NEMO Converter 3D: Reconstruction of 3D Objects from Photo and Video Footage for Ambient Learning Spaces

David Bouck-Standen, Alexander Ohlei, Viktor Daibert, Thomas Winkler and Michael Herczeg
Institute for Multimedia and Interactive Systems
University of Luebeck
Luebeck, Germany
email: [bouck-standen, winkler, ohlei, daibert, herczeg]@imis.uni-luebeck.de

Abstract— **In ambient and mobile learning contexts, 3D renderings create higher states of immersion compared to still images or video. To cope with the considerable effort to create 3D objects from images, with the NEMO Converter 3D (NOC3D) this paper presents a technical approach to automatically reconstruct 3D objects from semantically annotated media, such as photos and more importantly video footage, in a background process. By using the Mobile Learning Exploration System (MoLES) with a smartphone, the user creates and collects media in mobile context, which are automatically uploaded into the NEMO-Framework (Network Environment for Multimedia Objects) together with semantic annotations for contextualized access and retrieval. NEMO provides an extendable web-based framework to store media like photos, videos and 3D objects together with semantic annotations. The framework has been developed for Ambient Learning Spaces (ALS) in a research project. With InfoGrid, a mobile augmented reality application connected to NEMO, the user experiences the previously generated 3D object placed and aligned into real world scenes. 3D objects automatically reconstructed from photo and video footage by NOC3D are stored in NEMO and thus provided to all applications accessing the NEMO API. Related to the pedagogical background of our research project, this paper focuses on the technical realization and validation of NOC3D with reference to a realistic scenario for the usage of NOC3D in ambient and mobile contexts. In Section 2, we regard related work. In Section 3, we present a practical scenario for using NOC3D. In Sections 4, we describe the technical environment for NOC3D and our research project. In Section 5, we outline the realization of NOC3D in the ambient context of our scenario. In Section 6, we present our findings and conclude with a summary and outlook in Section 7.**

Keywords — Mobile media; Mobile learning; Ambient Learning Spaces; Multimedia Storage; 3D Conversion

I. INTRODUCTION

Today, in our interconnected society people live in close relationship with their digitally enriched environments. Together with ambient and mobile technology, this individual interconnection between physical and digital worlds plays an important role. Contemporary pedagogical approaches follow the assumption that humans learn individually and during all of their life. Since the learning process also takes place by being and acting in the physical world, one important goal is to offer ubiquitous learning environments; we called them *Ambient Learning Spaces (ALS)*, as described by Winkler et al. [1]. In ALS, working with media in general, and especially mobile media supports the following learning objective: the learner creates contextualized and personalized media, which is stored as digital data and simultaneously enriched with a dynamic set of semantic annotations. This so-called *enriched media* is managed by the *Network Environment for Multimedia Objects (NEMO)* we now use in its latest implementation, based on the original concepts of Lob et al. [2]. NEMO stores text, still images, video, 3D objects, animations, and audio, which are extended by digital properties represented by semantic annotations. Through a digital overlay for physical objects, the NEMO framework provides web-based access to enriched media within ALS. The relatedness of body and space supports the individuality of the learning process. Together with the loss of spatial distance and the exponentially growing quantity of information, this induces new technical requirements, as a single individual is no longer capable of consuming and structuring the globally and permanently available information in its entireness [3]-[5]. ALS enables learners to structure information themselves using ambient technology in web-based applications in mobile contexts on their smartphones. This seems to be fostering the construction of sustainable and mindful knowledge. In this setting, enriched media become the carrier of information utilized in various contexts [6] within ALS, where 3D renderings empower imagination, creativity and learning compared to still images or video [7].

In ALS, enriched media is managed via the *ALS Portal* [6], a web-based platform that features modularized media management, ALS applications, such as mentioned below, and settings stored in NEMO for any ALS applications. For each learning application, a special area within the ALS-Portal allows teachers and learners to manage information, primarily enriched media, depending on their access rights and permissions.

