Generic model for international assembly instructions for special machinery assembly

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INTRODUCTION

Knowledge transfer is a tremendous task for the assembly of complex products while increasing the production share at a new location, because no or little experience about the new product's assembly processes is available at the new site. Companies are facing high costs for exchanging trained and qualified workers to the new facilities in order to increase the knowledge and skill level of the partners of the abroad location (see *Fig. 1*). Increasing the knowledge level means in this context to enhance the theoretical understanding of the assembly and increasing the skill level means to expand the proficiencies in assembling a special product. Taking a multitude of cultural and organizational issues like mental models, different languages and software availability into consideration, the task of knowledge transfer gets complex.

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In addition, the information to be transferred has to be understood in the same way in both countries. To cope with this challenge, the usage of models seems to be promising. Models are abstracted representations of the reality which show only the relevant issues to the learner. One suitable model for the purpose of knowledge transfer for assembly between different countries is an assembly instruction. A generic structure for documenting respective assembly is presented in this paper. The structure is validated and evaluated on the example of large scaled compressors, at which the local production share worldwide and especially in the BRIC states shall be increased. The arrow in *Fig. 1* shows, how the knowledge level of the workers is increased, first by help of the assembly instruction to create a basis on which in a further step the skills of the workers for the assembly of a certain product are increased through training. The feedback about the created instruction of the workers of one of the abroad sites is evaluated.

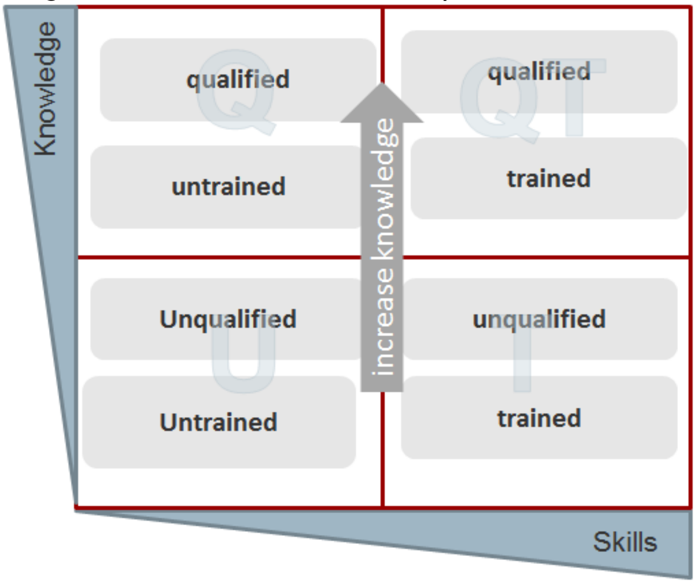

Fig. 1, Knowledge-Skill Framework [1]

1 STATE OF THE ART

1.1 Information- and Communication (ICT) based methods

In a ***Virtual Reality (VR)*** a person is “surrounded by a three-dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it.” [2] The user can wear a Head Mounted Display (HMD) or enter a special room to get a 3D-visualization. The technologies used to interact with these digital objects are under development by companies and research institutes like the Fraunhofer Institute for Production Systems and Design Technology (IPK). At the CAVE™ at Fraunhofer IPK in Berlin, five projectors are displaying pictures of a virtual object from the outside onto five permeable surfaces of a cubic room. The user stands inside of the cube and gets a three dimensional view of the virtual object while wearing a HMD. [3] VR can be used for assembly instructions in the form of Computer Aided Design (CAD) exploded views. Using CAD-pictures instead of photographs reduces the amount of information to the required level, because no environment distributes the reader from the important information about the assembly parts. “The development of ***Augmented Reality (AR)*** technology initiated in the 1990's as a parallel technology from VR. In AR, virtual objects are combined with real surroundings, seen with the human eye. The augmented view is for example projected to a computer screen or a miniature PC, or seen through data glasses.” [4] Big application can be found in simplifying maintenance, repair and assembly of components. [5] The Technical Research Centre of Finland launched in 2006 a project about augmented assembly, where the user has a helmet with an implemented camera and a second device with a small screen in front of his/her eye. In case he or she needs to assemble a part, the AR-screen on the HMD shows the assembly steps. The helmet-camera recognizes the assembly object, its orientation and its distance to the worker. The camera sends the information via cable or wireless technology to a stationary server, where the CAD-data for the assembly, the instructions and the software for the program are stored. The program recognizes which assembly step follows next and sends the information about the part to a personal computer (PC). This PC stores the information about the product in front of the worker and about the CAD-data for the next part to be assembled. The PC calculates where the CAD part needs to be assembled in real world and displays this information on the workers HMD. Additional information like tightening torques or the direction in which the component needs to be moved is provided. One approach taken by the collaborative research center 1026 at Technische Universität Berlin is a ***human motion capture technology*** which can improve the efficiency of a manual assembly process while enabling ergonomic working. By help of a so called qualification module, intuitive work descriptions can be generated and distributed. The qualification module consists of a combined pose-recognition module with a learning module for assembly sequence definition and control. [6] By adapting the learning content according to the individual performance of the worker, the authors suggest to avoid a cognitive overload. By comparing the behavior of the worker during assembly through motion capture technology with predefined times according to Methods-Time Measurement, the performance of the worker is measured. Furthermore the error free assembly of the working piece is ensured by motion capture technology. The assembly instruction is displayed step by step on a screen located at the manual assembly workplace. Only if the worker performed the right assembly step, the instruction for the next step will be shown to the user. The instruction utilizes textual and language independent graphics as well as visual representations of the working system for every individual assembly step. [7] This technique can be combined with e-learning and e-teaching technologies, which allows a global, location independent learning. [1] [8] ***3D-Portable Document Formats*** *(PDF)s* are an easy way to show how a finished product looks like. CAD data gets converted to a portable format. The device for showing the 3D-content only needs standard and free software like Adobe Acrobat and no CAD software. The 3D-model can be rotated freely with a mouse and parts can be faded in or out. When animated, the 3D-PDF reveals itself as a tool suitable to be used as an assembly instruction. With JavaScript explosive drawings and animations generated with a CAD program or a comparable tool are linked with buttons in the PDF. By clicking buttons users can easily move from one assembly step to the next. While the animation is displayed, the user is still able to rotate the CAD part and zoom into the document freely.

