CONTEXT AND SIZE MATTERS: INTEGRATED AMBIENT LEARNING SPACES FROM MOBILE TO IMMERSIVE MEDIA

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Abstract

With the Ambient Learning Spaces (ALS) environment, we developed a didactic infrastructure as an integrated environment for self-directed and distributed learning inside and outside school. The environment combines and interlinks mobile, stationary and immersive learning applications on a variety of interaction devices. The artificial division between the classroom and the world outside vanishes through the pervasive cloud-based backend repository NEMO (Network Environment for Multimedia Objects) connecting a growing number of interactive learning applications with a central semantic media storage. This contribution emphasizes on the different form factors and settings of interaction devices to support different teaching and learning contexts inside and outside school. It describes a learning environment for ubiquitous interaction based on semantic media that fits to different contexts of space, time and social structures in school like in classrooms, foyers, team spaces, school gardens, school theatres or digital domes, and as well to out of school contexts like urban spaces, museums, biotopes, and industrial environments.

Keywords: Ambient Learning Spaces, Teaching and Learning Contexts, Digital Technologies for Learning, Interactive Learning Devices, Collaborative Learning.

1 INTRODUCTION

Today, we can find teaching and learning applications for a large spectrum of types and sizes of interactive devices. Some of them can more or less easily been attached to network systems and data clouds. However, through these attachments, the applications usually only interoperate on the level of basic data, mostly file exchange or data streaming. The attachment of different devices does not provide an integrated knowledge-based learning and teaching environment on the level of a didactic infrastructure that can be used in different spatial, temporal and social settings in the context of schooling.

A solution can be a learning environment for *pervasive interaction* based on *semantic media (knowledge media)* that fits to different contexts of space, time and social structures in schools like classrooms, foyers, team spaces, school gardens, school theatres or digital domes through stationary devices and installations. This learning environment should also adapt to out of school contexts like urban spaces, museums, biotopes, and industrial environments through mobile devices. Because of its ubiquitous and pervasive nature, we called it *Ambient Learning Spaces (ALS).*

With the ALS idea in mind, we developed a didactic infrastructure as an integrated environment for self-directed and distributed learning inside and outside schools. The environment combines and interlinks mobile and stationary learning applications on a variety of interaction devices. The artificial division between the classroom and the world outside vanishes through the pervasive cloud-based backend repository *NEMO (Network Environment for Multimedia Objects)* connecting a growing number of interactive learning applications with a central semantic media storage.

The ALS environment provides a variety of modular learning applications used on different devices. These include smartphones, tablets, head-mounted displays, PCs, smartboards, multitouch tables as well as immersive theatres and domes. In ALS these devices are coupled through the backend repository NEMO delivering requested media automatically converted to the appropriate media resolutions and media types. Students can collect media such as text, sketches, images, sound or video footage out of school with the task-oriented *MoLES* mobile app and other media capturing applications. The collected media will be stored in NEMO and may later be discussed, tagged, edited, combined and presented in schools on interactive smartboards and tables, in school theatres or even media domes. Media can later be reused, for example in the discovery-oriented augmented reality app *InfoGrid*. Teachers can decide to publish selected media productions in social spaces inside school or on the schools' website for public presentation.

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ALS applications search, create, connect and utilize semantic media using *tags* and *ontologies*. The students discuss, transform and combine media from basic media into complex *interactive knowledge media* by enriching them with semantic information. The resulting *semantic media* can be reused in other teaching contexts, creating topical links between the curriculum and the semantic media constructed by the students or their teachers.

According to Mark Weiser, connected digital technologies will be available in a ubiquitous way in different sizes to be suited to particular tasks at any time and any place [1]. Mark Weiser called them *tabs*, *pads* and *boards* coming close to today's smartphones, tablets and interactive large screens. This can be extended by immersive devices and installations like large theatres, digital domes or head-mounted devices. Bringing this idea to school and teaching we lay the foundation for seamless ubiquitous computing that concentrates on content instead of technology. In this sense, Mark Weiser and later Donald Norman [2] have as well been discussing the *"disappearing computer"* replaced by media that find their meaning in our everyday life ("Lebenswelt") in a natural way and situated form, or as Weiser put it [1]: *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."* Contextualized semantic media content can even be understood as a way of bringing back school to the world the students live in. This is basically what our conceptualizations and implementations of Ambient Learning Spaces are about. Introductions and overviews of ALS can be found in ([3], [4], [5], [6], [7], [8]).