With the help of the *Mobile Learning Exploration System (MoLES)*, a mobile ALS application running on smartphones originally introduced by Winkler et al. [8], students create enriched media in a mobile context to answer given questions for a specific task assigned by their teacher whilst conducting an exploration outside of school. For example, they take photos and video footage from objects they encounter and add digital notes within MoLES by annotating the media. This enriched media is transferred to NEMO for storage. After finishing a field trip, the students use the enriched media they created to reflect and present their findings to their fellow students.

For mobile context in ALS, we have developed the augmented reality application *InfoGrid* that recognizes visual markers or detects Bluetooth beacons both triggering the display of images and video, the playback of audio or the augmented reality presentation and alignment of 3D models provided by NEMO.

In its semantic repository, the NEMO framework stores media from all the students as outlined. Images or video footage of the same physical objects often occur many times, but differ with regard to the angle, lightning or framing. With the NEMO Converter 3D (NOC3D), this paper presents a solution to make use of such footage collectively created by the students in order to enhance the learner's experience in an ambient learning context.

II. Related Work

Semantic media comprises the integration of data, information and knowledge. This relates to the Semantic Web [9] and aims at allowing computer systems as well as humans to make sense of data found on the web. This research field is of core interest for our work since it yields structured data in a well-defined, reusable, and contextualized manner.

The field of metadata-driven digital media repositories is related to this work [10] as well. Apart from the goals of, e.g., delivering improved search results with the help of meta information or even a semantic schemata, the NEMO framework distinguishes itself from a mere repository by containing and using repositories as internal components, delivering more complex features through the NEMO logic described below.

NEMO facilitates collecting, consuming and structuring information by interacting device-independently with enriched media, whereas the linked data research targets sharing and connecting data, information and knowledge on the Web [11].

Various implementations exist in order to reconstruct 3D objects from photographic images, but the implementation examined in our work have in common not being integrated into a fully automated web-based framework making use of semantically annotated data in mobile contexts providing background services for ambient learning environments.

In the research field of e-learning, other work connecting semantic structures with learning can be found [12]-[14]. In contrast, our work focuses on linking educational contents with the living environment (Lebenswelt) and thus engaging learners in communicative processes through contextualized and personalized enriched media. For this purpose, NEMO provides means of connecting formal and non-formal learning, e.g., in schools, as well as non-formal and informal learning outside of schools, like in museums. However, NEMO is not used to examine the learner's performance, provide standard learning materials or collect homework, such as Moodle [15].

III. A Practical Scenario

Michelle, a fourteen year-old student, joins a field trip through the Hanseatic City of Luebeck at school. Prior to the field trip, with the help of the ALS-Portal, Michelle's teacher prepared some questions for the students to be answered using MoLES, for example "*Who are famous composers who left their tracks in Luebeck?*" While exploring their city, Michelle answers this question with the MoLES application running on her smartphone. Michelle uses MoLES and takes photos and tapes videos of what she thinks is related to the question at hand. In this case, for instance, she discovers the statue of composer Johannes Brahms on the riverside of the Trave River. Using MoLES, she takes a few photos and records a video. For every medium she creates, Michelle notes a few keywords and sentences to remember better later on. MoLES uploads this enriched media automatically into NEMO over a secure connection.

Back in school, Michelle prepares a short presentation of her findings from the field trip. Meanwhile, she knows that composer Johannes Brahms never lived in Luebeck himself. Michelle also learns that during the Imperial Era some 'moneybags' from Luebeck were fond of Brahms and centuries later, during the 1990s, the local Music Academy founded the Brahms Institute. She logs on to the ALS-Portal and, among her media, she discovers that the statue of Johannes Brahms is now available as a 3D model, which she incorporates into her presentation. With the help of the mobile application InfoGrid, during the presentation, her classmates, who are surprised that they did not notice the statue themselves before, are now able to take a closer look at it and are astonished to hear from Michelle's presentation, that Brahms is also linked to the Hanseatic City of Luebeck.

