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Towards augmented reality manuals for industry 4.0: A methodology

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ABSTRACT

Augmented Reality (AR), is one of the most promising technology for technical manuals in the context of Industry 4.0. However, the implementation of AR documentation in industry is still challenging because specific standards and guidelines are missing. In this work, we propose a novel methodology for the conversion of existing "traditional" documentation, and for the authoring of new manuals in AR in compliance to Industry 4.0 principles. The methodology is based on the optimization of text usage with the ASD Simplified Technical English, the conversion of text instructions into 2D graphic symbols, and the structuring of the content through the combination of Darwin Information Typing Architecture (DITA) and Information Mapping (IM). We tested the proposed approach with a case study of a maintenance manual of hydraulic breakers. We validated it with a user test collecting subjective feedbacks of 22 users. The results of this experiment confirm that the manual obtained using our methodology is clearer than other templates.

1. Introduction

In the last years, we have been assisting to a rapid transformation of our daily life pushed by computers' miniaturization and inclusion in almost all our technical devices. Furthermore, smart things communicate to each other through the Internet. These innovations in ICT (Information and Communication Technologies) and computer sciences affect also industrial manufacturing. Started in Germany, this trend is called the 4th Industrial Revolution, in shorthand, Industry 4.0 [1]. To support companies in developing strategies to implement Industry 4.0 in their factories, six design principles were presented in [2]. We define, in the following items, how these design principles affect the management of technical documentation.

- Interoperability: in Industry 4.0, Cyber-Physical Systems (CPS), humans, and the factory communicate with each other and are connected over the Internet of Things (IoT) and the Internet of Service (IoS). Technical documentation should be connected to the IoT and the IoS and to facilitate communications between machines and humans, standardization is crucial as well as ease translation in all languages.
- Virtualization: a virtual copy of the physical world is created by linking CPS to virtual plants and simulation models; in this way CPS can monitor physical processes and notify humans. Therefore a digital version of the technical documentation is needed.
- Decentralization: the rising demand for individual products makes it increasingly difficult to control systems centrally. Thus, embedded computers enable CPS to make decisions on their own. Only in cases of failure tasks are delegated to a higher level. Therefore, even if the whole technical documentation must be retained, an eased access to the technical documentation should be provided locally. For example, when a failure occurs the system should provide just the exact procedure to accomplish and without the need to browse it from the overall manual.
- Real-Time capability: data are collected and analyzed in real time, so the status of the plant is permanently tracked and analyzed to react immediately to failures, production changes, and so on. Also technical documentation must be updatable in real time and follow the status of the plant.
- Service orientation: the plants of the future are based on a service-oriented architecture. CPS, humans, services of other companies are all organized as a service, available over the IoS. As a result, the process operations on a product can be composed based on the customer specific requirements. Maintenance processes, that involve most of the technical documentation produced in a factory, should be organized as a service too; a valid solution could be the one of remote maintenance [3–5]. In particular, in [5] the main technical and organizational challenges to face in introducing such a

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technology in an industrial context are described through a real case study.

- Modularity: modular systems can flexibly adapt to changing requirements, for example in case of seasonal fluctuations or changed product characteristics. This can be done by replacing or expanding individual modules based on standardized software and hardware interfaces. Technical documentation should be modular, i.e. the integrations of new procedures, new technologies, and so on should be easy to accomplish.

Our research question assesses whether today's documentation technology and practices meet these requirements.

Barthelmey et al. [6] point out that the documentation is still structured manually referencing all relevant aspects of the current physical production environment, thus it is a static (i.e. not updatable in real time) documentation. Other issues founded by Barthelmey et al. [6] regard the complexity: data types are inconsistent and structure is lacking. Engelke et al. [7] confirm that traditional paper documentation templates (often deployed as PDFs) are an established state of the art in industry and consumer products. This is confirmed by our experience with companies where documentation is often present in the form of printed manuals, it is difficult to update, to translate, and to access. In the last decade, the explosive growth in social media sites, such as YouTube [8] and wikiHow [9], together with the availability of open-source publishing platform, such as Darwin Information Typing Architecture (DITA) [10] and the oManual [11], pushed technical communicators to deploy user-generated content strategies. The most successful example is iFixit [12], whose main feature is the large use of visuals (photos, videos, diagrams) avoiding technical jargon, which makes it suitable to non-professional users [13]. However, the use of illustrations may introduce a cognitive payload, since users must match the images in the manual with the physical object. In addition, inferring actions from a sequence of 2D images can be a mentally demanding task [14]. A solution can be provided by Augmented Reality (AR) technology. As reported in literature for industrial usage, AR manuals can present the technical information registered to the object in the real workspace with potential benefit that increases with higher complexity of the operations [15,16]. It is also proven that AR can reduce the cognitive load when using technical documentation [17–20]. Exploiting AR is also a valid way to create technical documentation compliant to Industry 4.0, since it is one of the nine enabling technologies [21]. The idea is not new and Palmarini et al. in their review [22] analyze the attempts that have been done in the last years to promote AR as a support for in industrial maintenance, highlighting the technical limitations preventing this technology to be effectively used by industry. In AR, instructions can benefit from the use of visual elements instead of text, and provide only the essential information to users. However, authoring AR documentation is still a complex and time-consuming process: it requires 3D modeling, computer graphics/animation skills, programming and expertise about registration and tracking. These competences are not typically part of technical writers' background.

Lately, we are assisting to the development of commercial authoring tools to help non-experts in the development of AR contents. Using these tools is a valid solution to create new AR contents from scratch, as demonstrated by many case studies deployed [23]. However, technical manuals are still complex and difficult to manage: a prior analysis of the documentation is always required to set up the proper strategy to organize contents in AR. In the literature we found some approaches aimed to simplify the authoring of AR manuals. Knpfle and Weidenhausen [24] describe a concept to simplify the creation of AR based manuals, accessible also to people without specific skills. The core idea is template-based authoring: tasks are divided into atomic operations and these are transformed into VRML-based statements including animations. Stock et al. [25] proposed a metadata-based authoring to generate technical documentation. They use information (e.g. geometry, positions, connections) recorded during the entire design and development process of technical products to support technical writers in generating manuals. In [26] the ARAUM (Augmented Reality Authoring for Maintenance) system is described, which is specifically designed to simplify the authoring and to make it simple also for technicians with no prior knowledge on AR. Part of the information is also gathered in realtime from available data. Another example of authoring tool for non-programming users is provided by Gimeno et al. [27], whose novel aspect is the use of Microsoft Kinect to create a depth map of the scene, instead of using 3D models.