1.2 International understandable instructions

If an assembly instruction shall become international understandable, the usage of words is not suitable. Possible options on making knowledge accessible beyond the limits of language are photographs, CAD-pictures, videos, 3D-PDFs, pictograms or Blissymbolics. ***Videos*** show how to assemble a part without the need of words. If the assembly task gets more complicated, additional information like tightening torques has to be added to the videos, which makes it more difficult to keep it on an international understandable level. Another way is the usage of pictograms or Blissymbolics. "***Pictograms*** are descriptive symbols that illustrate information." [9] They can be used to provide the reader very fast with important information. A research about safety pictograms shows "that pictograms are more noticeable when used with text and similarly that pictograms increase the noticeability of a text message." [10] Therefore it is suitable to use pictograms for assembly documentations when special content needs special attention, e.g. safety instructions. Beside the usage of pictograms, ***Blissymbolics*** are another form of simple visual communication. The visual language "Blissym", invented by the chemical engineer Charles K. Bliss, was intended to be used as a "universal written language which would enable speakers of different languages to communicate with one another." [11] The main use since 1971 is to help people (especially children) with communication, language and learning difficulties, which have limited or no “ability to use ordinary spoken and/or written language but manage to learn Blissymbolics.” [11]

1.3 Examples for different assembly instructions

Table 1 shows examples for assembly instructions. The assembly challenge is increasing with each of the mentioned instruction.

Table 1, Brief comparison of the analyzed assembly instructions

Instruction:	Kinder Egg	Lego	IKEA	Repair Manual
Assembly level:	simple	simple-medium	simple-medium	medium-complex
User age:	3-10	3-99	16-99	16-99
User knowledge level:	low	low-medium	low-high	medium-high

The so-called ***“Kinder Egg”*** provides its young customers with one of the simplest assembly instructions. A picture of the completely assembled toy is shown and pictures illustrate in two to ten steps how to assemble the included toy. The parts only need to be patched together without the need of tools. Therefore, it is possible to provide customers with an easy assembly instruction only consisting of pictures. An example for a complex product are the toy bricks from ***Lego****.* They are delivered with an easy understandable assembly instruction with no need for words. That makes it internationally understandable. Most of the Lego bricks stick together with two basic components: studs on top and tubes on the inside. The only information needed for this simple method is where to position the bricks. This can be transferred easier by pictures than by text because one can spot, where the bricks shall be positioned. Finding the differences between two pictures of two assembly steps is possible without the need of words and therefore understandable in every language. Standardized ***IKEA*** assembly instructions are more complex and technically more developed than the instructions from Lego, but they are still easy to understand. The assembly instruction of the IKEA BILLY bookshelf [12] is examined as an example. Pictures of all parts and tools and their quantity and an identification number are shown. Easy understandable pictograms visualize how to assemble the parts. No additional text is needed. If the unlikely possibility is given that a part could be assembled in a wrong direction, both directions are shown in a magnification and the wrong direction is marked out by an X. If a screw is used, the screwdriver is shown together with the screw. A pictogram in the form of an arrow implies the rotational direction of the screwdriver. For special assembly steps, where the user needs additional information, a pictogram is shown with the information that further instructions can be found on a special sheet. As example for technically high-developed products, a ***repair manual*** for a go-kart-engine [13] is analysed. Beside legal directives, the table of contents, general advices, explanations of symbols and further technical information, a visual bill of material for special tools and fluids are given in the beginning. Main assembly steps divide the instruction into segments for the biggest parts. The first minor assembly step can be seen as the removal of the engine. They consist of CAD explosion drawings with numbered parts or photos of the parts as well as written assembly instructions. Different levels of information are shown by five symbols for *Warning*, *Attention*, *Hint*, *Working Step* and *Quality Check*. These symbols help to find the desired content, because they give a visual help to differentiate the five types of content. This repair manual is in the same well-structured and easy understandable layout like other manuals from the creators company and therefore standardized.