IV. NEMO at a Glance

NEMO is a web-based framework for ALS. As shown in Figure 1, the framework primarily consists of three main levels: (1) the NEMO Application Programming Interface (API) level giving ALS applications access to NEMO, (2) the NEMO Logic level and (3) the NEMO Core level. NEMO as well as NOC3D have been implemented in C# running on Windows Server and Microsoft .NET architecture, also making use of the Windows Communication Foundation (WCF) framework.

The NEMO API (cf. Figure 1) provides access for applications, such as MoLES, interacting through Web Services in an authenticated context over a secure connection. Each application accesses a specific Web Service to achieve a higher level of transparency and

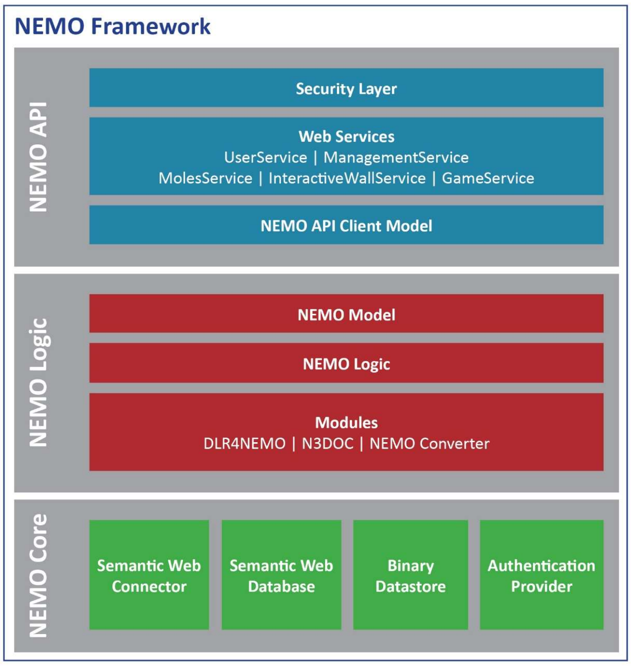

Figure 1: The NEMO framework. The NEMO Logic computes, e.g., coherences, semantic models, and data mapping and a modularised interface for feature extendibility.

maintainability. With the NEMO API Client Model, we created a model for a well-defined data interchange between NEMO and any application in ALS through the Web, following the idea of knowledge representation in a formal and explicit way. From experience, we expect any information entered by a learner to be incomplete, as he or she is still engaged in a process of gathering, structuring, and memorizing, thus NEMO is able to handle incomplete and uncertain information [16] in the NEMO Logic and Core levels. Therefore, the model for any client application is independent of any internal model used by the NEMO framework. In addition, this minimizes the learning curve for ALS application development, as no detailed knowledge of semantic modeling is required when developing an application accessing NEMO. NEMO also provides cross-platform capabilities [17].

In the NEMO Logic, we implemented the NEMO Model, which abstracts ALS as a semantic model. Here, the computational logic resides, which initiates and controls like semantic searches and context analysis in the NEMO Core. In the NEMO Logic, mappings are conducted between the NEMO Model and the NEMO API Client Model through a modified Semantic Object Relational Mapping (SORM). For any Web Service, the NEMO Logic holds the specific application logic and thus interconnecting the applications accessing the NEMO framework semantically through an extendable modular structure with loose coupling. We have already developed extensions for NEMO, e.g., the NEMO Converter (cf. Figure 1), which delivers media in device-specific formats and resolution as requested. For research purposes, another extension tracks all requests, actions, as well the corresponding application state of the NEMO framework. NOC3D also extends NEMO Logic. All data collected is stored anonymously, due to the sensitivity of the data and legal regulations for public organizations like schools and museums. In a defined context of an evaluation, personal information may be collected synonymously. As we develop NEMO with scalability and diversity in mind, NEMO also runs in multiple interconnected instances.