A common aspect in the presented works is the lack of guidelines on how to convert and reuse existing technical documentation. In fact, a large amount of documentation still exists on paper (or in traditional digital templates, often deployed as PDFs) but remains unused for AR applications [14]. The possibility to support the conversion of existing documentation into AR is then the main objective of this work. At this purpose, Mohr et al. [14] proposed a system capable of automatically transferring traditional printed documentation to AR. Their system generates interactive AR presentations from 2D documentation as a collection of images, and a 3D CAD model of the target object. However, as argued by the authors, this solution has some limitations: propagation of pose estimation errors, extraction of invisible elements and small elements. Furthermore, most of the information in traditional technical documentation is presented as text instructions, and in these cases the methodology is no longer applicable. Engelke et al. [7] presented a framework based on common standards that allows the conversion of existing instructions on paper to electronic devices. Contents can be presented in three forms: AR mode, VR mode, and 2D mode. They found certain recurring elements within technical documentations, but they focused on task descriptions. They did not modify the text provided in the original manuals, leaving the technical author to decide for the granularity needed for context transfer both for textual description and 3D models.

The presented methodologies are valuable, but they do not offer general and well established guidelines for the technical writers using AR. In [28] a framework to integrate AR in maintenance systems is described. This framework is based on semi-structured interviews and surveys conducted with maintainers. Among the challenges, pointed out in this paper, it emerges that in maintenance tasks and operations *"the supportive information given is not delivered properly"*. For this reasons technicians might have problems in interpreting it correctly. We propose a methodology to convert existing technical documentation from a traditional display mode (mainly text, printed or PDF files), to an AR based one (less text, more graphics, symbols, and icons) according to Industry 4.0 design principles. The proposed methodology may serve also as reference for technical writers who want to write AR technical manuals.

We reported the methodology and detailed the rationale of our approach in Section 2. In Section 3 we described how the methodology was applied to two case studies. In Section 4 we described a subjective experiment with users to validate the organization of information with the visual manual. In Section 5 we provided a discussion of the work related to the state of the art about current technical documentation, and of the main results of the experiment. Finally, in Section 6, we reported the main contributions of this work.

2. Proposed methodology

The work-flow presented in Fig. 1 describes the methodology proposed in this work. It was developed thinking to existing manuals mainly based on text instructions grouped into a single sentence. As an example, refer to the following instruction, taken from the manual used for the case study: "Turn the accumulator and pour in oil to fill the cavity with the holes and check that the membrane has no porosity. If there is no leakage, it means that the accumulator has been charged correctly and is ready to be fitted on".

The first stage of the proposed methodology contemplates the

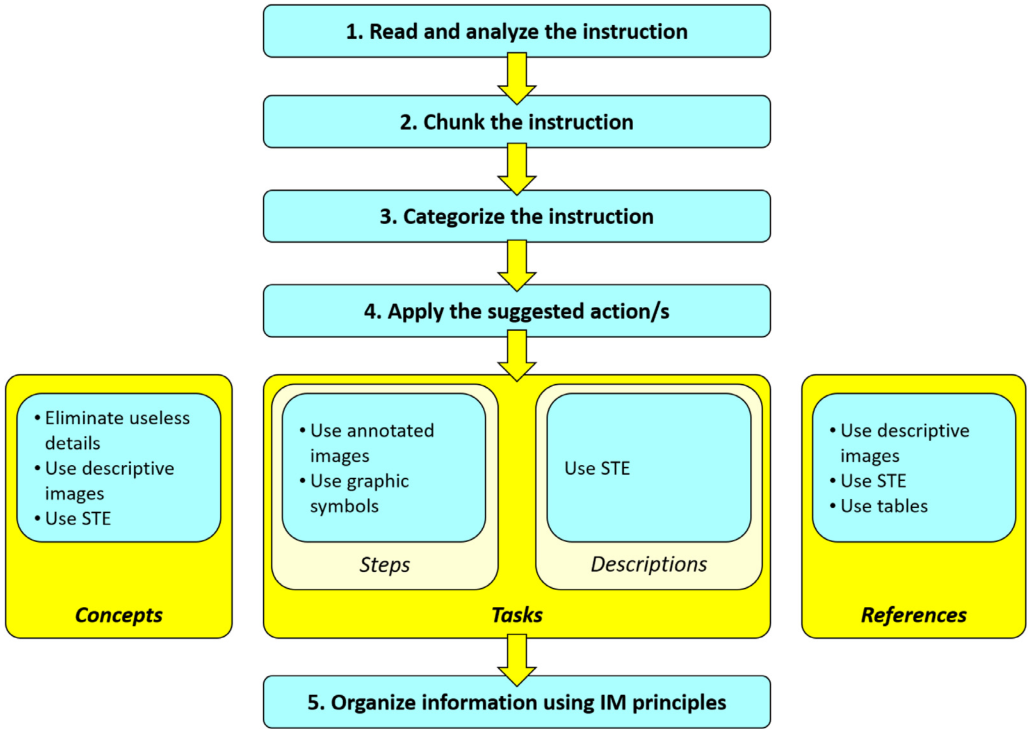

Fig. 1. methodology proposed to manage existing technical instructions for their use in visual manuals.

reading and analyzing of the instruction, thinking to how it can be divided into atomic actions with the chunking to be made in the second stage. In our example we have the following pieces of instruction: 1) "Turn the accumulator"; 2) "pour in oil to fill the cavity with the holes"; 3) "check that the membrane has no porosity"; 4) "If there is no leakage, it means that the accumulator has been charged correctly and is ready to be fitted on".

Then, each single piece of instruction should be assigned to one of these categories: concepts, for conceptual or descriptive information; tasks, for procedural information, in turn divided into steps and descriptions; references, for factual information. Instructions 1, 2, and 3 are three steps of a single task, whereas instruction 4 is a description of the same task.

Depending on which category the piece of instruction belongs to, different conversion actions are proposed: for concepts and descriptions it is difficult to replace the whole text with visual elements, then a text optimization strategy is proposed; while the procedural information provided in step instructions can benefit a lot from the use of visual elements (e.g., annotated images, graphic symbols), in particular exploiting AR; finally, factual data provided with reference information can be organized into tables. In instructions 1, 2, and 3 the action verbs (turn, pour in, check) can be replaced with graphic symbols with the same meaning, while the objects they refer to (the accumulator, the cavity with the holes, the membrane) can be localized exploiting geo-referenced signs (e.g. circles, arrows) in AR, and for the conditions (to fill the cavity, no porosity) text or 3D animations can be used. In instruction 4, text cannot be eliminated, but can be optimized using adequate strategies.

The final output, i.e. the form of these pieces of information, can be customized by graphic designers, but we proposed and evaluated a basic layout of contents following the principles of Information Mapping (IM).

