors' stay worthwhile.

Flavia Sparacino [15] presents a wearable computer that serves as a personalized story teller through exhibitions. Using infrared sensors, the semantic location of the visitor is assessed. The glass-like device features a display in front of the right eye which shows additional information based on the physical object in front of the user. The information is then fused into one augmented reality image.

Another work dealing with augmented reality, in this case for cultural heritage management, was developed by Kovachev et al. [16]. They developed the XMPP-based Mobile Multimedia Collaboration (XmmC) infrastructure for near real-time semantic annotation of multimedia with augmented reality features. A mobile app for Android-based systems allows users to display and create annotations on the live image taken by the smartphone's camera. A conflict-resolution engine ensures data integrity when multiple users are working on the same annotation.

## 3.3. Near Real-Time Visual Analytics of Social Networks

Social graph-based visualizations show people as nodes and their connections (or instant messages sent) as edges. *Near real-time* is defined as a time span that is greater than the real-time characteristics of the embedded system community, but below the human-perceivable treshold of around 100 ms [17]. Systems have been developed for the Internet Relay Chat (IRC) protocol [18] and the Friendster social network [19]. The analytics system for IRC gathers statistics about the social interactions of users by monitoring IRC channels with a bot. The bot keeps track of channels by logging participants and chats between users. In the Vizster system, Heer et al. [19] collect data from the Friendster social network. In particular, they focus on multiple graph algorithms and visualization techniques, e.g. by grouping and coloring nodes.

The Tracking User Intelligence (TUI) system was designed to help emergency response organizations to increase situational awareness through real-time visual analytics of social media [20]. Geotagged tweets are displayed on a map. Widgets on the interface allow filtering for special relevant Twitter messages. Filters can be created in the ScatterBlogs2 [21] system as well. It was designed for real-time monitoring and analysis of microblog feeds (of which Twitter is just one representative). The client features a number of different views to allow the adjustment of filters.

## 3.4. Community Learning Analytics

Community learning analytics comprises the identification, analysis, visualization and support of informal community-regulated learning processes. Here, we highlight some earlier work of our research group about community learning analytics that has guided our work in this article. A general introduction to the topic is given in [1].

Dashboards aggregate data from different channels and make it all accessible on one page. Derntl et al. provide configurable personal dashboards for interactive visualizations of the technology-enhanced learning research community [22]. A generator app creates Web widgets that allow selecting different data sources in order to visualize them on a diagram. The data may also come from the MobSOS [23] database, a model and testbed for mobile community success measurement based on the model of DeLone and McLean [24]. MobSOS combines quantitative and qualitative factors by considering both Web logs and questionnaire data.

Near real-time event detection, monitoring and analysis of Twitter data is achieved in the system presented by Petrushyna et al. [25]. It employs a distributed near real-time computational framework that analyzes Twitter streams according to given metrics. It can be used for data analysis of other social media data as well.

In this section, we have given an overview of related work in the areas of wearable-enhanced learning, near real-time analytics and the field of community learning analytics. In the next section, we present our technological framework.

## 4. Smart Ambient Devices

Before delving into the details of our informal learning scenarios using wearables, we define the terminology used in the rest of the paper. Then, the technological backgrounds for linking digital devices to physical artifacts are highlighted.

The goal of our system is to attach digital content to physical artifacts. Therefore, devices able to retrieve, compute and output digital information are needed for the users to interact with the digital material provided. To offer a wide variety of interaction possibilities, involve the largest possible user group and to account for the limited availability of particular equipment, we chose to support various device types. Here, we define the device class terminology that we use throughout the paper; in the brackets we list concrete instances of these device types that we used during the development and test phases of our case study.

- As *stationary devices*, we refer to desktop PCs and laptops (Windows and MacBook). In our test we used laptops with 8 GB RAM and a state-of-the-art (2015) multicore CPU.

- As *ambient devices*, we refer to public displays, i.e. fixed large-screen monitors that augment a user's mobile screen space (a state-of-the-art 50 inch flat TV connected to a Google Chromecast). A particular challenge using public displays is their lack of easy customizability and contextualization for short periods of interactivity with users.

- As *mobile devices*, we refer to smartphones and tablets (Nexus 5 and Nexus 7).

- As *wearable devices*, we refer to smart glasses and smart watches (Google Glass and LG G Watch). Here, smart watches are characterized as devices of a wristband type either connected to the Internet directly or via a tethered smartphone; i.e. we exclude the wide range of fitness trackers solely able to track parameters like heart rate or steps taken.