The NEMO framework is based on the NEMO Core where enriched media is stored (cf. Figure 1). A semantic database provides internal storage for any digital entity in the form of semantic annotations. Through the Semantic Web Connector, (cf. Figure 1) any semantic database can be used as internal data store, thus developing applications accessing NEMO requires no knowledge of the respective database query language. Any query result of the internal or any external semantic database is mapped into the NEMO Model. In the NEMO Logic, this data will be processed as described above. Binary media is stored in the Binary Storage (cf. Figure 1), which is linked to the internal semantic database in order to retrieve the stored object as enriched media again and also serves as cache in order to reduce on-the-fly conversion time of the NEMO Converter. An authentication module provides an interface to connect to different authoritative systems in order to check application or media-specific permission settings and user access rights.

V. THE NEMO CONVERTER 3D

NOC3D is developed as a component for the NEMO Logic under the following assumptions, which are partly derived from the scenario described above:

- NOC3D runs in an autonomous mode as a background service without any user interaction required.
- Images and videos are taken with different camera models, mostly with smartphones, from various angles and may contain only sections of the object. Therefore, an input for NOC3D can most certainly not be described as “ideal” or “complete”. The cameras are not calibrated.
- No additional markers are used in the process of media creation, only steady surroundings around the object are required. Every photo or video has to contain surroundings around the object of reconstruction.
- An object for reconstruction has to be sized between 5cm and 5m in height.
- Images and videos may not contain multiple objects and only one object will be reconstructed per run.

A. 3D Reconstruction

In general, the algorithms used in each step and data they require or provide as input and output determine the sequence of steps of 3D reconstruction. For our scenario in an ambient context, we have enhanced their combination and derived parameters from the tests we conducted. At first, from automatically generated and manually entered semantic annotations, GPS coordinates, date and time and with regard to different calendrical seasons, for each possible 3D object, NEMO compiles a selection of images and videos, which possibly show the same object. All media is transferred to NOC3D, as shown in Figure 2. As NOC3D provides a web-based API, NOC3D may be set up on a dedicated server. An identifier passed additionally allows NEMO to link the original media with the 3D object after the asynchronous task of NOC3D finishes.

Operating on the media selection passed on by NEMO, NOC3D at first calculates camera parameters, which will be used for the process of reconstruction later on. 3D object reconstruction starts by calculating match points of all images and grouping them using VisualSFM [18]. This is necessary in order to find the object for 3D reconstruction in the images automatically. Every two images with at least 40 match points are grouped. To receive a high quality result from later steps, all images with a resolution below 1200x1200px are discarded at this point, if a group has a minimum of 10 images with a resolution above 1200x1200px. A group with less than 10 images is discarded, because these will not be of any use for further processing. We found these parameter values through experimental testing during development. Running VisualSFM on the group of images, until no other image of the selection can be grouped repeating all steps outputs a group of images containing the object for 3D reconstruction.

In the next step, depicted in Figure 2, the Center for Machine Perception Multi-view Reconstruction Software (CMPMVS) [19] calculates the cloud of points using the camera parameters from the first step [20][21]. CMPMVS transforms the point cloud into a mesh model and separately calculates a preliminary texture.

