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Mixed Reality for On-Site Self-Instruction and Self-Inspection with Building Information Models

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Abstract

Mixed Reality (MR) solutions for the manufacturing domain aim to support the construction, production and maintenance processes of factories, its equipment and products. Within the European project "INSITER", Fraunhofer developed visualization solutions and MR prototypes aiming to provide relevant data for different stakeholders using Building Information Modeling (BIM)-based information. Planning data of production environments or construction sites is made available on site via MR. The main objective of the work presented in this paper, is to support planning processes as well as production and construction workflows with in-situ visualization of digital planning or process data in MR.

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Keywords: Mixed Reality; Augmented Reality; Production Planning; Assembly; Process; Self-Instruction; Self-Inspection; INSITER

1. Introduction

The global competition in innovation with increasing digitization, networking and social challenges such as the demographic change are shaping our modern society and lead to substantial changes in production. Increasing complexity in manufacturing due to the trend to personalized production and its rise of product variants requires new solutions within the manufacturing sector by usage of "Industrie 4.0" technologies. This trend has often been referred to as fourth industrial revolution in Europe [1].

The merge of the virtual and the real world with a high degree of connected devices and services requires new innovative applications and user interfaces for integrating and supporting human actors within their working environment.

Thus, Mixed Reality (MR) [2] technologies that also include Augmented Reality (AR) are becoming more and more relevant for human interaction in different fields of manufacturing and construction [3, 4] by connecting the on-site real work environment with digital information or virtual objects.

Information concerning any construction, production and maintenance processes, on-site parts or equipment can be made easily accessible via several channels of communication, such as voices, gestures, in-situ projections, MR or AR [5].

This paper presents an approach developed within the European project INSITER (Intuitive Self-Inspection Techniques using Augmented Reality for construction, refurbishment and maintenance of energy-efficient buildings made of prefabricated components) [6], to support planning processes as well as production and construction workflows by interactive MR visualization solutions and prototypes. The developed prototypes connect virtual models and digital planning information based on Building Information Models with the physical building or production site, to provide relevant data for different stakeholders on-site [7].

Thus, new ways of self-inspection and self-instruction can be performed simultaneously to on-site work processes.

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2. Motivation and vision

The main focus of the developments presented, is to support human workers in the production and construction environment of the future with new ways of interactive planning, instruction and inspection capabilities. One of the key components cornering the INSITER toolset is the utilization and development of MR solutions, which connect the virtual and physical environment for self-inspection and self-instruction.

Self-inspection functionalities should enable and encourage workers and stakeholders on site to check their own working processes and the results respectively, both individually as well as in collaboration with others.

Moreover, self-instruction features provide interactive guidance to any actors on site during their working processes, preventing incorrect actions and helping the workers to rectify any error immediately.

Digital planning data, such as 3D objects, BIM models and BIM-based simulations with all its parts and assembly workflows are going to be superimposed into the field of vision of the user to expand the perception of reality. Moreover, referenced planning and instrumentation data from diagnostic instruments and devices like thermal images or acoustic measurements are integrated into the BIM to become available and accessible for the INSITER toolset and MR applications.

Dedicated use cases and prototype demonstrations have been defined in the field of on-site self-inspection and self-instruction including measurement data from instrumentation devices, also taking into account the usability and user acceptance on site [8]. Existing software and hardware solutions in the field of MR or AR for e.g. worker training [9] or approaches for BIM-based AR [10] are good starting points but further aspects such as support for complex and large BIM models as well as the applicability for on-site self-instruction and self-inspection with provision of further planning data have to be considered for INSITER.

The vision is to support planning processes as well as production and construction workflows with in-situ visualization of digital planning or process data. A challenge concerning implementation is to combine new technologies including MR hardware systems and software development frameworks as well as to adapt them for direct use by stakeholders on-site without adverse implications on their operating procedures [11].

3. MR visualization approaches and system design

A requirements analysis has been performed to analyze and identify the specifications of the MR system developments and prototypes. The main aspects of the MR solutions and prototypes are to provide and visualize data on-site concerning planning, construction and assembly processes with focus on:

- BIM and 3D objects in relation to the actual on-site environment and camera image. Superimposed, virtual objects associated with the real construction and production site.
- Self-instruction with process sequences, 3D animations and workflows.
- BIM-referenced information like instrumentation device data (e.g. thermal images, acoustic measurements) for self-inspection among other planning data linked to BIM model in external viewer applications (e.g. documents, videos).

Self-inspection and self-instruction processes are performed by the involved actors on site. Any stakeholder (for example planners, construction managers, site managers, engineers, designers, clients, construction workers) should be able to visualize the 3D BIM objects and referenced planning data in MR on mobile devices in order to perform their tasks.