Apart from these concrete instances of devices, we are confident that our technological findings and prototypes can be transferred easily to other brands, models and even new types of devices that are not yet conceivable today, since we are using Web technologies as the underlying platform. Besides Web browsers being installed on every device, various cross-platform environments like PhoneGap or Sequoia Touch exist that enable developers to transform their applications from HTML5 into native app packages for Android or iOS. This may be especially important when accessing special hardware capabilities of devices. The availability of interfaces to hardware sensors, in turn, is crucial when trying to discover physical artifacts, as in our scenarios (see Section 5). Approaches for establishing the link from physical artifacts to digital background data are presented below.

### 4.1. Technologies for Discovery

Making smartphones and wearables aware of the physical presence of artifacts is a crucial requirement for our system to be able to present additional information about these items to the learners using them. In various domains of computer science, the detection of capabilities or services from the service user about the service advertises is called service discovery. In software engineering, the mechanism of services to find and talk to one another is called *service discovery*. In our setting, service discovery therefore describes an automated identification of the availability of physical artifacts in the smart space around the mobile and wearable device.

To identify physical objects, each object's identifier or at least the object's type has to be advertised by any means. Therefore in our infrastructure, every entity (i.e. physical artifact) has to be uniquely identifiable. We achieve this by allocating every participant in the sociotechnical network a Universally Unique Identifier (UUID). The canonical format of a UUID uses hexadecimal text with inserted hyphen characters (e.g. 656f1378-b6a8-49b4-8802-01677294c438). When a user walks around in the smart space of the exhibition, the wearable devices need to sense the identifier by technical means in order to associate the linked

**Table 1.** Applicability of Physical Object Discovery Techniques with Examples of Commodity Hardware

| Device | QR Codes | Near Field Communication | Bluetooth Low Energy |
|---|---|---|---|
| *PC/Laptop* | webcam | – | ✓ |
| *Public display* | – | – | possibly |
| *Smartphone* | ✓ | ✓ | ✓ |
| *Tablet* | ✓ | ✓ | ✓ |
| *Smart watch* | – | – | ✓ |
| *Smart glass* | ✓ | – | ✓ |

information. In the following, we therefore discuss technologies that allow physical artifacts to expose a unique identifier.

**QR Codes** encode certain chunks of information visually, similar to barcodes that are found on almost every product in supermarkets for many years. While barcodes encode a product's item number in vertical bars, QR codes consist of up to hundreds of squares whose arrangement is able to encode as much information as around 4000 alphanumerical characters. Over recent years, QR codes have gained huge momentum in street and magazine advertisements where the advertised product's website is often encoded in a QR code. Mobile apps capable of decoding QR codes are called barcode scanners or readers and are available for free on most mobile operating systems. Additionally, open source QR code readers are available and embeddable as a library within custom apps. The main advantage of QR codes is their cheap reproducibility and customizability by simply generating codes through free online services and then printing them out on any printer. It is also the most interoperable technology out of those presented here, as except requiring a built-in camera, no additional hardware is necessary on mobile devices to use QR codes.

***Near Field Communication (NFC)*** is a contact-free technology for transferring small chunks of information between devices equipped with NFC hardware. The principle is established in public transportation ticketing systems and credit cards; the microchip that is usually embedded in the cards has to be held close to the reader for a short amount of time so that the data on the NFC chip can be read out and processed in another step. NFC typically works over a range of a few millimeters; it has an active and a passive mode. The active mode allows two NFC devices to actively exchange information over a wireless link; the speed is usually as low as around 100-400 kilobits per second, which is satisfactory fast for the minimal amount of information that NFC devices exchange. In the passive mode, the accessing device is sending out wireless waves on a specific frequency. Via electromagnetic induction, the field in the sending circuit on the NFC chip is activated and

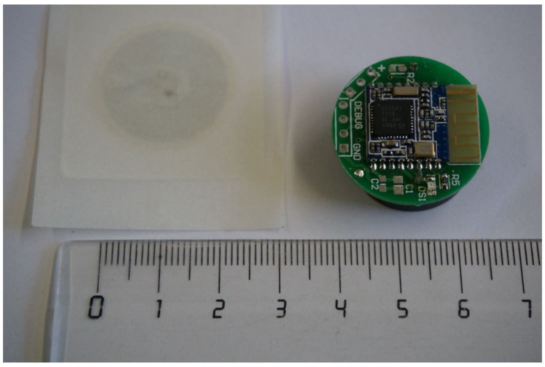


**Figure 2.** Size Comparison (in cm) of Near Field Communication (left) and Bluetooth Low Energy Chips (right)

enough energy is harvested to answer the request with the data that was previously saved on the chip. These chips are usually called NFC tags. They are available in different shapes such as the already mentioned credit cards, or simple stickers as shown on the left in Figure 2. NFC technology is available on state-of-the-art Android smartphones and many tablets. Though NFC is also available on the iOS platform, Apple limits the hardware's usage to mobile payment applications.