 ISBN: 978-1-61208-601-9

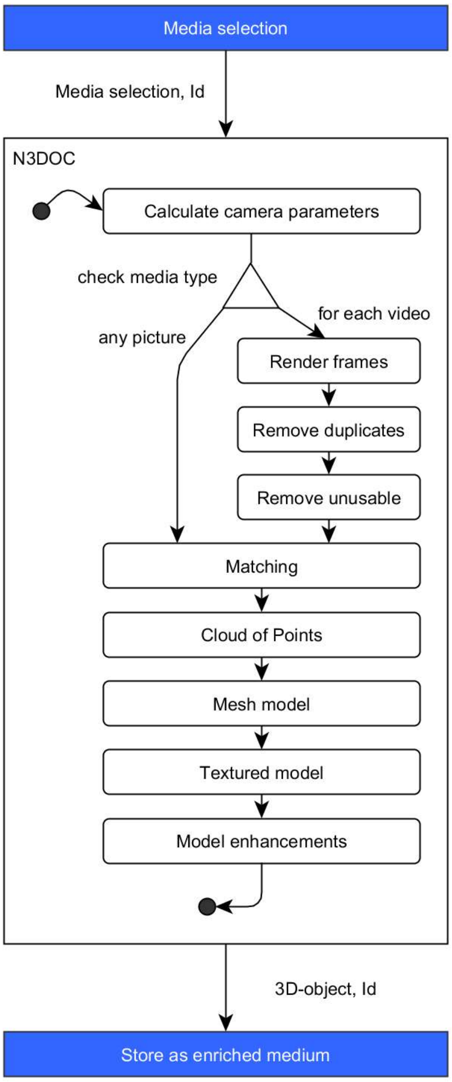

Figure 2. Sequence of the NOC3D algorithm, as more detailed described in section V.A. Media selection as well as storing the 3D object is performed externally from NOC3D by NEMO.

The textured model is handed over to MeshLab [22]. At first, small artifacts are removed and, for web-based and browser compatibility, the number of polygons is reduced to 30.000. In addition, MeshLab is used to close polygon gaps in the reconstructed model, remove devious edges and smooth the entire model. After conversion into a NEMO-compatible file format, NOC3D hands over the completed 3D object to NEMO. NEMO stores the 3D object together with the semantic annotations of the images used to reconstruct the model, omitting those annotations from the enriched media that do not match. Afterwards, the 3D object is available in NEMO.

B. 3D Reconstruction from Video Footage

In general, in the process of 3D reconstruction more images from different angles lead to qualitatively better results. During the development of NOC3D through qualitative evaluation with university students, we found out that taking hundreds of images of the same object does not integrate well with our usage scenario. In case of an entire class of 20 or more students, who take at least five images of the same object, NOC3D produces acceptable results. However, the challenge of acquiring sufficient footage remains.

Figure 3. Screenshot of a 3D object reconstructed with NOC3D from 225 images automatically extracted from semantically annotated videos. The blue background is rendered by the 3D object viewer.

The process of acquiring footage used for 3D reconstruction is simplified by supporting videos as input format. As a video generally consists of at least 24 frames per second, just moving around the object taping a video will produce enough material. Before starting the process of reconstruction, videos have to be pre-processed, as illustrated in Figure 2. The video frames are extracted frame-by-frame into images using FFmpeg and stored temporarily. This leads to duplicate or similar images, e.g., when the camera movement around the object is slow. All duplicates are removed during pre-processing using the imaging library ImageMagick, as they do not contribute usable data in the object reconstruction process. In addition, unusable images like from overexposed or black frames will be removed. After pre-processing, all images extracted from the video footage are joined with other images for reconstruction. Our tests indicate, that at least one image (e.g. photo) not taken from a video is required in order to produce acceptable results. This is due to camera parameters, which are not separately stored with each video frame, but are required for the process of 3D reconstruction. As for our scenario, smartphones used to take photos and tape videos available today produce video footage in similar quality to images, which are sufficient for NOC3D, as illustrated in Figure 3.

C. Running Time Issues

With regard to 3D reconstruction, running time of the module is critical. Preparing the media for processing is performed with linear effort, including extracting usable still images from video as shown in Figure 2. All further steps require significantly more effort, depending on the number of images, the objects complexity and the image resolution. Through experiments, we found that this process is speeded-up without losing quality by reducing the image resolution of all images with a resolution above 1200x1200px in half. Additionally, running time improves significantly, whenever images are omitted that do not contain the object, which is reconstructed.