The bases of our methodology, discussed in the following subsections, are:

- Optimizing text use, through the ASD Simplified Technical English (STE) [29];
- Converting, as much as possible, text instructions into 2D graphic symbols [30]; not convertible instructions (e.g., descriptions, concepts) are provided in textual form using STE;
- Structuring the content through the combination of DITA, as regards information types (concept, task, reference) [10], and Information Mapping [31].

2.1. ASD simplified technical english

A well known method to improve readability of text instructions is the use of Controlled Natural Languages (CNL) or simply Controlled Languages (CL). Kittredge [32] defined a CL as a restricted version of a natural language which has been engineered to meet a special purpose, most often the one of writing technical documentation for non-native speakers of the document language. A typical CL uses a well-defined subset of a language's grammar and lexicon, but adds the terminology needed in a technical domain.

The main advantages of CNL are the improvement of communication among humans, the facilitation of translation, and a natural and intuitive representation for formal notations. These advantages justify the use of CNL for the creation of new digital manuals. Even if CNL exist from the 1930s and emerged also in the industrial environments, their use is still not so widespread for technical documentation. Many big companies (e.g., Kodak, Caterpillar, IBM, GM, etc.) tried to develop their own CNL, but after a few years they abandoned the development.

Kamprath et al. [33], based on the experience made in Caterpillar, suggest that CNL and authoring should be developed simultaneously. Then, the new industrial approaches to the creation of technical documentation suggested by Industry 4.0, together with the development of new software tools for authoring, represent a good opportunity for the use of CNL in the industrial world. However, there are still no standards to follow, so we made a review of all existing CNL to choose the one to be used for our methodology. Kuhn [34] provided a detailed survey of CNL. He assigned to each language a rank from 1 to 5 to the parameters precision, expressiveness, naturalness, simplicity, thus creating the PENS classification. For example, for basic English we have $P^2E^5N^5S^1$. Then, every language has some properties, related to the goal (e.g. T = Translation), the origin (e.g. I = Industry), the use (e.g. W = language intended to be written). For the choice of the CNL to be used in our model, we considered the property I, that means language originated from Industry considering all the languages with this property, the average PENS value is P = 2.3, E = 4.3, N = 4.7, S = 1.4. Then we considered all the language with the PENS value closer to the average, that is $P^2E^5N^5S^1$. Many languages belong to this PENS class; among them, we considered those with the following properties:

- C, goal is comprehensibility.
- T, goal is translation.
- W, language intended to be written.
- D, language designed for a specific narrow domain.
- I, language originated from industry.

Among all the languages with these properties, the one still in use is ASD Simplified Technical English. It was developed from the aerospace industry and was used to improve the readability and comprehensibility of technical documentation [35]. ASD-STE is based on English with restrictions expressed in about 60 general rules [36]. These rules restrict the language on the lexical level, on the syntactic level, as well as on the semantic level.

2.2. Visual elements

The availability of innovative computer graphics interfaces, like Augmented and Virtual Reality, can change significantly the way technical information is presented to the user. In fact, in the past, paper-based information was mainly in textual form and was marginally supported by static tables, images, and drawings. Head mounted displays (HMD) with high resolution and the possibility to use on-board 3D real world scanning and voice and gesture recognition are becoming very common and low cost (e.g. Microsoft Hololens). Also, AR deployed on handheld devices can provide a low cost and easy to use approach to technical documentation for small and medium-sized enterprises. With these devices, digital information can be dynamic and based on interactive and complex virtual graphics. The use of such visual elements is a key factor in the development of technical documentation in the age of Industry 4.0, because it allows the possibility of conveying customized information (from non experts to senior technicians).

In the industrial field, AR or VR contents have been proposed as a support for maintenance [22,37], for assembly simulation [38–41] sometimes including tactile communication and also to improve information delivery and perception in manufacturing systems [42]. Furthermore VR has also been proposed as a tool to support industrial processes, for example to improve processes control [43], to analyze and improve ergonomics [44] or to study and analyze human-robot interaction [45].

In previous studies we explored the possibility to use AR for maintenance and assembly manuals [18,19]. We observed that the use of visual elements was particularly effective to deliver to the operator the tasks to accomplish and the specific modality of how to accomplish it. AR visual elements can help the operator in two distinct tasks:

- the localization of the components: e.g., inside a military vehicle using a red line as indicator and text labels in ARMAR [17];
- the procedure to carry out: e.g., unscrew a bolt in an automotive scenario, using an animated 3D model (i.e. a screwdriver), text (i.e. ”Release 2 screws” on the top), and icon of the tool insert (i.e. Torx screwdriver number 25).

We classified visual elements for AR technical documentation into five categories:

- Simple 2D graphic elements (Fig. 2). These are simple graphical primitives (e.g. circles, lines, callouts) that have no specific meaning, but they are useful to provide indications, simple annotations and positioning hints.
- Icons and symbols (Fig. 3): they convey a message using a specific standard. For example, in safety [46] standards, the yellow triangle with the exclamation mark, means caution.
- Multimedia elements (Fig. 4). Pictures or videos eventually taken from the real plant/scene. They can also be annotated with audio messages and/or addition graphic elements to enrich the information provided (text, icons, filters, etc.). Lately both pictures and video can be captured by cheap 360-degree cameras and the user can interactively change the point of view in the so-called cinematic VR.
- 2D technical drawings and pictorial illustrations (Fig. 5). These graphical elements are ruled by technical standards (e.g. ISO EN 128-20, ”Technical drawings, product definition and related documentation”). They define products geometry and how they are

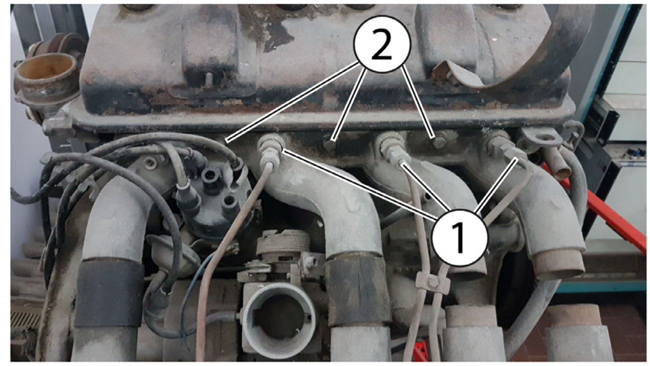

Fig. 2. An example of using simple 2D graphic elements. Numbered callouts from automotive workshop manual.

Fig. 3. Examples of international safety symbols. From the left: a mandatory symbol, a prohibition symbol and a warning symbol (from UNI EN ISO 7010:2012 [46]).