3.1. BIM-based process simulations and visualization concepts

BIM and its shared digital representation data formats such as IFC (Industry Foundation Classes) is focused on interoperability. The static BIM model can be further enhanced with process simulations to include dynamic 4D information, handed from the design team to the stakeholders and workers on site [12].

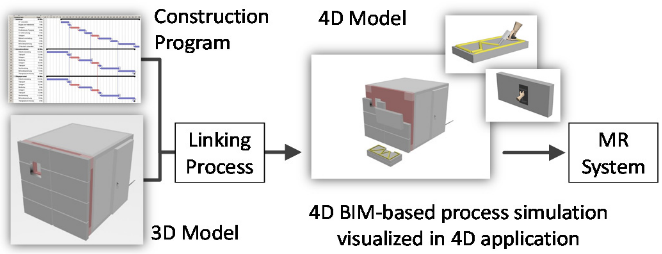

Fig. 1. Basic process of developing 4D simulations for MR

BIM-based simulation is developed and applied for construction and assembly processes to design dynamic work instructions for 3D CAD or BIM models. Associated work plans are the basis to visualize process sequences and construction or assembly steps among other issues like maintenance or inspection processes. The process workflow information is the basis to develop BIM-based 4D simulations of defined tasks. To create 4D simulations all relevant BIM objects have to be linked to the process data of a time schedule, see Fig.1. This enables the functionality to highlight and simulate specific objects of the BIM model depending on the representing activities in the schedule. By doing so, the whole assembly or construction process will be visualized in a way that is easy to understand for any stakeholder on-site.

Within INSITER, 4D step-by-step simulations of on-site construction processes and product assembly steps within production environments have been developed. After the creation of 4D simulations, the data can be made available via export of the 4D simulations to the BIM or standardized file formats to become available for self-instruction with the help of MR.

3.2. INSITER system design

Within INSITER a general framework has been set-up in order to ensure interoperability of the different tools applied within the project. Thus, the INSITER IT environment includes four different layers: The acquisition layer represents the gathering of on-site information. This information will be transferred via the adoption layer into appropriate formats to be stored on the INSITER BIM platform (BIM layer). This platform combines a Postgre SQL database, an Open BIM server and a SharePoint server. The application layer provides the whole INSITER toolset to interact with the collected information to create benefits, see Fig.2.

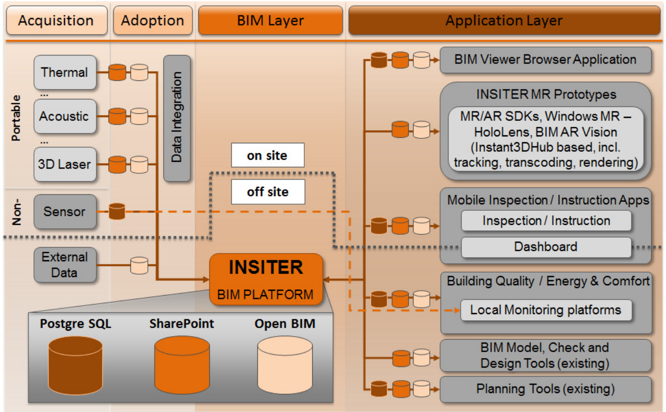

Fig.2. Current concept of the INSITER framework and data integration

Part of the applications are MR or AR solutions for the in-situ visualization of digital planning or process data.

Besides the functional requirements further non-functional and use case specific system specifications have been made on MR systems to be utilized within the project. Thus, the application of MR systems in correlation with the actual working situation for different stakeholders and deployment scenarios have been analyzed. As a result, different hardware devices, such as mobile computers or smart glasses for hands-free operations will be utilized.

3.3. MR system design

There are a lot of different approaches and solutions to utilize MR or AR applications within working environments [13]. For INSITER mobile devices such as tablet computers are used, where the multi-platform 3D development environment Unity 3D is applied together with open source MR SDKs. Moreover, a new solution for extensive and complex 3D models including BIM and referenced planning and instrumentation device data (e.g.: thermal images or instruction manuals) will be applied as "BIM AR Vision App", based on the Fraunhofer instant3DHub platform in combination with computer vision tracking methods and algorithms for multi-marker and enhanced model tracking. Thus, a web-components based framework together with a visual computing infrastructure provide a comprehensive and interactive 3D data visualization platform for INSITER [14]. The data relevant for MR is obtained via the INSITER BIM platform and managed within the MR applications.