During development, we found that integrating NOC3D directly on the same server with NEMO is unpractical, as 3D reconstruction in general results in high processor (CPU) utilization. Besides, 3D reconstruction performs up to 75% faster on Graphics Processing Units (GPU) than on CPUs. The solution we implemented is to run NOC3D on a dedicated server. Therefore, we extended NOC3D to connect with NEMO through over Web Services. As a

Figure 4. Statue called "Dorothea" by the people of the Hanseatic City of Luebeck. Number of images used for 3D reconstruction, from left to right: 62, 110, 233, 327.

result, NEMO transfers all footage to NOC3D, which stores all data temporarily on that server. The process of 3D reconstruction is started after all footage has been transferred and NOC3D signals NEMO the completion of a conversion process via callback. Because we are using a dedicated server, we are now able to choose CMPMVS as cloud of points algorithm, which only runs on CUDA-enabled (Compute Unified Device Architecture) GPUs.

VI. FINDINGS

In summary, NOC3D produces 3D objects (cf. Figure 3) with an acceptable quality given the mobile and ambient context of our scenario in the open standard OBJ-file-format. Due to the automatic process, it is inevitable that 3D objects may contain some surroundings, like, e.g., the grass and path around the statue shown in Figure 3.

In order to integrate NOC3D in a timely manner as outlined in our scenario, most importantly a multi-GPU system consisting of multiple CUDA-compatible graphic boards is recommended. In addition, free RAM capacity of at least the size of the footage used for conversion as well as hard disk storage of at least ten times the size of the footage for temporary storage is advisable. For evaluation purposes, we have tested our implementation with series of photos taken with different smartphones (e.g. Samsung SM-G531F, Nokia Lumia 650 and 930, Motorola Moto G4 and X Play). With regard to the quality of the resulting 3D objects, we also used photos from digital cameras (e.g. Olympus D595Z, Nikon D7000). We have taken footage from 20 different statues across the Hanseatic City of Luebeck, Germany, and compiled them into different selections according to semantic annotations using NEMO. The footage taken cannot be described as 'ideal', as we cared to take mostly snapshots, e.g., only showing parts of the objects or without optimal lightning that would be used when reconstructing 3D models in, for instance, a laboratory with a special 3D scanner. Thus, our tests reflect media expected to be created by students on a field trip, matching our scenario.

Our evaluation shows that, in our scenario, an average minimum of 110 images is required in order to be able to recognize the resulting 3D object as such, as illustrated in Figure 4. The maximum of images is only limited by hardware resources, but keeping in mind the time-consuming process of 3D reconstruction should be limited to a maximum of 450 images. This value is derived from our experiments in context with our scenario and is depending on the objects complexity, desired quality, hardware capabilities, as described below, and the usage

Figure 5. On the left: Statue "Panther" in a botanic garden in the Hanseatic City of Luebeck. On the Right: The output from 175 photos is hardly recognizable as a panther.

scenario. In addition, our tests indicate that using images with the same resolution enhances performance, but our research does not focus on optimizing the algorithms employed for 3D reconstruction within NOC3D. Hence, we recommend setting up NOC3D on a dedicated GPU render server.

Using footage from symmetric objects especially in front of symmetric or repeating backgrounds leads to unusable 3D objects, as the example in Figure 5 shows. Using more photos does not enhance the output. Generally and as expected, higher resolution of footage as well as using more images results in more detailed 3D objects. Nevertheless, using MoLES in context with our scenario limits students to the use of smartphones, which is why or primary focus lies on generating acceptable 3D models from smartphone-generated footage.

During our tests, we found that in some cases NOC3D aborted due to a memory overflow. This occurs due to limited hardware resources, exhausted by huge amounts of input data. Apart from upgrading the hardware, our solution is to catch the exception and remove images with the highest and lowest resolution gradually, restarting the process. With this strategy we try to keep as much information on the object and as much high quality footage as possible. This strategy may be optimized with the help of future experience.