Fig. 4. An example of using multimedia elements. A picture is taken during the operation and used as instruction guide on iFixit web platform [12].

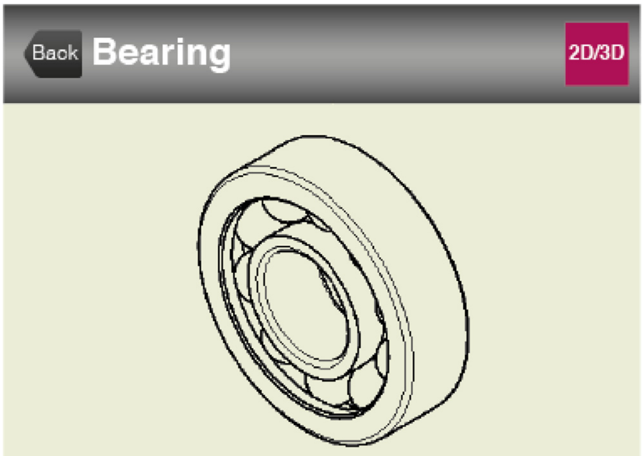

Fig. 5. An example of a pictorial illustration in mobile device based manuals inspired by Engelke et al. [7].

constructed. In maintenance and assembly documentation it is common to find the followings: i) exploded views (e.g., to show the internal parts of an assembly and their position); ii) technical illustrations (e.g. to simplify the localization of specific parts to be operated). They are mainly produced with Computer-Aided Design systems (CAD), both 2D and 3D ones, and available in form of images (e.g., jpg, gif, png) or vector graphics (e.g., dwg, dxf).

- 3D navigable models (Fig. 6): they are a graphical representation of the products, using a standard CAD format (e.g., IGES, STEP, JT) or a simplified mesh (e.g., VRML, WEBGL, COLLADA). The user can benefit from an interactive and immediate understanding of the model shape by rotation, zoom, sectioning and moving. The use of photo-realistic rendering can provide also a real-life feeling. 3D models can be either static or animated to show the user the procedure to be carried out (e.g. opening a panel door). The models are usually exported as triangle meshes from the engineering CAD systems, and the animation are provided into mesh editing tools like 3DS MAX or blender. Most of the CAD systems now support natively the generation of model and animations, avoiding the conversion phase (e.g. Catia composer by Dassault Systems).

We evaluated these five categories of visual elements based on intuitiveness for the operator, availability of the graphics, authoring effort, updating effort, standardization, eligibility for deployment in AR

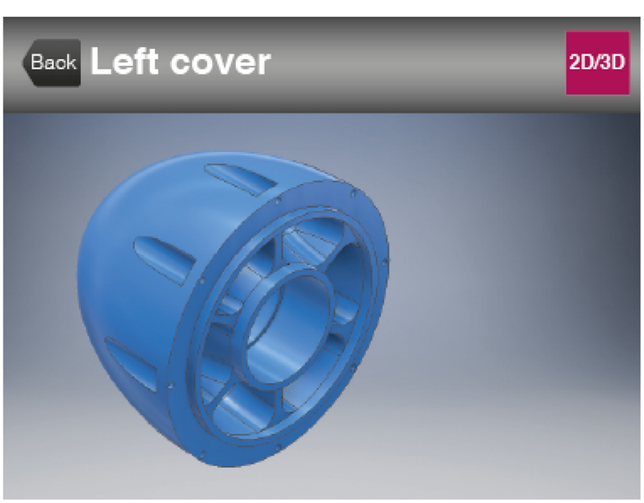

Fig. 6. An example of using 3D navigable models on mobile devices inspired by Engelke et al. [7].

Table 1
Comparison of visual elements categories for AR technical documentation.

	Intuitiveness	Availability	Ease of authoring	Ease of updating	Existing standardization	Eligibility for AR deployment
Simple 2D graphic elements	High	Always	High	High	No	High
Icons and symbols	Medium	Always, but limited	High	High	No (for Technical Documentation)	High
Multimedia elements	High	Not always	Medium	Low	No	Low(occlusion)
2D technical drawings and pictorial illustrations	Medium	Not always	Low	High (digital models)	Yes (ISO EN 128-20)	Low (occlusion)
3D navigable models	High	Not always	Low	High	No	Medium (accurate overlap)

interfaces (Table 1).

Drawings require moderate-high authoring effort also when they are generated from 3D CAD system. In fact, they are created by a technician/engineer for the specific purpose. For example, disassembly operation may require different sequences, where the model parts are located and colored differently. Most of the effort is also spent for the indication of the part to be operated. Drawings can be considered not optimal for an AR documentation because they do not exploit appropriately the integration with the real world, and cause visual occlusion for the user. Specifically, their usage in AR will be at user request and for short time span. On the other hand, 3D computer graphics models are very intuitive for the user, especially if animated. However, they are not always available in a AR compatible format. The authoring time needed to create from scratch and/or convert from CAD is relevant and increases with the complexity of the product.

3D models and 3D animations are very common in AR instructions presented in literature. However, because the virtual object are rendered directly over the real ones, the user will spot easily and immediately any flaw in model geometry and tracking. Therefore, a good AR experience 3D modeling requires very long authoring time. Pictures and videos acquired from the real scene (for example the video capture made by another operator) can be very useful and are widely used in crowd-driven wiki guides like iFixit [12] or on YouTube repairing channels. However, in an industrial scenario it is not always possible to acquire multimedia due to accessibility, safety or security reasons. Acquiring pictures is faster than modeling using CAD, but it requires authorizations, the preparation of the scene, and post-processing. But a known issue is that, in case the product/procedure is modified, the multimedia may become obsolete and must be re-acquired. In addition, like 2D drawings, they are difficult to be integrated in an AR environment due to occlusion. 2D graphics and symbols are well known in paper based technical literature and very used in practice. The authoring time when using symbols is low because the technical writer should only choose the symbol from a vocabulary. Symbols can be very “stable” to product shape changes and updates. In AR documentation, the symbols can be positioned or not into the scene (e.g. displayed near a component for indicate an operation or in a fixed region of the GUI). In some cases, symbols do not require accurate positioning compared to real objects, reducing authoring effort. As drawback, they can be not intuitive and require an initial training. Moreover, at present time there are not specific standards to follow for AR documentation.

Based on these considerations, we decided to define a strategy based on 2D symbols because they show important advantages compared to the other visual elements, especially considering the authoring effort and the integration into an AR environment. Regarding the problem of standardization, we carried out an elicitation study to find a vocabulary of graphical symbols to be used in AR to represent maintenance instructions [30]. We are confident that similar research studies would encourage the scientific community to develop standards of graphic symbols for maintenance tasks documentation. However, 2D symbols are not enough to provide all the information about a task, i.e. the localization of the components involved should be provided. Without AR, it can be provided using an annotated picture that in future AR applications would be replaced by the live stream of the camera with referenced graphic signs used for the localization.