In the following sections, we will discuss the meaning of ALS for a broad spectrum of learning contexts in more detail.

2 LEARNING WITH DIFFERENT DEVICES IN DIFFERENT CONTEXTS

ALS enables teaching and learning with interactive digital media in different contexts. This means it is built as a *pervasive ubiquitous system* with modular frontend applications connected to a central backend for storage and reuse of multimedia content. It is *pervasive* in the sense that the components of ALS are integrated in a modular and seamless way and it is *ubiquitous* in the sense that practically any stationary, mobile or wearable can be supported and connected. The infrastructure supports a variety of teaching and learning environments and contexts. At the time being, the world of teaching and learning is typically divided into in-school and out-of-school contexts.

2.1 In-School Contexts

In-school teaching is an old but well cultured form of education. Even when more flexible solutions like homeschooling will be available through digital media, the school as a space will keep its dominant role as the primary place for teaching, learning and socializing. Nevertheless, future digital teaching and learning solutions have not only to allow access in classrooms, they will have to be redesigned for much more open situations in modern school buildings. We will discuss some of the possibilities starting with the classroom.

2.1.1 Classrooms

The classic classroom teaching will still be widely used. However, the classroom is a place that needs to be connected to digital media, which can be created, presented, and changed by the teachers and learners inside and outside the classroom. Typical trends in the classroom are the availability of large digital and interactive (TV) screens (often called digital blackboards) or digital projectors (often called digital whiteboards) in the front or at the side walls of the classrooms, depending on the classroom layout. The classroom and its displays need to be connected to the central backend storage. In ALS we call these basic concepts *InteractiveWall (IW)* ([9], [10], [11]) and *InteractiveTable (IT),* which can be used in many other settings as well.

2.1.2 Group Spaces

Students will need group spaces for their project and topical work. These can be smaller rooms, similar to classrooms, or may be designed as "work islands" equipped with interactive boards and tables additionally to classical teaching equipment for collaborative use. In group spaces, the students shall be able to use their own, i.e. personal computer devices like notebooks, tablets or smartphones connected to the same digital resources. It is important to make it possible that students use their own digital devices inside and outside schools to create a pervasive learning environment in the sense of *"Bring your own Device (BYOD")* [6]. Making differences between in-school and personal equipment will constantly create disruptions and discontinuities in the thinking and acting of the students while working on their topics and projects.

2.1.3 Foyer

The school foyer is a social area, where students, in the natural context of socializing with other students, can present their work results and other media before and after school hours as well as during breaks. They might use several interactive walls and tables to interact with digital media that has been created during learning. Presenting their work in their "social hours" will make teaching and learning part of their daily social lives. It will bridge between courses and it will bridge school with the world outside. The foyer may also be a place for playing games and discuss findings and opinions in a social context. Other information that can be presented on interactive boards in the social space can be announcements, daily schedules or the school canteen menu. The foyer will not be just the room to be between the classes, it will be an ambient media space that invites to think, explore and discuss together.

2.1.4 Theaters

Many schools have theaters with classical stages for live presentations, like stage plays, musicals or dance performances. While this initially was done with physical and mechanical stage decorations, we can now use interactive technologies to track the actors and create audiovisual presentations on stage. A digital stage leads from classical theater or dance performances to programmed interactive multimedia performances. The media presented on stage can be connected to the multimedia backend media storage. The stage will then become part of the teaching and learning processes themselves [12].

2.1.5 Domes

In some schools, we find immersive 360° theaters (domes) initially used for astronomical and geographical presentations like the planetarium. While the mechanical "star projector" is out of use, these special spaces can now be reused for digital photographic or synthetic 360° presentations. The content can be created by 360° cameras or Virtual Reality (VR) platforms. The domes can be used for streaming presentations, like 360° movies, or for interactive presentations, like in VR games. If schools do not have a dome, meanwhile cheap VR head-up-displays (HUDs) can be used instead, however with the drawback, that it is not a social experience like being physically in "the same room". ALS has been connected to a dome installation in a school. This dome will be used for many teaching topics as an immersive presentation and interaction environment.

2.2 Out-Of-School Contexts

In-school teaching brings a lot of drawbacks for motivation and authenticity. Out-of-school learning at home, urban, industrial or natural locations can overcome some of these drawbacks but needs certain flexibilities provided by the digital learning infrastructures.