**Bluetooth Low Energy (BLE)** is a sub-specification of the latest version of the Bluetooth standard stack for resource-efficient data transfer that is similar to NFC. The circuit for a BLE chip fits on a thumbnail and can be powered by a coin-sized battery for around 1-2 years. To advertise its presence, it periodically broadcasts messages with a configurable signal strength. After calibration, i.e. measuring the signal strength at distance intervals of 1 meter, a mobile device may measure its distance to the BLE chip; typically this can range from a few centimeters to around 70 meters. The broadcast data packets include a few bytes of data that can be predefined similarly to those of an NFC chip. The iBeacon specification by Apple defines the broadcast data to include a UUID as well as a *major* and a *minor* ID. The UUID is typically the identifier of a specific deployment; the minor and major identifiers mark iBeacons within the UUID. E.g., a retail chain may define a UUID for all its stores, a major ID for a specific store and a minor ID for a particular iBeacon within the store. While iBeacons are natively accessible through the iOS development framework, libraries with similar functionality are available for Android. Figure 2 (on the right) shows a typical BLE chip. In early 2015, Google announced another protocol for BLE chips called *Eddystone* that directly competes with Apple's stack. The open source protocol specification defines specific message frames that Eddystone-enabled devices know. In addition to a unique identifier similar to that in the iBeacon specification, Eddystone is also able to send a so called *Eddystone-URL* for sending full Internet addresses. Besides, Eddystone beacons send out a namespace.

In this section we discussed different technologies for the discovery of physical artifacts from a mobile device. We defined that artifacts need a unique identifier to be digitally representable, no matter what specific technology is used. Table 1 shows an overview of the presented approaches and their applicability for the device types presented in Section 4.

## 5. Scenarios for Learning with Physical Artifacts

In this section, we give examples of real-life scenarios for learning with physical artifacts. They originate from the third-party funded project *Learning Layers*[5] that is dealing with informal learning in the workplace for the construction and healthcare sectors. The scenarios aim to enable different types of digital devices to digitally enhance physical artifacts like tools with additional information. The objects should also be able to be virtually discussed by users. Social Web 2.0 features like sharing to social networks or via messages are also of interest.

At **construction sites**, workers have to deal not only with a large variety of building materials, but also with a huge quantity of different tools. As an additional burden for fast adaption of construction techniques, these materials and tools are rapidly changing. Thus in this scenario, workers carry around a mobile device in their work belt and wear smart watches on their wrists and possibly even wear a smart helmet[6]. At the start of the day, the workers open a digital toolbox app for getting a list of the day's tasks. Depending on the specific task that the worker has to fulfill, the app presents a list of tools like drills and screws that need to be collected first. For every tool, comments from other workers or annotated videos are available as manuals that can be displayed on a mobile device or on the visor of a smart helmet. Additionally, new videos may be recorded and uploaded to a repository to be discussed by co-workers. Finally, the apps for wearables may track the current context to prompt construction workers in case there are subtle improvements possible to their work progress.

In the **healthcare** scenario, staff in a hospital carries around tablets and wears smart watches and smart glasses. When entering a patient's room, the doctors and nurses are reminded on their wearables that healthcare data has been loaded onto the tablet. The wearable may already have presented the most important actions like medications due on its display. During these actions, further data may be shown on the smart glass as an augmented reality overlay, e.g. during operations. Finally, critical alerts on a patient's status may be automatically received on the smart glass at any time, just like pagers notify doctors about certain events.