In total, NOC3D generates all sample models without any unexpected result or malfunctioning. Processing the sample models on our dedicated system using an NVidia GeForce GTX 560 takes between four and eight hours each, depending on model complexity and the amount of data to process.

VII. SUMMARY AND OUTLOOK

NOC3D is a module for NEMO that serves fully automated reconstruction of 3D objects from images and most importantly from video footage created in ambient and mobile context and is used for learning scenarios in Ambient Learning Spaces (ALS). Through NOC3D, enriched media collectively created by students using their smartphones in mobile context is converted into 3D objects. Using Web technology, we integrate 3D models seamlessly with applications from ALS which are used in mobile contexts and in context of learning with media.

It is our hypothesis that learning in a formal and non-formal learning space [6][23], which is digitally enriched through ambient media, fosters cognitive skills and intelligent knowledge in a communicative environment [24][25]. We are going to evaluate this in the near future.

With regard to 3D objects, we plan to evaluate their values in a digitally enriched learning environment. In the setting of our ongoing research, InfoGrid will be deployed in two museums in the Hanseatic City of Luebeck, which are our ALS project partners, later this year and we are currently developing scenarios for integrating 3D objects in museum context. Thus, 3D objects play a vital role in our research project. Later this year, we plan to integrate 3D objects from NOC3D in our ALS Portal in order to provide specific features to allow post processing the automatically generated 3D objects from NOC3D. With the help of these features, the user, e.g., may remove unwanted surroundings around 3D objects.

For any ALS application of the research project, among other features, NEMO provides persistent semantic storage of enriched media. Together with our project partners, two schools and two museums located in the Hanseatic City of Luebeck, the use of these applications together with NEMO in context of mobile and ambient learning is currently being evaluated. NEMO is running in multiple instances on-site. The ALS applications are featuring the creation, presentation, use and interaction with enriched media. The applications are developed for various platforms, in desktop, stationary and mobile contexts. Thus, NEMO is technically connecting the learner’s knowledge into an ambient context, bridging the learning environment and lived-in world (Lebenswelt) to foster sustainable learning and meaningful knowledge.

ACKNOWLEDGMENT

We develop NEMO in the research project “Ambient Learning Spaces” supported by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG).

REFERENCES

[1] T. Winkler, F. Scharf, C. Hahn, and M. Herczeg, "Ambient Learning Spaces," in *Education in a Technological World: Communicating Current and Emerging Research and Technological Efforts,* pp. 56-67, 2011.

[2] S. Lob, J. Cassens, M. Herczeg, and J. Stoddart, "NEMO - The Network Environment for Multimedia Objects," *ACM (Proceedings of the First International Conference on Intelligent Interactive Technologies and Multimedia, Allahabad, India),* pp. 245-249, 2010.

[3] A. Lugmayr, T. Risse, B. Stockleben, K. Laurila, and J. Kaario, "Semantic ambient media - an introduction," *Multimedia Tools and Applications,* vol. 44, no. 3, pp. 337-359, 2009.

[4] M. McLuhan, "Understanding Media: The Extensions of Man," McGraw-Hill, New York, 1964.

[5] A. Whitmore, A. Agarwal, and L. Da Xu, "The Internet of Things - A survey of topics and trends," *Information Systems Frontiers,* vol. 17, no. 2, pp. 261-274, 2015.

[6] T. Winkler, D. Bouck-Standen, M. Ide, A. Ohlei, and M. Herczeg, *InteractiveWall 3.1 - Formal and Non-Formal Learning at School with Web-3.0-based Technology in Front of Large Multi-touch Screens (In Press),* Washington DC, USA: AACE, 2017.

[7] K. Persefoni, and A. Tsinakos, "Use of Augmented Reality in terms of creativity in School learning," in *Make2Learn workshop (ICEC’15)*, Trondheim, Norway, pp. 45-53, 2015.