2.3. Structured writing

Structured writing is an authoring methodology that enables the separation of content from form, content reuse, and multichannel publishing. The authoring strategy is based on predefined rules to create consistently organized categories of information that can be reused in multiple contexts. Two well established approaches in structured writing domain are DITA and Information Mapping. In the following paragraphs, we describe our novel strategy of combining the use of DITA information types and the principles of Information Mapping.

DITA was released in March of 2001 by a workgroup inside IBM's User Technology community [10]. It is one of the most widely used document-type definition (DTD) for structuring content in technical documentation, together with DocBook and S1000D. However literature shows that the adoption of DITA has now far surpassed that of DocBook and S1000D [47]. DITA's most important basic principles are topic orientation and information typing. Information is then organized in small units (topics) that cover a specific subject or answer a particular question. Furthermore, content is described independently of how that content is delivered, but it is just tagged into information types. A different form in the output manual could be then provided to each information type. For this reason, we exploited the three main DITA information types for instruction distinction: concepts, tasks, and references.

While DITA is the rising star in the world of XML-based authoring, Information Mapping is a structured writing method with a long and successful history. Information Mapping and DITA are often juxtaposed, however the former is a method and provides all the guidelines to follow for structured writing, the latter is a technological solution to author and publish content. Information Mapping is a methodology emerged from a research phase supported by the U.S. Air Force Systems Command. Its main feature is the replacing of paragraphs with Information Blocks that are units of information and the collections of these blocks are called Information Maps.

We described, in the following items, how the principles of Information Mapping were applied in our methodology for the development of a digital manual displayed on a screen:

- Chunking: all information should be grouped into small, manageable units (information blocks). Then, we distinguished instructions into concepts, tasks, and references.
- Relevance: just one relevant point should be covered in each unit. Then, we decided to display one piece of information at a time on user screen.
- Labelling: each relevant unit of information should have a label to prepare the reader about the content of that unit. Then, for each topic, we provided a title and a subtitle at the top of the GUI.
- Consistency: the same principles should be used for all blocks of information in a document. Once the organization of information in the GUI is established, it then must be maintained for all the produced documentation.
- Integrated graphics: all the visuals (pictures, diagrams, tables) should provide effective information at the same level of importance of text. The visual elements of the topics should then occupy the main central zone of the GUI because most of the information would be provided with this means.
- Accessible detail: information that user needs should be put where the reader needs it. The text information of the topics can be put in a peripheral area of the GUI: in the scheme in Fig. 7, they are at the bottom.
- Hierarchy: small units of information should be organized hierarchically into larger groups with relative labels. A table of contents should be then provided with all the topics organized in a hierarchic way, so that the user can be aware of the point reached in the overall procedure.

3. Case studies

In this work we developed two case studies of the application of the proposed methodology, taken from real maintenance manuals.

A first case study shows an AR manual generated implementing the methodology for the conversion of instructions taken from a real technical manual of a hydraulic valve for elevators. In Fig. 8 we reported a page example of the resulting manual. We converted the following instruction: “push the manual descent (MM) button to unload the pressure.” It is the first out of four instructions contained in the

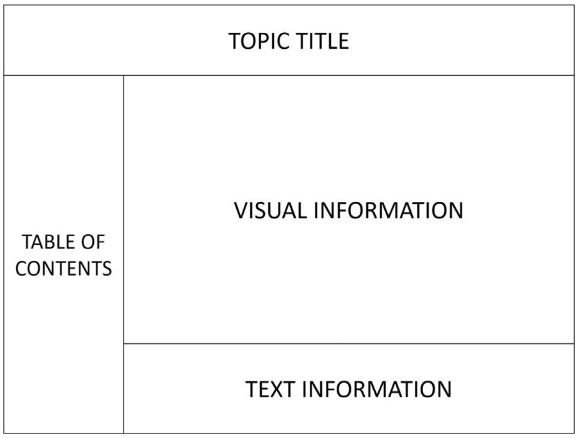

Fig. 7. An example of subdivision of the GUI in the visual mode, deriving from the application of the proposed methodology.

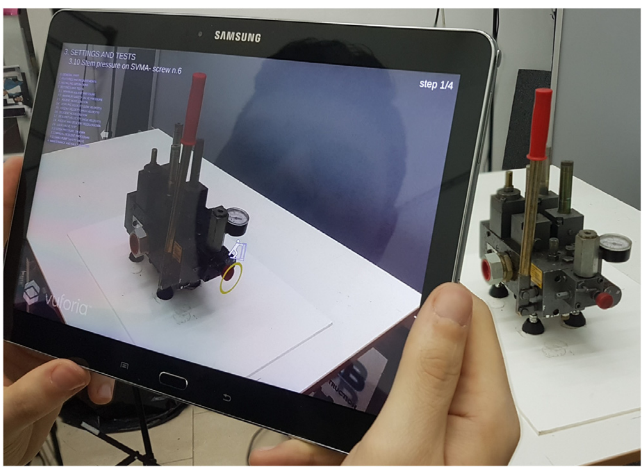

Fig. 8. Example of application of the proposed methodology for the conversion of a real manual in AR.

procedure for the pressure regulation of the stem. It is a task information type with just one step. The action verb is "push" and the object it refers to is "the manual descent button." We neglected the purpose of the action, i.e. "to unload the pressure" because we do believe the operator is aware of this since it is the main goal of this procedure. In AR manuals it is important to provide only the needed information without useless details because they imply the use of text that occludes the real scene and is difficult to relate unambiguously with the rest of instruction provided with visual elements. The verb "push" is conveyed through a 2D symbol with that meaning, while the object is localized highlighting it with a virtual circle attached to the real button. As to the 2D symbol, we explored both the placement in a fixed position on the GUI (on the right) and geo-referenced on the real object. In the first case the authoring is simpler than the other because the symbol should not be aligned to the CAD model, however it implies a higher cognitive load for the final user due to the separation of the two cognitive information about the localization and the action. Furthermore, if there were two or more steps to accomplish in the same instruction, it would be difficult to associate the symbols on the GUI to the related circles on the real objects. For these reasons, we opted for the geo-referenced solution and we made sure that the symbol was always aligned parallel to the camera plane. In the GUI we reported also the titles of the section of the manual and of the procedure, the table of contents, and the progressive number of the instruction in that procedure. As to the textual elements, we used the guidelines provided in the literature [48,49] for text legibility in AR: text color is white with a blue outline. This same style was used for the graphic symbol.