The **exhibition concept** can be seen in Figure 4. In the scenario, visitors enter a museum space and then use their mobile and wearable devices for interacting with the exhibition items. For every exhibition item on display, more digital material is available on a Web-based backend. Notifications on the wearables guide the visitors to further material that can be accessed with the help of mobile devices. Such digital information include a textual description of the object, PDF documents, and multimedia information such as audio tracks and videos. Users may discuss the exhibits by adding comments to the digital versions of the items and even comment on remarks made by previous visitors, enabling a discussion. Besides simply viewing the items, visitors are able to bookmark links to physical artifacts in a personal library within the system. To take home the virtual impressions and collections after visiting the museum, users may email their library to an email address after the visit, with links to any discussion threads for further comments. A public display may temporarily be used to see the content on a larger screen; the material may also be printed out on a stationary printer in the museum. Both emails and printouts include Web links to the system, so that the discussion may be even continued later on.

Besides high potential for new innovative ideas to make use of wearable computing in the above-mentioned three use cases, the downsides of introducing computers into these situations also need to be discussed. This is especially important in the healthcare sector, where national and international privacy regulations prohibit the wide exchange of data. But even in the construction sector, our commercial partners in the Layers project are concerned about intellectual property rights and related issues such as what information to share and what to keep private. Taking these aspects into consideration is therefore of high importance. Gaff identified three main legal issues with wearable technologies [26]. *Data Ownership* questions what claim the wearable's manufacturer or app provider have on the data that is produced by a wearable. For instance, heart

[5]see http://learning-layers.eu

[6]E.g. the one available at http://hardware.daqri.com/smarthelmet/

| Stages | Traditionally | With Smart Technology |
|---|---|---|
| 1. Preparation | Maps, leaflets, press releases, press coverage, catalogs | Community Website with subscriptions, blogs, press releases, social media presence, apps |
| 2. Visit | Audio guide, catalog, exhibition design, helpers, guides, shop, special events | Smart devices for hire, virtual catalog, exhibits with smart codes, notifications & alerts, bookmarks, app for keeping the context and collecting virtual items, printing services |
| 3. Follow-up | Catalog management | E-mail, blog, social features, contact management via community Website |

**Figure 3.** The Stages of the Exhibition Journey

rate monitors collect very personal data that could lead to negative consequences if leaked to health insurance companies (or loan providers etc). On an organizational level, internal data as consequence of recording videos within a company could find its way to competitors. *Privacy* concerns relate to personal details like the user's current location. A cloud service where the location data of multiple wearable app users is collected could be hacked and thus reveal patterns of the user's absence from home, enabling opportunities for burglars. *Intellectual Property* protection is especially hard as wearables could enable hidden capturing of sensitive data.

The authors suggest to clarify such issues on a case-by-case basis prior to using wearables, to prevent disputes. As many different kind of devices are being released currently, lawmakers cannot fully grasp beforehand what laws are applicable to which technology. We will show later, how we tackled these threats. However, this is not the main focus of our exploratory approach. In the next section, we further elaborate on the exhibition use case and develop a conceptual approach to guide visitors through the learning experience at the museum's smart space.

## 6. Exhibition Customer Journey

In the following, we further analyze the exhibition scenario and develop a conceptual approach and prototypical implementation to tackle the challenges of the museum's visitor communities. The exhibition as presented herein is not a typical mainstream museum setting where visits enrich the cultural horizon in an entertaining and informative way. Instead, the exhibition focuses on innovative construction materials that are not necessarily available in classical do-it-yourself stores.

We present a visit to the exhibition as a *Customer Journey*. The term borrowed from marketing literature describes the phases that a customer is confronted with when investigating a specific product, before he decides to purchase the product. In our case, our product is the knowledge gained through previous learning processes. The three phases are preparation, visit and follow-up activities. Figure 3 compares how exhibition visitors traditionally dealt with these phases, and how smart technologies, i.e. smartphones and wearables, can enhance the stations. First, the visitors start with the preparation phase. Traditionally, visitors are drawn to exhibitions via press coverage, ads or leaflets found at particular places. Potentially, this could include planning the visit with a map and marking the most interesting exhibits. In our concept we want to enable engagement of visitors with the exhibits already before their visit. Previous visitors should be able to recommend interesting activities and exhibits to future guests through social media. In a traditional museum, audio guides or catalogs are typically available to guide visitors through the museum space during the visit,. A connected wearable device opens up new possibilities for recommending users other items based on their previous path. Wearable devices should be available for hire, just like audio guides can be borrowed in museums worldwide for the duration of the visit. The exhibition app may allow users to bookmark items to come back to them later. Also, social collaboration features like commenting should be easily available. At the end, the bookmarked items can be printed out as a personal catalog of the exhibition and the collection can be sent home via email. After the visit, the follow-up phase begins. Traditionally, this means engaging with the catalog or planning future visits and noting down what techniques learned can be transferred into one's daily routine. In our concept, attending the exhibition is only the start of the engagement with the exhibits and the respective learning material. We envision building a community around the exhibits on a common exhibition platform. Here, further experiences with the innovative construction material can be collected and shared.