[8] T. Winkler, S. Günther, and M. Herczeg, "Moles: Mobile Learning Exploration System," in *Society for Information Technology & Teacher Education International Conference (SITE)*, Charleston, SC, USA, pp. 348-351, 2009.

[9] T. Berners-Lee, J. Hendler, and O. Lassila, "The Semantic Web," *Scientific American,* pp. 30-37, 2001.

[10] F. Nack, "The future in digital media computing is meta," *IEEE MultiMedia,* vol. 11, no. 2, pp. 10-13, 2004.

[11] C. Bizer, T. Heath, and T. Berners-Lee, "Linked Data - The Story So Far," *International Journal of Semantic Web Information Systems,* vol. 5, no. 3, pp. 1-22, 2009.

[12] S. S. Kusumawardani, L. E. Nugroho, A. Susanto, A. Kumara, H. S. Wasisto, and U. Cortés, "Ontology Development of Semantic E-Learning for Final Project Course," *Advanced Science Letters,* vol. 21, no. 1, pp. 46-51, 2015.

[13] M. Masud, "Collaborative e-learning systems using semantic data interoperability," *Computers in Human Behavior,* vol. 61, pp. 127-135, 2016.

[14] P. Bouquet and A. Molinari, "A New Approach to the Use of Semantic Technologies in E-Learning Platforms," *International Journal of Advanced Corporate Learning,* vol. 9, no. 2, pp. 5-12, 2016.

[15] M. Dougiamas, and P. Taylor, "Moodle: Using Learning Communities to Create an Open Source Course Management System," *World Conference on Educational Multimedia, Hypermedia and Telecommunications (EDMEDIA),* pp. 171-178, 2003.

[16] P. Oliveira, and P. Gomes, "Instance-based Probabilistic Reasoning in the Semantic Web," in *Proceedings of the 18th International Conference on World Wide Web.* ACM, New York, pp. 1067-1068, 2009.

[17] D. Bouck-Standen, M. Schwandt, T. Winkler, and M. Herczeg, "ELBlocks - An Interactive Semantic Learning Platform for Tangibles," *Mensch und Computer 2016 - Workshopband,* Regensburg, 2016.

[18] C. Wu, "VisualSFM : A Visual Structure from Motion System," 2011. [Online]. Available: http://ccwu.me/vsfm/. [Accessed 20 May 2017].

[19] Center for Machine Perception Multi-view Reconstruction Software (CMPMVS). [Online]. [Accessed 20 May 2017]. Available: http://cmp.felk.cvut.cz/

[20] M. Jancosek, and T. Pajdla, *Multi-View Reconstruction Preserving Weakly-Supported Surfaces, CVPR 2011,* IEEE Conference on Computer Vision and Pattern Recognition 2011, pp. 3121-3128, 2011.

[21] Y. Furukawa, and J. Ponce, "Accurate, Dense, and Robust Multi-View Stereopsis," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 32, no. 8, pp. 1362-1376, 2010.

[22] P. Cignoni, M. Callieri, M. Corsini, M. Dellepiane, F. Ganovelli, and G. Ranzuglia, "MeshLab: an Open-Source Mesh Processing Tool", *Eurographics Italian Chapter Conference*, pp. 129-136, 2008.

[23] T. Winkler, and M. Herczeg, "The Mobile Learning Exploration System (MoLES) in Semantically Modeled Ambient Learning Spaces," *IDC ’13 Proceedings of the 12th International Conference on Interaction Design and Children,* pp. 348-351, 2013.

[24] C.-C. Huang, T.-K. Yeh, T.-Y. Li, and C.-Y. Chang, "The Idea Storming Cube: Evaluating the Effects of Using Game and Computer Agent to Support Divergent Thinking," *Educational Technology & Society,* vol. 13, no. 4, pp. 180-191, 2010.

[25] M. D. Dickey, *Engaging by design: How engagement strategies in popular computer and video games can inform instructional design,* vol. 53, Kluwer Academic Publishers, 2005, pp. 67-83.