Besides tablet computers, also smart glasses such as the Microsoft HoloLens, based on the Windows Mixed Reality (WMR) platform are applied to develop and provide a hands-free MR application for INSITER. The use of head mounted MR see through technology in combination with an advanced tracking system enable detailed 3D scenes evaluation or dynamic process visualization. Depending on the application scenario, stakeholders and their requirements, the developed MR solutions and prototypes will be utilized on different hardware configurations.

3.4. Tracking

An important aspect of MR systems is the further development and application of tracking solutions and methods for the positioning of digital planning objects within relation to the real work environment and on-site situation.

The following tracking solutions are implemented concerning MR solutions for INSITER:

- Feature-based tracking:

Derived feature points of surrounding elements are the basis for feature tracking maps based on e.g. distinct points, curves, contours or regions. Once an element, feature or marker is recognized and its location is known, simultaneous localization and mapping (SLAM) methods and algorithms are being applied to update the tracking map while moving to an unknown but texture-rich or feature-rich part of a real scene and to keep track of the location simultaneously. If the environment contains too less features, additional (multi-) markers or feature-rich objects have to be introduced to the scene in order to track the digital BIM model. Consequently, the features are tracked by embedded camera systems and computer vision tracking algorithms. Where available, additional inertial sensors can be applied to support the tracking.

- Model-based tracking:

The model-based tracking establishes a correlation of the 3D model geometry and the real environment captured by an attached or integrated camera. Model-based tracking enables the detection and tracking of BIM objects based on their 3D representation. Thus, the digital model needs geometrical structures that can be recognized according to their shape within the physical surrounding to be tracked. Via the 3D geometry, a correlation from BIM to the monocular camera image of a real building element can be established [15]. 3D CAD or BIM data is the basis to extract silhouette or contour information and compare this information with the near environment. As of missing complexity in the geometric structure or differences in BIM model and real environment, feature-based tracking will be applied in parallel.

- Spatial environment-based tracking:

Concerning the Microsoft HoloLens, also spatial surface-based tracking methods were used, as the systems provides additional computer vision hardware such as environment sensing cameras to acquire the spatial surroundings and depth information of nearby surfaces. Thus, the spatial map is used to place digital objects in exact relation with the real environment.

4. MR applications and prototype demonstrations

Depending on the on-site application scenario, involved stakeholders and requirements, the MR solutions and prototypes have been developed and utilized accordingly. In the following chapters, the developed results and application of

MR solutions and prototypes are presented. The MR systems have been implemented within four main use case studies, to support on-site planning processes as well as production and construction workflows.

4.1. Factory and production

In the context of Industrie 4.0 and the ever-increasing merging of real and virtual worlds an implementation and validation use case for assembly processes has been established within the "Application Center Industrie 4.0", a dedicated research, development and demonstration environment of Fraunhofer IPA.

Within this MR use case application, a guided process workflow and assembly process with detailed and dynamic work instructions has been developed and implemented to be used by assembly and construction workers on site, see Fig 3.

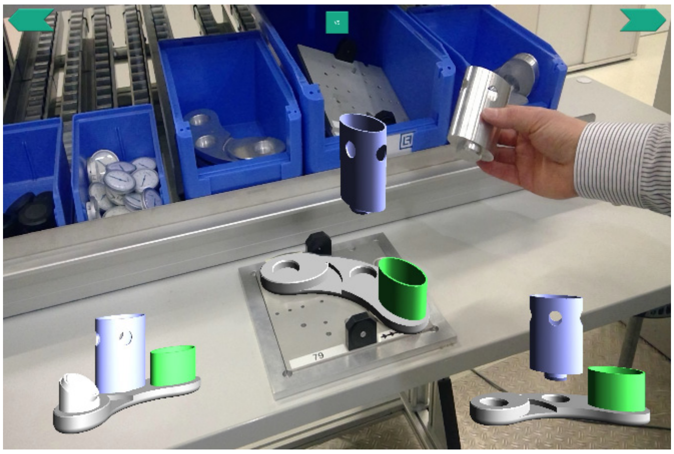

Fig. 3. MR use case for visualization and simulation of assembly process sequences (On the left current variant, on the right current step and part)

The functionalities for self-inspection and self-instruction are:

- obtain current order number and variant to be produced
- select variant to be assembled
- in-situ visualization of the variant and its parts to be produced, along with process data and actual work instructions to execute the assembly process in combination with the real workpiece
- identification and localization of process associated material supply containers and parts to be installed
- provision of dynamic assembly simulation and steps visualization for self-instruction with assembly location to verify the position and orientation of parts to be assembled

The interactive process workflow and assembly support the error-free assembly of components. Thus, a possible mix-up of components can be prevented by the targeted and guided processing of products. Besides the use of 4D simulations and process workflows, generic placement zones have been defined within the MR application that allows the configuration of any part or variant to be displayed at the assigned assembly spots.