### 6.1. User Concept

User engagement, in terms of discussion with other users, sharing and later retrieval of the collected information, is an essential part of our system as discussed in the previous section. To keep track of exhibition visitors in the discussions and to maintain the library of bookmarked exhibits, a user management system is necessary which includes a unique identifier for each user. Exhibition visitors should be able to use their own familiar devices and accounts for interacting with the exhibits. The user authentication mechanism in our system is therefore based on the OpenID Connect (OIDC) single sign-on standard that is widely supported by big players such as Google and Microsoft. With OIDC, visitors use their usual third-party accounts to access the exhibition.

**Figure 4.** The Exhibition Scenario with Physical Artifacts

### 6.2. Digital Counterpart of the Exhibition

For linking physical artifacts to their digital counterpart, we employ the notion of a digital exhibition repository. This repository contains all the learning material related to the exhibits including longer texts, graphics and multimedia elements like audio recordings and videos. While the physical items in the exhibition are possibly fixed in their position, with their arrangement intrinsically suggesting a certain visit or learning path, the digital version may be traversed via links. This may even imply a custom route between the exhibits based on previous knowledge, personal preference or qualification.

### 6.3. Connection to Physical Artifacts

While moving through the exhibition, users need to be able to get to the digital counterpart of the exhibits through their mobile and/or wearable devices. This step from the physical to the digital world needs to be as easy as possible, i.e. without requiring much user interaction. Since visitors are able to virtually jump from one item to the other, we also want to support moving the other way round, from the digital page of an item to the appropriate part of the exhibition space. We support this via an interactive room map that displays the positions of the items at their approximate real locations.

### 6.4. Reflection After the Visit

As mentioned earlier, the visit to the learning exhibition is not finished at the exit door. To enable reflection, sharing, discussion and extension of the learning materials after the visit, the content visited can be bookmarked whilst moving around the exhibition both physically and virtually. During the exhibition, this list can be accessed at any time. The system compiles the list of the user's bookmarks and allows it to be shared via email. Additionally, the material may be compiled as a PDF to be printed on a stationary printer somewhere in the exhibition space.

This section has presented the main components of the exhibition journey in detail. In the following, we present a prototypical implementation of our concepts.

## 7. Prototype Implementation

The previous section presented the concepts of our exhibition use case for using wearable computers and mobile devices to augment physical artifacts with digital media. In the following, our prototypical implementation is discussed. First, the Web-based backend solution, including its WordPress application and the established XMPP [27] network, is described. Then, the mobile app as information hub and finally the wearable prototypes for enhancing the experience are detailed.

The development was carried out in an open source process. It is based on the recent DevOps [28] methodology, that stands for an environment where developers and operators are working together to automate as many parts of the development and operation of software as possible. Furthermore, we coined the DevOpsUse term by integrating the notion of end users into the development process [29]. We created a feedback workflow in the continuous innovation platform Requirements Bazaar [30] that allows users of our exhibition system to get in touch with the other stakeholders in the process, namely researchers, developers and operators. The overall aim is to establish a continuous innovation life cycle where advancements in the software follow the real needs of the whole community.

### 7.1. Backend

**WordPress** is an open source blogging software and is one of the most widely used content management systems on the Web [31]. Its wide availability guarantees both a huge possible user base, as well as a large amount of open tutorials and help possibilities. This is in line with our goal to make the system as simple as possible for both users as well as content creators. With its extendable plugin system, WordPress allows the installation of a wide variety of extensions. For the feature of creating a new information page for an exhibit, we employ standard WordPress pages with custom URLs. E.g., the URL of an augmented drill can simply be `http://exhibition.app/exhibition/drill`. On every page, we activated the WordPress comment functionality to make discussions possible. This allows users to reflect on the material together with other people accessing the page. Pages also contain social media sharing buttons for Facebook, Twitter and Google+. To help content creators, we created a WordPress plugin called *Captus* that introduces the notion of exhibition items to the WordPress admin frontend and additionally displays recent activity relating to these contents on the front page.