2 GAP

By this time there is no systematic approach on how an assembly instruction in the field of special machinery should look like, especially not, if the knowledge is transferred between countries of different languages. Compared to serial production the number of produced units per product is much lower in special machinery production. Therefore, the assembly instructions should be suitable for different product variants and easy and fast to understand. A long learning curve is not possible as for the mass production since most of the products have to be assembled first-time-right. A standardized layout is necessary because workers assemble many product variants and need to know how and where to find information.

3 CONCEPT DEVELOPMENT

3.1 Social and organizational requirements

The value creation module, presented in *Fig. 2*, shows the five value creation factors and how they influence each other. The following requirements for the assembly instruction are derived by the value creation module: The ***product*** has to be shown within the necessary assembly steps, visualised by photos, exploded views, CAD pictures, CAD videos and drawings as well as descriptive text. ***Organizational*** requirements are the time needed for assembly steps, necessary documents, required time and the number of workers needed for each assembly step. A requirement for the ***equipment*** is that all the tools and measurement instruments are available for the assembly. This has to be ensured before the assembly starts as well as that each tool fulfils the specifications necessary for the assembly. The assembly ***process*** of the product is centred in the middle of the above mentioned factors. The instruction should contain a way for the workers to check whether they assembled a part in the right way. A challenge on the ***human*** side for international knowledge transfer is not only the language but also the cultural differences between the countries. This includes the usage and understanding of different colours, symbols and pictograms as well as the reading direction.

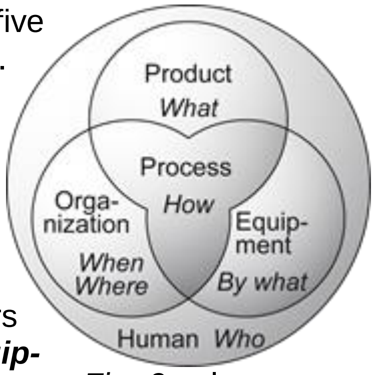

Fig. 2 value creation module [14]

3.2 Requirements for special machinery industry

Compared to mass and serial production, the industry for the production of special machinery has different requirements for assembly instructions. The production of special machinery is a one of a kind production and the product has to be first time right. Workers need a lot of additional knowledge and experience compared to serial production. Much information has to be transferred to the worker in a very short time. A lot of tacit knowledge and experience has to be transferred from the mind of the workers of one plant to a document and then to the workers of another plant.

3.3 Specific requirements for the MAN Diesel & Turbo plant in China

As an example for special machinery the specific training material needs of the MAN Diesel & Turbo plant in Changzhou (MDT-CZH) are presented. All Chinese workers at MDT-CZH have different levels of knowledge. Therefore, the assembly documentation has to be easy to understand without background knowledge. ***Assembly time***, ***number of workers*** and ***necessary tools*** for different assembly steps give essential information to plan ahead how to use resources for the assembly. ***Special documents*** like drawings and records have to be presented for every assembly step to ensure the workers are able to find additional information. *A* ***visual impression*** of each assembly part is needed to help the workers to kit the necessary assembly parts for the next assembly step. They can tick all the already assembled parts on the paper to ensure everything is assembled. CAD-***videos*** help to get a better impression of the parts and the way of how to assemble them. To ensure a high level of

quality, checkpoints have to be set up. These quality checkpoints show special working steps which could be easily forgotten. They are essential to ensure a good quality or give the workers additional information on how to perform a quality check. ***Pictures*** deliver a high quantity of information and show things more easily to people with different background knowledge and education than text. They help to understand connections faster and more easily. The ***text*** of the work instruction additionally helps to understand the pictures in a more detailed way. Ensuring the ***health and safety*** of the employees is one of the biggest concerns of MAN. ***Pictograms*** together with descriptive texts have been used to emphasize important safety content.