The assembly locations as well as material supply containers can be assigned to defined placement IDs, to be configured within a JavaScript Object Notation (JSON) file to define and exchange data cornering product variants and placement spots.

This use case was implemented on tablet computers as well as on smart glasses for the hands free assembly using feature and spatial parameters for tracking.

Enhanced MR visualizations, including assembly process information, allow a high flexibility and productivity, not only in the manufacturing domain but also in the field of building construction. The developed application is not limited to the specific use case but can provide process information wherever required for the corresponding actors and personnel. If additional information besides 3D models or objects has to be visualized, further planning information could be linked and accessed concerning the displayed object. Any guidelines can be generated and integrated also for another construction process or complex work sequences, supporting stakeholders and construction workers with interactive guidance and self-instruction data.

4.2. Construction and refurbishment

Based on the design and development of the MR solutions for assembly, the application has been further developed and adapted to be used within on-site construction environments and its process workflows. Besides the assembly support also a direct access to embedded self-instruction and instrumentation data of thermal and acoustic measurements has been implemented, enabling thermal and acoustic evaluation of buildings and equipment, among detailed BIM-based process simulation for self-instruction.

Prior to the application of MR, the personnel on site such as structural engineers or energy planners gather the relevant instrumentation and sensor data (e.g. thermal images) to be available for self-inspection. The data is integrated and referenced within the BIM model to be accessible for the INSITER toolset. In this use case, thermal and acoustic instrumentation data concerning a lab mock-up (cooling room) has become available for evaluation in MR.

With the applied Siemens SoundBrush System an acoustic leakage on the side of the lab mock-up was discovered. For visualization in MR, the SoundBrush data tables are processed by Siemens with OpenJSCAD in order to establish 3D models of sound intensity vectors, as shown in Fig. 4.

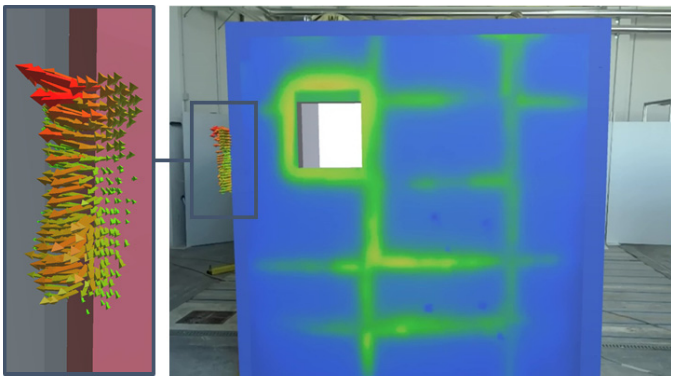

Fig. 4. MR use case for instrumentation data with sound intensity vectors and thermal images

In order to fix the leakage, structural engineers together with the project manager inform construction workers about the attachment of additional insulation boards, for example. Thus, the construction workers are provided with detailed 4D BIM-based on-site instructions. Within the described MR use case, a BIM-based simulation of construction or refurbishment processes, including additional animated elements to attach insulation boards to the facade panel (see Fig. 5), has been developed and integrated.

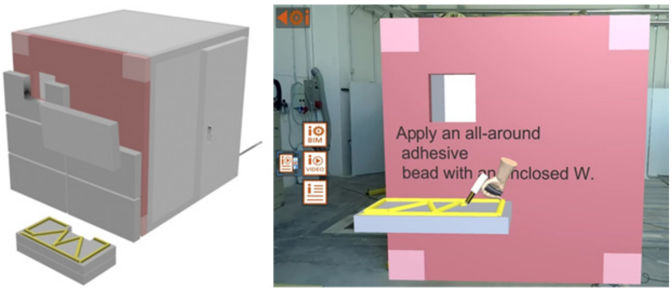

Fig. 5. MR use case for 4D BIM-based simulation of construction processes

4.3. Extensive, complex BIM models with referenced planning and instrumentation data

Besides detailed MR solutions for dedicated use cases, also extensive BIM data files, including complete production or building models, have to be viewed in MR, without detailed 4D scenes configuration and preparation in advanced.

Thus, a general approach and MR application was developed as "BIM AR Vision App", based on the Fraunhofer instant3DHub platform, for visualization of large geometry models. With this solution, shown in Fig. 6, the actors on site are able to display and select individual 3D building elements from complex BIM or CAD models as well as view linked and referenced planning data such as available guidelines and self-instruction videos.