The **Messaging and Presence Protocol (XMPP)** and its various extensions are widely used in instant messaging scenarios to send structured messages between any two (or more) entities [32]. For persistently connecting visitors in the exhibition to the physical artifacts and bookmarking items, we make use of concepts of XMPP known from the Internet of Things (IoT) [33]. In particular, the bookmarking system is implemented as an XMPP contact list; i.e. every time a user connects with a physical object to display its digital information on his mobile device, a virtual 'friendship' is created between the user and the object. Technically, every WordPress page is represented by an ID in the XMPP network. After discovery, a *Presence* subscription request is sent from the mobile device to the artifact's virtual ID. The list of added connections can be retrieved at any time. Another reason for this architecture is the wide availability of client libraries and servers with the required functionalities, without having to develop dedicated client and backend components.

As we show later, both the technology choices, WordPress and XMPP, allow us to benefit from existing solutions for technology and community analytics.

### 7.2. Frontends

On the user-facing side, our mobile app is the main part of our system that connects to physical objects and many other devices including wearables and public displays. It is operating as an information hub for accessing physical artifacts; the app includes functionality for reading QR codes, touching NFC tags and accessing BLE beacons. Due to the missing availability of NFC and BLE APIs in HTML5, we implemented a hybrid solution for Android smartphones based on Android WebViews as a window to the actual WordPress Web content. Upon opening the app, it starts scanning the environment for nearby BLE beacons to retrieve their UUIDs. After such a discovery, it opens the URL associated with the UUID. We currently rely on a fixed mapping, but plan to extend WordPress to allow the automatic conversion of UUID into human-readable URLs. We also provide a functionally restricted version based on pure browser-based HTML5 that only supports reading QR codes from within the webpage. The advantage of the latter is that it does not need to be installed from the Google Play store previously. Another role of the mobile app is the interconnection with wearable devices. The power of the app is visible whenever an exhibition visitor approaches an iBeacon. The smartphone is able to detect the proximity of the beacon and then pushes the information to the smart glass which then shows a notification about the availability of further learning material.

In our scenario, the wearables are mainly responsible for the smartness of the exhibition by notifying the user about nearby items. For both of our tested wearable device types, smart watches and smart glasses, visitors get notified about learning material that is available for nearby exhibition items. We therefore employ Bluetooth Low Energy beacons that are broadcasting a unique identifier every second with limited signal strength. The mobile Android app listens to these local signals and then notifies the connected wearable devices. In the case of our Google Glass prototype, the wearer may also scan QR codes on exhibition items in order to open the digital content on the connected mobile device.

While moving through the smart ambient space, visitors generate a multitude of data that is interesting from the perspective of learning how the users interact with the space: physical artifacts are being looked at, interactions with the social Web 2.0 tools happen and even new social connections are made with other visitors from the past, present or in the future. To collect and gather this data, we introduce community analytics in the next section.

## 8. Community Analytics

As stated earlier, the construction exhibition is open to a heterogeneous visitor community. Our testbed alone covers a wide range of possible visitors, like private house builders, professional architects, managers and workers from small, medium- and large-sized enterprises in the construction sector, or even walk-in customers. Providing appropriate learning material is therefore a tough challenge, as the visitors' levels of expertise vary broadly. The presented features where exhibition items are annotated with comments or videos enable visitors to add their questions or expertise to exhibits and through that to further augment the information behind the items. This kind of collective knowledge creation, however, is extremely hard to manage, find and navigate through. In earlier work we proposed advanced community learning analytics as an approach to tackle the demands of informal learning communities [1].

Working with physical artifacts allows analysis of various interactions as can be observed from Figure 1: (a) device to device for the ambient intelligence; (b) device to user with the wearable technologies; (c) user to user for community interactions. The three phases of the exhibition visit provide an ideal testbed for analysis of these interaction possibilities. In the following, we show how the learners may benefit from advanced analytics. We then present our prototypical implementation of a graph-based visualization highlighting the connections between people and physical artifacts. First, the preparation phase where learners prepare their visit is the target for post mortem analysis (in contrast to real-time analysis), using traces of website visits. By analyzing which particular field captured the interest of the prospective visitor, a guided tour can be prepared beforehand. Then, when the actual visit takes place; near real-time analytics may figure out when the actual learning happens, e.g. by detecting when a learner has entered the exhibition and when he leaves it again. We have already shown in the technical sections of this article how to discover which exhibit the visitor is standing in front of. Reasoning about this data and the time period for which the exhibit is capturing the visitor's interest feeds near real-time analytics. Finally, learners further engage with the exhibits in follow-up activities and entries in discussion forums or social media. Through all three phases, we want to reason about the intentions of the learner to provide scaffolding to support and guide him/her through the learning resources. Furthermore, community learning analytics may recommend other persons present, such as experts in a field the visitor is interested in. By measuring interactions between community members, those with valid competence in a given domain can be identified. Experts in informal learning communities are not necessarily established leaders like master craftsmen. On the contrary, amateur contributions can also be justified as useful pieces of valid input.