3.4 Generic assembly instruction structure

The developed structure is created on the basis of the value creation module. The first part of the structure consists of general information presented on the title page, table of content and on a general information page. Information about *product* and *organization* is gathered here, like a CAD picture of the compressor, the assembly time, an identification number for the Product-Lifecycle-Management (PLM) system, purpose and terms and the scope of the assembly. The assembly is divided into main assembly steps. The decision where a main assembly step starts and ends differs from product to product. For this structure a new main assembly step starts after a big part or assembly group. Each main assembly step represents three fields of the value creation module: *product*, *equipment* and *process*. They are represented on differently designed pages. The level of detail increases within each main assembly step. In the digital version of the instruction a CAD-video is implemented for each main assembly step to increase the understanding of the general assembly process for unexperienced workers. The next page shows an explosion drawing of the parts to be assembled (*product*) and lists the needed *equipment*, assembly time and number of workers. The exploded parts are always oriented in the same way to increase and facilitate the object recognition value [15] and to additionally minimize accidental alignments. Dotted lines indicate where the parts fit together. The explosion is not intended to explain in detail how to assemble the parts, because “people prefer instructions that present the assembly operations across a sequence of diagrams rather than a single diagram showing all the operations.” [15] All information needed to prepare the next main assembly step is gathered on this page. The following page gives a visual representation of the required *equipment* with the help of photographs and names of the tools. This helps to minimize translation errors. The assembly *process* is described on the next pages, so called minor assembly steps. Each page is divided in three sections: *equipment*, quality checkpoints and *process* description by pictures, pictograms and by text, including safety instructions. The text helps untrained workers to understand the process together with the pictures in its complex details. More experienced workers can focus on the pictures. As example the Blissymbol for “time” is used to show that an assembly pressure has to be hold for a specific period of time. The last part of each main assembly step is shown on a page for so called escalation steps. They show how to deal with already known problems, where a problem avoidance strategy has not been implemented yet. This information is intended as a basis for a continuous improvement process.

4 IMPLEMENTATION

4.1 Assembly documentation for large scaled compressors

The value creation factor *human* gets important for the implementation of the instruction. For the quality checkpoints a red background is used to attract the readers’ attention. In Chinese culture the colour red is often associated with luck and strength which was used to emphasize the meaning that if the quality checkpoints are fulfilled the company is blessed with luck and a strong product. The cultural understanding of colours implemented in this assembly documentation has to be checked, if the documentation should be used in other countries than Germany or China. Health and safety instructions are implemented by pictograms on the concerning pictures and pictograms with an explanatory text. The work instruction mentions until which part weight it is allowed to manually lift the part and when and how to use lifting devices.

4.2 Worker's Feedback

The assembly workers at MDT-CZH have been asked to give a feedback about the assembly instruction after working for two weeks with it. The feedback from the Chinese workers has been very positive. According to their opinion, the instruction is designed very well. They appreciated the high number of photos and CAD pictures, because this makes it easier for new apprentices to understand the function of the parts and how they look like. 2D drawings are harder to understand. The pictures helped them to prepare the workplace and the tool arrangement in a more structured way. The pictures helped them additionally to execute the assembly process in a more efficient way. Some of the workers even wanted more pictures. It was easy for them because of the pictograms and different colours to find important information about quality and safety issues. They had no problem identifying the colour red with high importance which is different to the original meaning in the Chinese culture. Compared to other company instructions most workers said that the newly created instruction is "more detailed and has hints for tools […] and shows where special attention is needed. This will help to prepare the work and improve work efficiency."

5 SUMMARY AND OUTLOOK

The paper aimed at the establishment of a generic structure for international understandable assembly documentations for special machinery. Therefore the state of the art of ICT based methods for knowledge transfer and international understandable assembly instructions was analysed. Exemplary assembly instructions were compared towards the assembly level, the user's age and the user's knowledge level. The authors identified the need for a systematic approach for the arrangement of assembly instructions in the field of special machinery. The developed standardized assembly structure uses three-dimensional explosion drawings, pictograms, Blissymbols, colours and pictures to increase international intelligibility. For each main assembly step, all necessary information is gathered on one page. Three-dimensional explosion drawings help to understand how the parts generally fit together. Tools are shown by pictures and names as well as other product specific information. Hereafter, a more detailed assembly instruction follows, where assembly information for different purposes is consistently located which makes it easier traceable. Important content is emphasized by pictograms and different colours. Escalation steps show how to deal with known assembly problems. Additional text is only shown to ensure the pictures and pictograms are understood right. Further research has to be conducted in order to create an instruction completely without the need of text. An investigation towards the use of interactive 3D-PDFs seems to be attractive.

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