2.2.1 Homes

The perhaps most important space for out of school teaching might be the homes of the learners and teachers, where they prepare their lessons or do their homework. Meanwhile, most students and teachers will have digital equipment in their homes that can be connected to the digital teaching and learning infrastructure used in school. This approach is currently followed by standard *learning management systems (LMS)* mainly used for the distribution of course materials. The depth and quality of the integration of digital homes with digital school infrastructures will vary depending on the pedagogical concepts and requirements. ALS will be demanding the availability of appropriate devices and sufficient bandwidth to connect to highly interactive and high-volume multimedia resources. It can be assumed that this will be solved in near future in a way that a pervasive digital environment will be available. In many situations, this is already possible today, but needs to become a kind of standard.

2.2.2 Urban, Industrial and Natural Environments

Modern teaching of topics, like the history of settlements, urban architecture or economy can best take place in real urban spaces or real industrial areas. The "real", i.e. the authentic environment will provide much better access to the teaching content, as it consists of real people, buildings, traffic, stores, and factories. Digital access in urban spaces or industrial areas can best take place through carry-on devices like smartphones and tablets or any other digital mobile gadgets connected by mobile communication links to the backend of the teaching and learning infrastructure. Even in areas without network connection, offline application modes can be used, while system states and media will later be synchronized with the backend system, as soon as the mobile application reconnects. Similar to urban and industrial spaces, teaching and learning in biology or ecology can take place in real biotopes, like a close-by forest, lake, river or any natural habitat. Even the school garden can be such a place of teaching, studies and discoveries in the natural field. Students can use their mobiles to solve tasks there and collect data that have to be connected to their teaching and learning infrastructure ([6], [13], [14], [15], [16], [17], [18]). In such environments, it will be necessary and conceptually designed to bridge the gap between the physical and the digital world. Media concepts like Augmented Reality (AR) or Tangibles will fit quite well into these real world settings.

2.2.3 Museums and Archives

Since a long time, museums play an important role in teaching and learning. Meanwhile, many museums have digital infrastructures, like computer displays, digital theaters or augmented reality presentations [19]. These infrastructures can be used by the students on site. Much better will be a digital museum infrastructure that can be connected to the digital infrastructure of the school being used before and after the visit. This is possible either by using the same architecture or by using interfaces to exchange information between schools and museums. ALS is already used in schools and museums and is therefore enabled by the same architecture to connect these places of learning. Similar to museums, the teaching and learning can take place in public archives, like libraries or municipal archives. Modern archives already have digital platforms, where content like inventories, selected documents, or any other form of digital media can be accessed and connected to the teaching and learning infrastructure. Connecting school infrastructures pervasively to museums and archives opens a new world of teaching through a multitude of high-quality and well ordered sources of scientific and cultural knowledge.

2.3 System Contexts of ALS

Derived from the teaching and learning contexts discussed above, we can see the need to establish a strong relationship between the physical world connected to the bodies and the social realities of the learners and digital learning resources. In recent development of interactive multimedia systems, we see a revolution in the design of user interfaces like in peripherals, in the sense of surrounding media (e.g. immersives), tangibles, mobiles, or wearables embedding the human learner even bodily (Fig. 1). Learning applications, which use the much wider capabilities of the new interaction interfaces, have a high potential to support learning in the school contexts discussed and, above all, provide an authentic relationship to daily and “real” life physically and mentally.

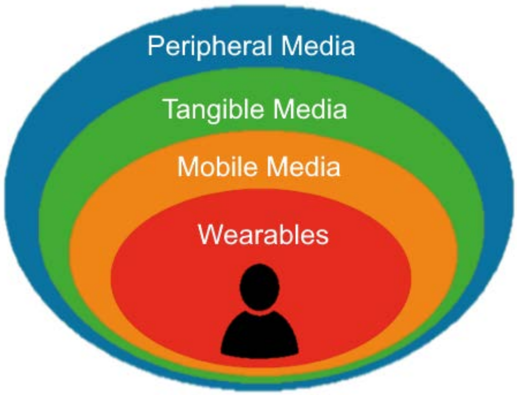

Figure 1. Shell model of ubiquitous media used in ALS.

ALS is a digital teaching and learning environment implementing the above-mentioned forms of contextualized learning connecting in and out of school activities through one central common storage system, the *Network Environment for Multimedia Objects (NEMO),* containing semantically annotated and structured media. Based on the shell model (Fig. 1) we developed a contextualized application structure providing a classification for the teaching and learning applications of ALS (Fig. 2). These applications will be discussed in more detail in the next section.