Based on the event type of a visit to an exhibition and the user dealing with physical artifacts, we are particularly interested in providing near real-time analytics during the visit. This could help figuring out which item is currently being viewed. With our WordPress and XMPP backends, we are able to collect both access and interaction metrics using Web standards. While the WordPress accesses can be collected via Web analytic tools, especially MobSOS [34], we present a novel approach for near real-time visual analytics of instant messaging and IoT networks spanned with XMPP.

Visual analytics facilitates the visual exploration of large data collections by allowing the users to interact with the presentation in a way according to their needs [4]. Most systems that visualize data follow Shneiderman's mantra "overview first, filter and zoom, details on demand" [35]. Visual analytics extends this mantra to "analyze first, show the important, zoom, filter and analyze further, details on demand" [4]. We are not aware of any system that applies the ideas of near real-time visual analytics on XMPP networks in a way that enables users to easily filter data and customize the analysis process. Since XMPP is used in a wide variety of fields ranging from instant messaging to the Internet of Things, we believe the research community could greatly benefit of our work on this.

As described in Section 7.1, all actors in the exhibition network, i.e. people using devices such as smartphones and wearable devices, as well as the exhibits and their virtual counterparts on WordPress, are represented using a unique identifier in the XMPP network that is similar to an email address. Once a connection is made between a mobile device and an exhibit, e.g. by touching the respective NFC tag, a virtual 'friendship' between the device and the item is made. Since all communication goes through the XMPP server, we extended it to log the data exchange. Specifically, we developed the *log module* plugin for the open source *Prosody* XMPP server. It is responsible for forwarding newly created connections to a logging client. The logging client has to be entered as administrator on the server. On the frontend, we developed multiple OpenSocial widgets that run within the ROLE SDK [36]. Initial queries like finding the specific server to analyze can be entered in the *Selector Gadget*. The *Statistics Gadget* shows performance metrics of the XMPP server such as memory used and demands on CPU resources. Finally, the *Network Gadget* builds the heart of our system by displaying the XMPP network in a graph-based visualization. We use the JSNetworkX[7] library for graph rendering. It is a JavaScript port of the popular NetworkX library for Python that allows for the "creation, manipulation, and study of the structure, dynamics, and functions of complex networks"[8].

Hereby, we can differentiate between logical and physical views. The logical view shows connections and message flows without considering the server in the middle. E.g., if the QR code of an exhibit is scanned to display the respective page within the WordPress backend, a connection would be created between the node of the visitor and the node of the exhibit. The physical view neglects such details and shows the connection with the exhibit as it occurs on the network, which is through the server.

The gradually constructed network of participants and physical artifacts can be exported using several available open data formats for further social network analysis, such as (overlapping) community detection.

In the next section, we present the evaluation of our system.

[7] http://jsnetworkx.org/
[8] http://networkx.github.io/

## 9. Evaluation

The presented conceptual work and implementation was evaluated in three contexts. First, the initial development was conducted in a project-based learning lab course at our technical university. Second, the results were embedded and published as open source resources in the realm of the research project *Learning Layers*. Third, we conducted a usability study and an extensive technical evaluation of the visual analytics system.

Concerning the time to get familiar with the used technologies, our students reported that, though extensive documentation was available for the WordPress and Android systems, implementing apps for smart watches was often frustrating due to immature software development kits and a lack of tutorials. In particular, the students complained about the need to have a physical smart watch running the Android Watch OS for development, since the coupling with a mobile device could not be achieved with an emulator.

The software was made available within the open source repository of the European Learning Layers project[9]. We presented the whole system at an internal project meeting by showing the prototype to around 40 researchers and collecting feedback. Though we got positive results for the innovativeness of our solutions, we noticed a lack of awareness for how technologies such as localization via Bluetooth Low Energy works. We expect raised awareness of these over the coming years, once the underlying technologies get widespread adoption. Therefore, testbeds like the one presented in this article should have a positive impact in the medium term.