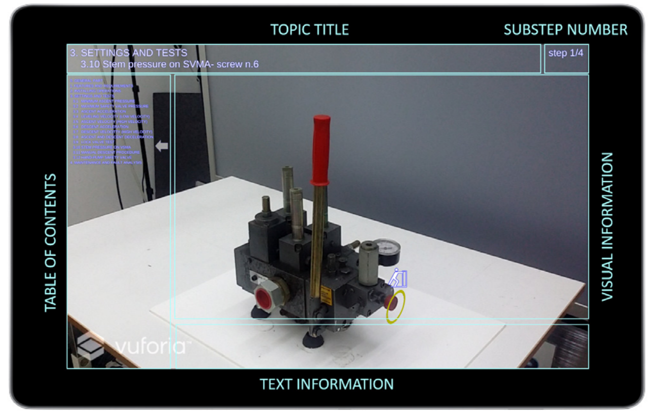

Fig. 9. Layout of technical information in the AR manual obtained using our methodology.

The application, thought for a handheld device, was developed with Unity 3D using Vuforia model target tracking: we did not use fiducial markers, but the application aligns a phantom CAD model of the valve with the real valve. The tracking is stable even moving around the valve with the tablet, as well as approaching and getting away. The quality of the tracking was sufficient for this type of application since we did not show a CAD model superimposed on the real object, then the estimated alignment error of about 5 mm is acceptable. We respected the layout proposed in Fig. 7 deriving from the usage of the proposed methodology (Fig. 9).

A second case study was developed to create a visual manual to be used for the user validation. In this case, we used the manual of "Instructions for use and maintenance of the ITR UEH hydraulic Breakers." The dealer of these hydraulic breakers [50] uses a traditional PDF version of this manual and is interested in its conversion in a novel digital manual. The main reason is that, as reported at the beginning of the manual, "dealers are obliged to have this manual translated into the language of the country where the breaker is used" and that "the Dealer is responsible for the translation, which must be faithful to this version (the only valid version)." Reducing the effort of translation by a manual mainly based on visual elements, would be a high economic saving for the dealer.

We applied the methodology described in Section 2. We started from reading and analyzing the instructions in the manual. Instructions were already chunked into small pieces of information and organized in bullet points. For the case study, we isolated just one example of concept, task, and reference topic. The reference topic chosen was in the section "instructions for recharging the accumulator with nitrogen" at the point "2. list of parts involved," (Fig. 10). The task topic was in the

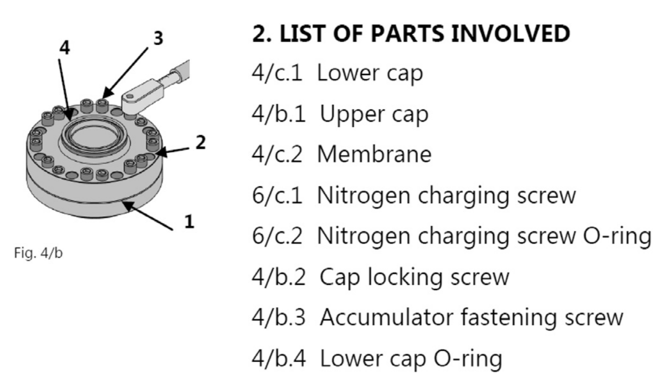

Fig. 10. Reference topic taken from the PDF manual and used for the test; "4/c" and "6/c" refer to illustrations present in other pages of the manual (courtesy of ITR HD).

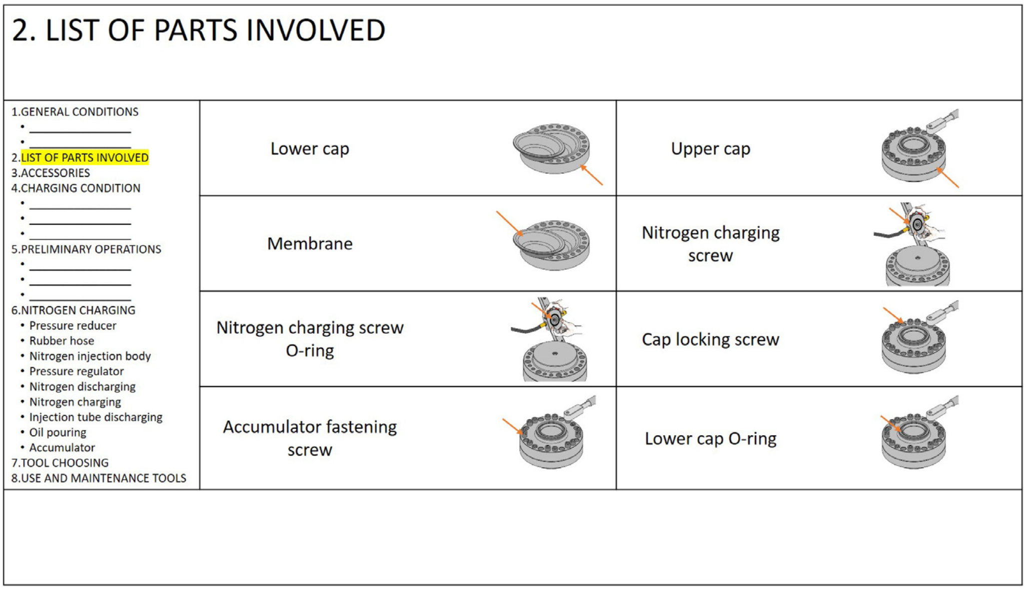

Fig. 11. Example of information organization in a reference topic according to the proposed methodology for visual manuals: there is a greater use of images and information is organized in a table (courtesy of ITR HD).

same section, at the point "6. description and procedure for nitrogen charging,"; this task is made of eleven steps and we referred to the ninth that we felt as that richer of information. Finally, the concept topic chosen was in the section "use and maintenance tools," last paragraph at page 22 .

We then converted these instructions in the visual mode. For the reference topic (Fig. 11), we arranged the list of parts in a table with the name and the corresponding picture of each part in the cells; the pictures were taken from the PDF manual. The task topic (Fig. 13) consists of four substeps, then we divided the middle area into four windows. In each window we reported the following information: i) the progressive number of the substep; ii) the symbol that indicates the action to be performed; iii) a picture of the real components with a yellow square or circle to highlight the part involved in the action; iv) other information as the tool and the final torque. In the concept topic (Fig. 12) we reported a picture taken from the PDF manual and the text instruction was converted in STE: we passed from 102 to 41 words to describe the instruction; furthermore, we chunked the instruction into three small pieces using a bulleted list.