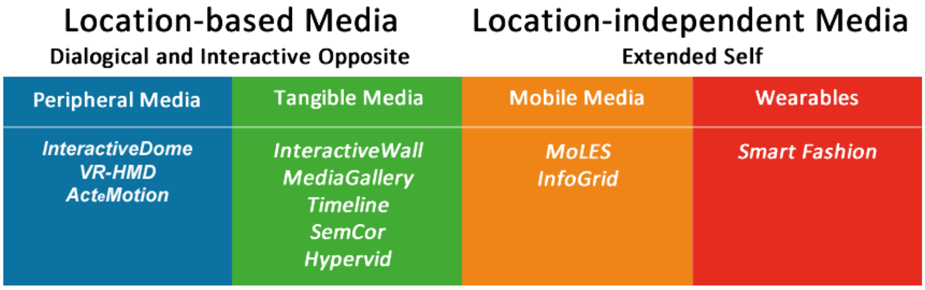

Figure 2. A suite of integrated ALS applications based on the shell model.

3 THE ALS TEACHING AND LEARNING MODULES

Ambient Learning Spaces is a didactic infrastructure providing modularized frontend applications *(ALS Modules)* for mobile, stationary, and immersive interactive computer systems. Each of these application modules is connected to the *NEMO backend system*.

3.1 ALS Wearables and Mobiles

Authentic education through social activities in context is a constructivistic approach to build individual knowledge within a cultural setting. Learners leave school and enter live spaces like urban, industrial and natural environments or places of collections like museums or archives. With networked mobile applications on smartphones, tablets or wearables ([20], [21]), the computing devices can be with the learners in the sense of BYOD [6]. This enables the learners to carry the scaffold of teaching in form of learning applications with them, study in context, and collect data and media then be brought or transmitted back to school.

The *MoLES (Mobile Learning Exploration System)* app provides a task-based teaching framework to guide the learners through a series of tasks and challenges along a learning path. It has been conceptualized, implemented and evaluated over years in several technological versions ([6], [13], [14], [15], [16], [17], [18]). A task may be to take pictures of certain plants or buildings or capture videos of city traffic or industrial processes. Students have to research and store data about the objects and contexts and follow the next task until the whole tour has been completed. Typically, the students will go out in small groups of 2 to 4 (Fig. 3) with fewer devices than group members to be forced to discuss and decide together what shall be collected and stored ([14], [16]). The MoLES system will store or transmit data and media to the NEMO backend system for later use.

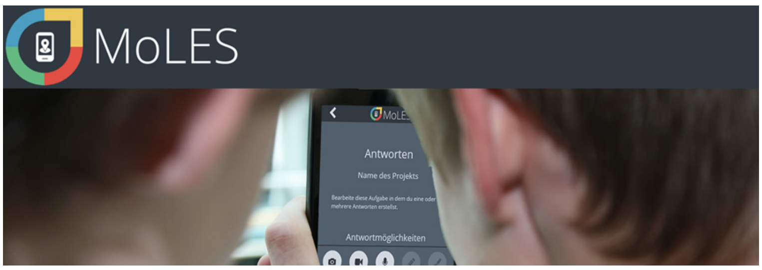

Figure 3. The ALS mobile app MoLES with tasks and challenges to collect data and media in the field.

InfoGrid is an *Augmented Reality (AR) app* that allows studying an environment by looking for active objects or targets by activating digital visual or auditory overlays in the form of images, audio or video clips, static or animated 3D models (Fig. 4). The students visit certain places and point their smartphone cameras towards physical objects like houses in a city or artifacts in a museum ([19], [22]). The AR system can display a map or a floor plan to guide the students through the environment. They can take snapshots of the objects found, collect information, and will be guided through the environment by printed signs or a digital plan integrated in the app.

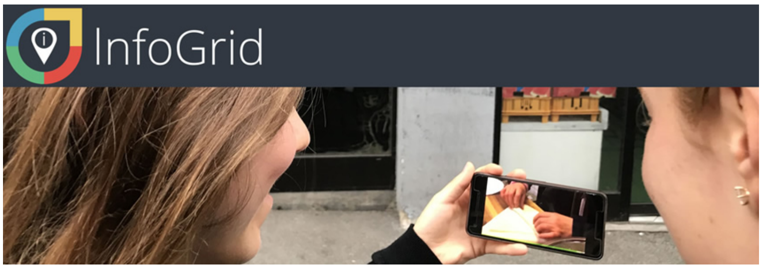

Figure 4. The ALS mobile augmented reality app InfoGrid to explore in the field.