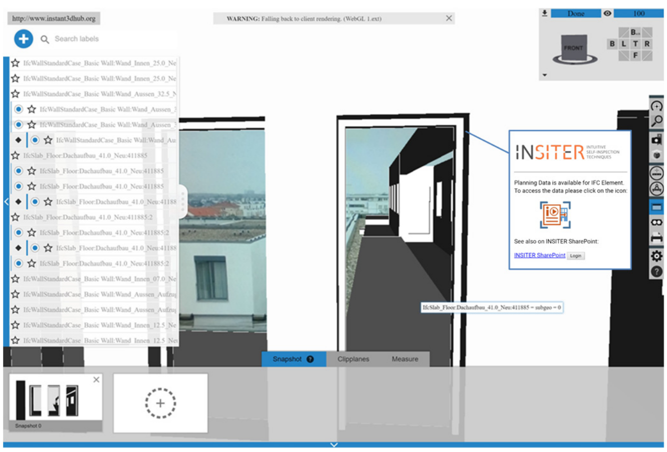

Fig. 6. MR use case for evaluation of extensive, complex BIM models with referenced planning and instrumentation data

The functionalities of BIM AR Vision App for self-inspection and self-instruction are:

- identification and visualization of complex BIM or CAD elements and parts in MR
- access to referenced planning information on INSITER SharePoint (guidelines, instrumentation data, etc.)
- in-situ visualization of building parts or equipment to be installed
- evaluation of defined BIM/CAD objects and prefabricated facade panels concerning e.g. the correct location and construction position
- analyses of construction errors and identification of inconsistencies with verification of the assembly location and placement of BIM elements

Mobile computers or tablets are applied for the described MR use cases. In addition to that, a solution for hands free assessments was developed, which is presented in the following chapter.

4.4. BIM-based evaluations in MR with smart glasses

In order to provide a further hands-free solution for stakeholders on site and to enrich their vision with virtual, interactive BIM objects and information, a dedicated application for the MS HoloLens was developed for INSITER. Head mounted see-through display technology in combination with spatial mapping-based object tracking enable further functionalities concerning self-inspection and self-instruction.

The focus of the INSITER HoloLens BIM-based mixed reality app is on:

- on-site factory and building planning with construction and layout planning
- BIM model evaluation for self-inspection of technical building services such as mechanical, electrical, and plumbing (MEP) or heating, ventilation, and air conditioning (HVAC) systems, see Fig 7
- visual comparison between virtual model and real on-site situation
- on-site planning and validation of manufacturing lines and construction sites, see Fig. 8
- visualization of architectural BIM models and evaluation in different scale levels

Fig. 7. MR use case for visual comparison between BIM model and realization of the MEP system

The developed MR prototype enables detailed 3D scenes evaluation for any production or construction element. Within the factory, the production layout can be planned and optimized on site within the real scale level.

Workers on site can visualize in-situ which elements have e.g. to be attached, installed or removed for refurbishment works or installations. Also project managers can monitor the installation work on site and check if new machines, construction elements or MEP systems are correctly installed. The planning tasks are supported with gestures and speech recognition enable intuitive interaction with the virtual objects and the real environment.

Fig. 8. MR use case for validation of complex manufacturing lines

Besides the development of further functionalities regarding the described MR applications there are still open usability issues to be faced as the available glasses have a restricted battery life, limited field of view or are still heavy and stressful if worn for a long time. Light, data glasses are available but they are providing only a limited MR experience or must be connected to a computer. Future hardware solution are expected to introduce new MR glasses that with will reach beyond today’s boundaries.

4. Conclusion

The development of innovative solutions and applications in the field of MR can change our daily process radically, on-site and off-site. Within the European project “INSITER”, visualization solutions and MR prototypes have been developed, aiming at providing relevant data for different stakeholders using BIM-based information. The established MR use cases are still in prototype stage, but they already demonstrate how MR applications can bring benefits for daily work on site in factories and construction environments. With the help of MR tools, errors can be prevented, quality can be improved and the overall work performance will be optimized.

The main aspects of the developed MR solutions and prototypes presented are to provide data concerning planning, construction and assembly processes in order to enhance the capabilities of any actor or stakeholder on site for self-inspection and self-instruction activities in an efficient and effective way.

The developed prototypes can be deployed on mobile devices or wearable smart glasses. Besides the definition and evaluation of on-site processes concerning the applicability and usability of MR systems, it has to be considered that there are further challenges that have to be faced, such as national and international regulations which do not yet cover the usage of MR tools on construction sites or within factories. Adjusting existing or establishing new regulations is necessary to pave the way for a successful implementation and usage of MR systems and technologies within real work environments.

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