4. Validation

We explored the effectiveness of our methodology designing a test to evaluate user preferences and feedbacks about the conversion of technical instructions in the visual manual created with the proposed methodology. The aim of this test is not to compare Graphical User Interfaces, but to understand user acceptance of instructions mainly based on visuals rather than on text, and organized in a novel manner.

The validation was made comparing:

- visual manual: the three instructions obtained with the application of our methodology, as described in Section 3;

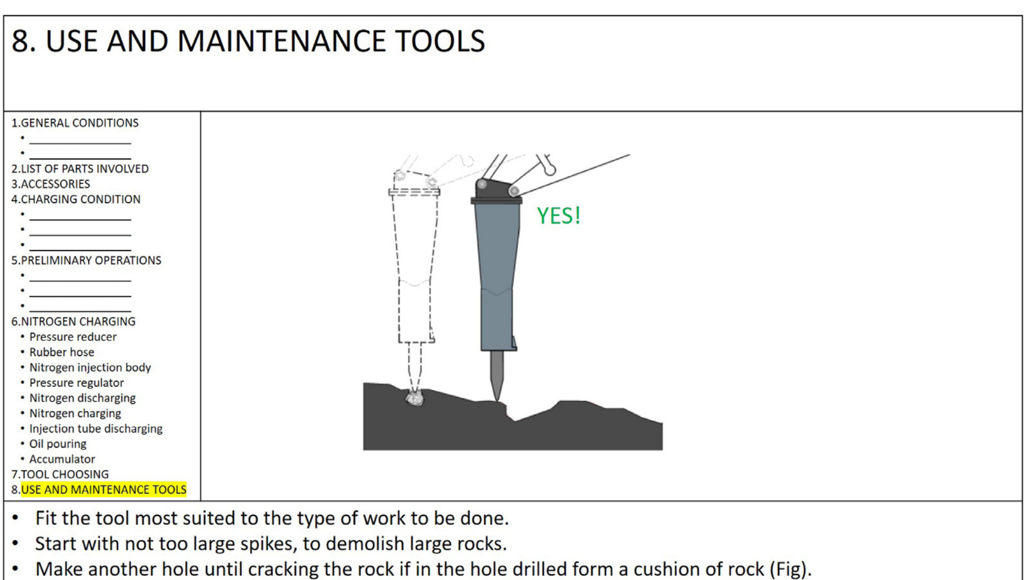

Fig. 12. Example of information organization in a concept topic according to the proposed methodology for visual manuals: there is a strong text reduction and the visual element is predominant (courtesy of ITR HD).

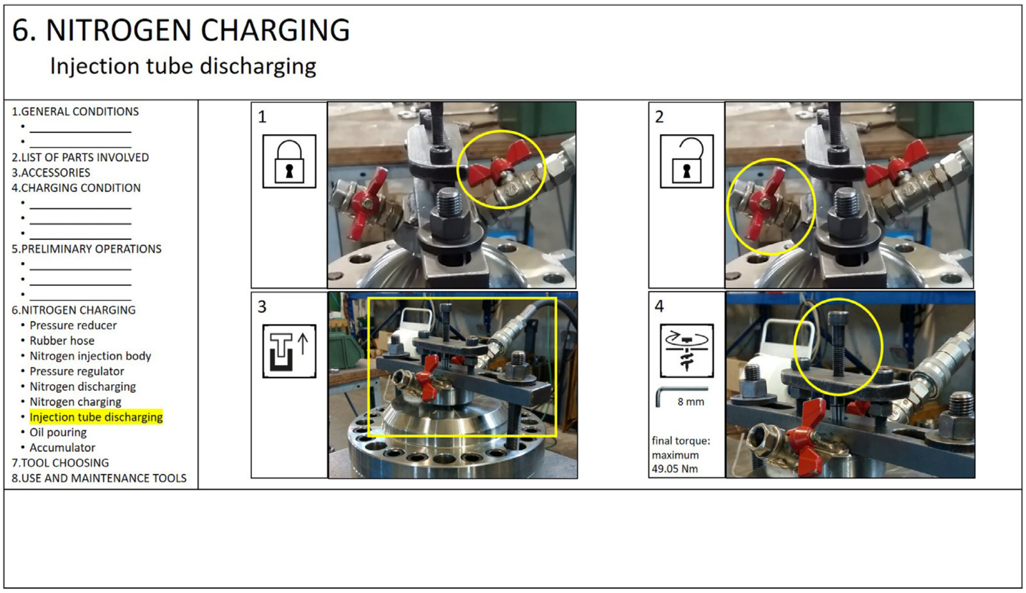

Fig. 13. Example of information organization in a task topic according to the proposed methodology for visual manuals: text disappears almost completely replaced by icons and images used for the localization (courtesy of ITR HD).

- PDF: the original instructions taken from the PDF manual;
- iFixit: the same instructions how they would appear on iFixit (procedure available at www.ifixit.com/Guide/embed/97845)

We wanted to include iFixit in the comparison because is the most common available solution to design visual manuals. For the instructions created in iFixit, we used the same text information provided in the PDF manual, but for the visual elements of the task instruction we used the same pictures of the visual manual, without symbols.

Users had to read the instructions in one of the three modalities (hereafter referred to as "visual," "PDF," and "iFixit") and then fill in a questionnaire about the organization of the information and its layout. In all the three modalities instructions were displayed on a monitor, and for the PDF the portions of instructions to read were outlined by a red frame. The questionnaire is made of seven questions, inspired from Lewis' "Computer System Usability Questionnaire (CSUQ)" [51]. Answers were in a 7 points Likert Scale (1 = "Strongly disagree", 7 = "Strongly agree"). The same questions were provided in each modality and, at the end of each modality, users could write comments about the experience with that type of manual. After that users answered to the questions for all the three modalities, they were asked to answer to other nine questions. The questionnaire, created on Google Survey, is available at https://goo.gl/forms/oXOy61j1duF6Euj13. We setup a Latin Square design of the test to reduce the bias of the order of modalities read. The test was carried out in the laboratory on the same screen for all the users.

22 users volunteered for the experiment, 18 were males, and the average age was 36.5 years old (SD = 13.7). Half of the users were workers; the other half were undergraduate students. In Table 2 we reported the median values of the scores given by the users for the seven main questions of the questionnaire. We used Kruskal–Wallis test (confidence level 95%) to understand if the differences among the three modalities were statistically significant or not. The test revealed that for Q3 ($\chi^2(2) = 8.195$; $p = 0.017$), Q4 ($\chi^2(2) = 8.860$; $p = 0.012$), and Q5 ($\chi^2(2) = 6.604$; $p = 0.037$) there are statistically significant differences among the scores of the users for the three modalities. According to the users, with the visual modality, organization of the information is significantly clearer than with PDF modality. Users considered significantly less pleasant the layout of the PDF modality. Finally, they preferred using the layout of the iFixit modality. It is also interesting to note that, considering only the workers, for none of the questions there were statistically significant differences.