MoLES and InfoGrid are generic learning instruments that fit into a pocket to act in an authentic environment, discuss with experts and learn by discovery. The content of MoLES (tasks) or InfoGrid (augmentations) can be created with easy to use authoring tools for the capturing and editing of image, video [23] and 3D ([24], [25], [26]). Even older students can design learning materials and tours for younger ones as part of their own reflections on knowledge they have been building up. Additionally to mobiles in the technical shape of tablets or smartphones, ALS is prepared for applications using modern *wearables* like smartwatches, digital glasses or intelligent fabrics for sensing and displaying information ([20], [21]). A motivating access to wearables is designing them by the students themselves in art and design workshops especially for theatrical performances [12].

3.2 ALS Stationaries and Tangibles

After searching, discussing and collecting media in the physical context, the students need to select and arrange their findings to answer questions or create abstractions of what they found. This can be done in a social process that will typically happen in school with larger devices in a group space or classroom context. To visualize the findings, the students can use large multitouch screens on the wall called the *InteractiveWall (IW)* (Fig. 5) ([9], [10], [11]). Besides the InteractiveWall there is an *InteractiveTable (IT)* that supports certain spatial working setups in school. Additionally to the IW, the IT will allow the use of *tangibles (fiducials),* i.e. objects that can be placed on the IT to interact with the applications, for example as physical tools for tagging or filtering.

Figure 5. An ALS foyer setting built with several InteractiveWalls

The IW will provide *MediaGalleries* that show collections of raw findings (e.g. media collections from the field collected with MoLES) or collections of selected, grouped, tagged and classified media bound semantically to objects of the learning domain (Fig. 6). From these collections, the students can create presentations or documents under supervision and guidance of their teachers or parents at home.

Figure 6. MediaGallery for media collections on an IW.

Learning applications supporting semantic modeling about knowledge entities *(SemCor)* and chronological structures *(TimeLine)* connected to media objects can be used on an IW or IT ([7], [27]).

TimeLine is a web application embedded in the IW. It displays a time axis visualizing knowledge entities with chronological meaning and dependencies (events) (Fig. 7) ([7], [27]). Events represent a point or a period of time on the chronological graph and can be annotated. TimeLines can be “filled” by media like text, image, audio, or video from the central media repository. Users can navigate by touch interaction through the chronological graph and explore knowledge entities and annotated content. A TimeLine display consists of one or more sub-timelines along one chronological axis, i.e. semantic dimensions over the same period of time. For example, political events can be shown in parallel to economical or technological developments. This allows multiple perspectives on history and helps to identify, question and explain causalities and other dependencies.

Figure 7. A TimeLine developed by students for the study of art history.

SemCor is a learning application for active search and knowledge creation within an IW. It supports interactive exploration of semantic correlations between media-enriched knowledge entities and allows inspecting interrelated visual representations of information in a *semantic web*. Students can provide a starting seed to explore semantic correlations from there. SemCor usually connects to a semantic repository (e.g. DBpedia) to search for related entities. Once related entities are found, they are grouped into categories and are visualized in a force-directed graph (Fig. 8). Entities can be selected to expand the visualized knowledge space. Selecting a knowledge entity, further detailed content (e.g. the corresponding Wikipedia article) is shown and can be explored further. SemCor will automatically and dynamically deliver new knowledge entities in the graph that can be selected by the user. These entities are internally searched and selected through certain search algorithms and filters. SemCor resembles and visualizes the mesh and complexity of world knowledge and motivates explorations through the serendipity phenomena. SemCor and its semantic networks need space for the visualization. Interactive Walls and Domes therefore fit best. The semantic repository SemCor is connected to knowledge repositories; they can be created or chosen from available ones. The basic system works with DBpedia and Wikipedia. External repositories for certain knowledge domains, which provide public interfaces, like the Europeana for cultural heritage, can be connected.

Figure 8. SemCor for the study of ontology-based semantic relationships.

IWs and ITs have been placed in social areas within school buildings like group spaces or the school foyer that will allow social interaction with media collections or presentations of contextualized projects as described above. Additionally, IWs can be used as general information terminals for any purpose and any web-based presentation. In a current study, we analyze the use of the *InteractiveDome* and its potentials for large and complex information display.