Technically, for connecting physical artifacts we had the best experiences with QR codes and NFC due to their technical maturity. The iBeacons we employed lacked a stable signal strength, but we solved this by increasing the frequency of broadcasts to every 500 ms. A practical issue in our evaluation was the limited battery life of mobile and wearable devices.

The separate technical evaluation of the visual analytics tool confirmed that up to 400 XMPP packets could be handled per second without any noticeable impact on the server. However, this load led to rendering issues on the browser. We were able to fix the problem by limiting the number of redraws per second, which did not have any impact on the people's perception. An example visualization of a real-world XMPP network can be seen in Figure 5. Overall, our assumptions on the technical feasibility were exceeded and we intend to continue using XMPP as the underlying technology for connecting people and devices with physical artifacts in our systems.

In the meantime, the "sustainable construction" exhibition has opened its doors. We expect to receive further feedback on the real-world feasibility of our concepts in the future. We further plan to conduct a more quantitative evaluation of the system in the real-world setting.

## 10. Conclusion

The foci of the research presented in this article were threefold. First, we developed three use cases coming from a third-party funded large-scale international research project. Second, we conducted a technical feasibility study by collecting requirements and implementing a prototype infrastructure for trying out new innovative wearable-enhanced learning scenarios and showed a specific implementation in the context of a construction exhibition. Third, we showed how interactions in learning scenarios can be analyzed using advanced community analytics.

The system allows people to interact with physical artifacts using mobile and wearable technologies. As the specific example, we used an exhibition setting where visitors are equipped with mobile devices such as smartphones and wearables like smart glasses and watches. The concept emphasizes the need of unique identifiers for both users and physical objects. Our work differs from other approaches, such as virtual reality, in the high level of integration with the smart ambient environment consisting of physical devices, allowing wearables to become pervasive. We go further beyond pure augmented reality, by considering different phases of a visit to the exhibition. During the visit, digital material may be collected and bookmarked within the system. All of a user's interactions with other visitors and the physical artifacts can be traced using a visual analytics frontend. The result is an integrated framework for developing and evaluating new kinds of wearable-enhanced learning applications in an open source software development strategy. We showed how borrowing concepts from the still very young Internet of Things research domain can be greatly beneficial for integrating learning analytics with wearable technologies. The development was accelerated via a project-based learning course at a technical university, using DevOpsUse for including end users in an extension of state-of-the-art agile software development methodologies.

In the future, the concept could be enriched with gamification elements, e.g. awarding points for collecting items and for starting discussions. In the example scenario, sensors for temperature or other environmental parameters may be integrated into the system in the future to provide an even more immersive experience. A major focus of future work will be the integration of further community learning analytics.

[9]https://github.com/learning-layers

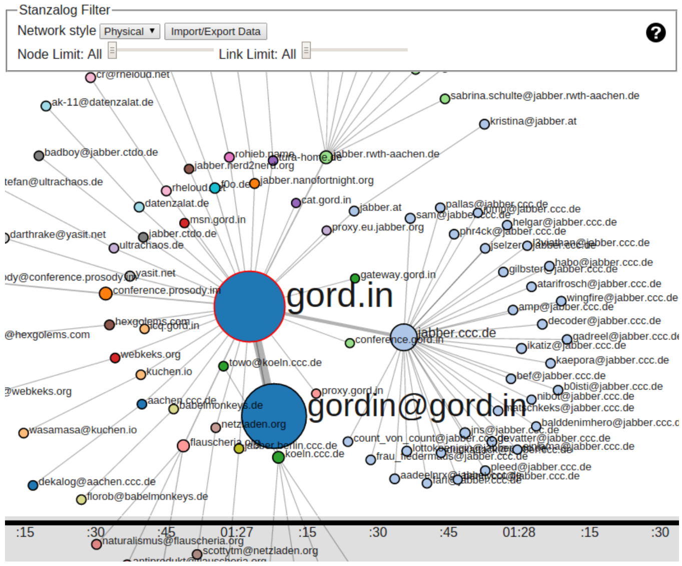


**Figure 5.** Graph Visualization of a Complex Personal XMPP Network

In particular, we are interested in how the results of analytics could be fed back to the community in a near real-time manner. In the field of data visualization, we see many open challenges concerning the constrained display sizes of many wearable devices. Due to the fully open source nature of our work we welcome other researchers continuing and extending our work.

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