Table 2
Questionnaire answers (1 = Strongly disagree, 7 = Strongly agree).

	iFixit	PDF	Visual
Q1) It is easy to find the information I need.	5	5	6
Q2) The information provided with the system is easy to understand	6	5	5
Q3) The organization of information on the system screens is clear	5	4	6
Q4) The layout of this system is pleasant	5,5	4	5,5
Q5) I like using the layout of this system	5,5	5	5
Q6) This system has all the functions and capabilities I expect it to have.	5	5	5
Q7) Overall, I am satisfied with this system.	5	4	5

As to the second part of the questionnaire, Kruskal–Wallis test did not reveal statistically significant differences: users did not show particular preferences for the modality preferred both to read and write technical documentation. Table 3 reveals that users felt that, both with the iFixit and visual modality, there was missing information respect to PDF modality. This result is more evident for the concept topic, where there is a strong text reduction with the STE conversion: 13 out of 22 users reported that visual modality has missing information. It is also interesting to note that for the task topic, among the 9 users which reported that visual has missing information, 7 were workers, whereas among all the 3 users that reported that PDF has missing information, nobody is a worker.

Users reported many feedbacks about their experience with the three modalities. We clustered their comments and reported them in Table 4, distinguishing between improvements, criticalities, and remarks. Criticalities concerned only the PDF modality: users found

Table 3
Users' answers about perceived missing information in the three types of manual.

	Reference	Task	Concept
"iFixit" has missing information	2	5	7
"PDF" has missing information	1	3	1
"Visual" has missing information	4	9	13
Same information in every modality	15	8	4

Table 4
Users' comments regarding improvements, criticalities, and remarks concerning the different modalities.

Modality	Comments	N. of users
iFixiit	**Improvement**: *relate the figures with the specific text*	3
	Improvement:*increase the number of information*	1
PDF	**Criticality**: *repetitive information*	5
	Criticality: *unclear information*	2
	Criticality: *too few graphic contents*	2
	Remark: *it is important to know the meaning of the symbols*	5
Visual	**Remark**:*it is important to know the meaning of the symbols*	5
	Improvement:*this modality could be improved with an appropriate design of the GUI*	3

information repetitive and unclear due to its organization in the manual. As to the visual modality, users remarked how it is crucial to know the meaning of the symbols used. For this reason, before the test, we trained users telling them the action verb associated to the symbols. In fact, we feel that if this system would be used in the industry, the set of symbols should be standardized, and operators would easily associate tasks to symbols after an initial training.

5. Discussion

This work follows the path that technical documentation is taking in the last years: use of digital supports, more visual elements and less text. The state of the art about digital technical documentation, in a visual form, is represented by user-generated content strategies, whose most relevant example is that of iFixit [12]. Though this kind of documentation is available, it still does not exploit the potentialities of Augmented Reality, since visual graphics rely on illustrations or video recordings. Furthermore, it does not consider how technical writers have produced documentation till now.

The resulting documentation obtainable with our methodology can be compared with that obtained with other methodologies available in the literature. Differently from Mohr et al. [14], our methodology is not automatic, but it is applicable to all types of documentation even those with much text and few images. Furthermore, in addition to what made by Engelke et al. [7], our methodology focuses on all the types of instructions (concept, task, reference) present in a manual and aims at text reduction.

In the development of our methodology, we made sure that the produced documentation would be compliant to Industry 4.0 design principles. In the following lines we discuss how our choices allow the respect of the six design principles of Industry 4.0.

Interoperability: the use of standards both for text information (STE) and visual elements (symbols) facilitate the communication between machines and humans.

Virtualization: the documentation created with our methodology is in a digital form, so it could be linked to a monitoring system of the plant that provide the needed documentation in case of failure.

Decentralization: the organization of documentation in topics, allows the creation of automatic maintenance procedures that the embedded computers on the machines produce when asked by the operator.

Real-Time capability: the virtual elements displayed are associated to a database of the product thus, updating the product, also the documentation will be updated.

Service orientation: the bases of our methodology allow the organization of maintenance procedures as a service: for example, the use of symbols and STE could be used for a remote maintenance service.

Modularity: the documentation produced with our methodology does not have the classic form of a rigid manual with an index, pages, and so on. It is a collection of modular topics that could be arranged according to specific requirements (e.g. change of product characteristics).

We tested our methodology applying it to instructions taken from a real maintenance manual of hydraulic breakers. We made a validation of the developed visual manual through a user study. Users reported that, with the proposed visual manual, organization of information is clearer than with PDF version of the manual. Furthermore, users found the layout of the PDF manual less pleasant, and information was repetitive and unclear. The main reason of this result is that, in the PDF manual, illustrations, if present, are often not in the same page of the relative text instructions. This event does not occur in the visual and iFixit manuals thanks to the respecting of the rules of structured writing. These results confirm the potential of our strategy to overcome the traditional templates, as PDF. Users are still not aware of the potentialities of this shift, since they would use indifferently one rather than another manual for both reading and writing technical instructions. Furthermore, even if companies ask for novel digital manuals, they still require also a printed version of the manual, mainly for legal purposes. For these reasons, our methodology allows technical writers to compile also a printable version of the manual. The organization in topics permits to assemble the manual in a customizable way and the separation of contents from styles allow the using of different output styles for AR and paper mode, for example regarding visual elements.

Another interesting finding is that, in visual manuals, text reduction, produced with the use of STE, made some users feel there was missing information. But the conversion in STE was made by a technical writer of the company who ensured to include all the needed information, so there is not actual missing information. This outcome is due to the visual impact of perceiving much less text by users. In our future studies we will test the comprehension of information with visual manuals obtained with our methodology, compared to traditional templates, measuring users' accuracy and times in executing a task.

6. Conclusion

In this work we proposed a methodology to support technical writers in the creation of technical documentation suitable for Augmented Reality interfaces. Following this methodology, it is also possible to convert in AR the large amount of existing documentation on traditional PDF templates.

We applied successfully this methodology to two case studies taken from real maintenance manuals. Our methodology allows the creation of visual manuals accessible both in AR and not. This is a great advantage for those enterprises that are not ready for the introduction of AR in their facilities, but want to adequate their documentation to Industry 4.0.

We validated the layout of information in the visual manual obtained with our methodology with a subjective user study. The results showed that, with visual manual, organization of information is clearer than with PDF version of the manual. However, users felt there was missing information.

In future works, we will create an optimized GUI for the visual manual. Then, we will evaluate accuracy, scalability, and user friendliness of the final interface, as suggested by Navab [52].

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