3.3 ALS Immersive Media

Special properties of media come with immersive media. They are more a result of human perception than of a certain kind of technology. Sherman & Craig [28] distinguish *physical and mental besides immersion in genera*l. We will mainly refer to physical immersion when we discuss immersive media in the context of ALS. However, this will mainly address the visual and the auditive senses, as full motion simulators are usually not available in school contexts.

The media currently in use in ALS for immersive applications are mainly 360° images and videos. Both can be enriched by interactive elements, like in HyperVid [29], to create non-linear 360° hypervideo structures with interactive buttons to change position, i.e. concatenate to another image or video taken from the spot selected in the video.

As the presentation and interaction technologies, we used VR HUD presentations like Oculus Rift and Oculus Go as well as full dome presentations. Rectangular 360° images and videos can be transformed into HUD and dome formats (mainly fisheye views) to create a strong immersive perception. The dome system in one of the schools gives place up to 15 students or teachers (Fig. 9).

Another technology that has been used for immersive presentation and interaction are VR players for Web VR solutions like A-Frame that can be integrated in the IW, IT or an *InteractiveDome (ID)*. Certain embeddable VR engines, like the Unity framework, can create similar effects. The VR modes support the interaction with 3D objects that can be created by students themselves through a photogrammetric pipeline from images and video footage ([24], [25]).

Figure 9. ALS-based full dome installation in a school (© Photo courtesy of Ralph Heinsohn).

Most of the ALS teaching and learning modules discussed above can be adapted to immersive environments. This transformation through editing, morphing, mapping, embedding or linking media into immersive forms can be an active design process performed by the students themselves. The more of these immersive applications will be available, the more we will create a *Mixed Reality Learning Environment* [30].

4 NEMO, THE INTEGRATED BACKEND PLATFORM OF ALS

To create the pervasive experience of integrated seamless media, ALS is based on a central cloud-based backend system, the *Network Environment for Multimedia Objects (NEMO)* ([5], [31], [32]).

The basic system architecture of ALS is shown in Figure 10. The applications are decoupled from the backend by web-services. Most of the frontend applications and authoring systems are web-based for maximum flexibility within network structures. The backend system NEMO can be installed and operated at any place inside or outside schools, only depending on internet web access and sufficient bandwidth, depending mostly on the volume of digital media used.

The ALS-Portal combines a content management system with the functionality to annotate, edit and link media to the corresponding ALS applications.

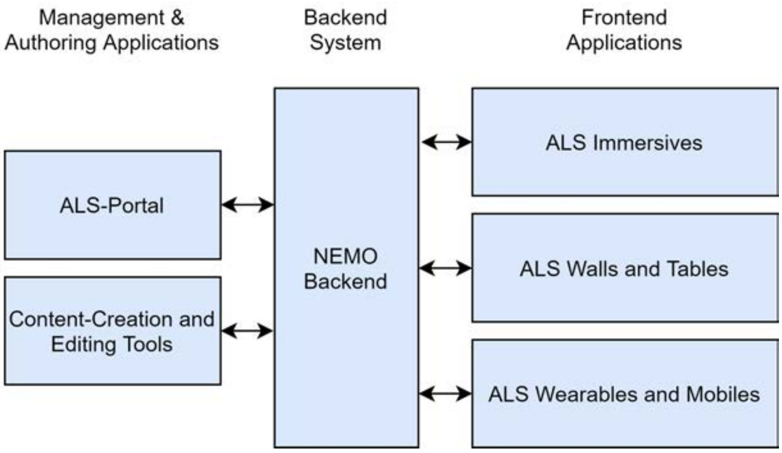

Figure 10. ALS system architecture

5 SUMMARY AND CONCLUSIONS

Ambient Learning Spaces (ALS) is an integrated multimedia platform for teaching and learning. Based on a central data and media storage system it allows to create, construct and share knowledge media across a variety of interactive applications like wearables and mobiles, stationaries like interactive walls and tables, and immersives like head-mounted displays and interactive domes. These applications in different form factors and sizes empower to adapt to learning situations of practically any learning context inside and outside schools. The system is used in several pilot installations in schools and museums and has been evaluated for its usability and didactic use. The results show that teachers and learners are enabled to use the different modular teaching applications of the ALS system as a modeling environment as well as learning applications.

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