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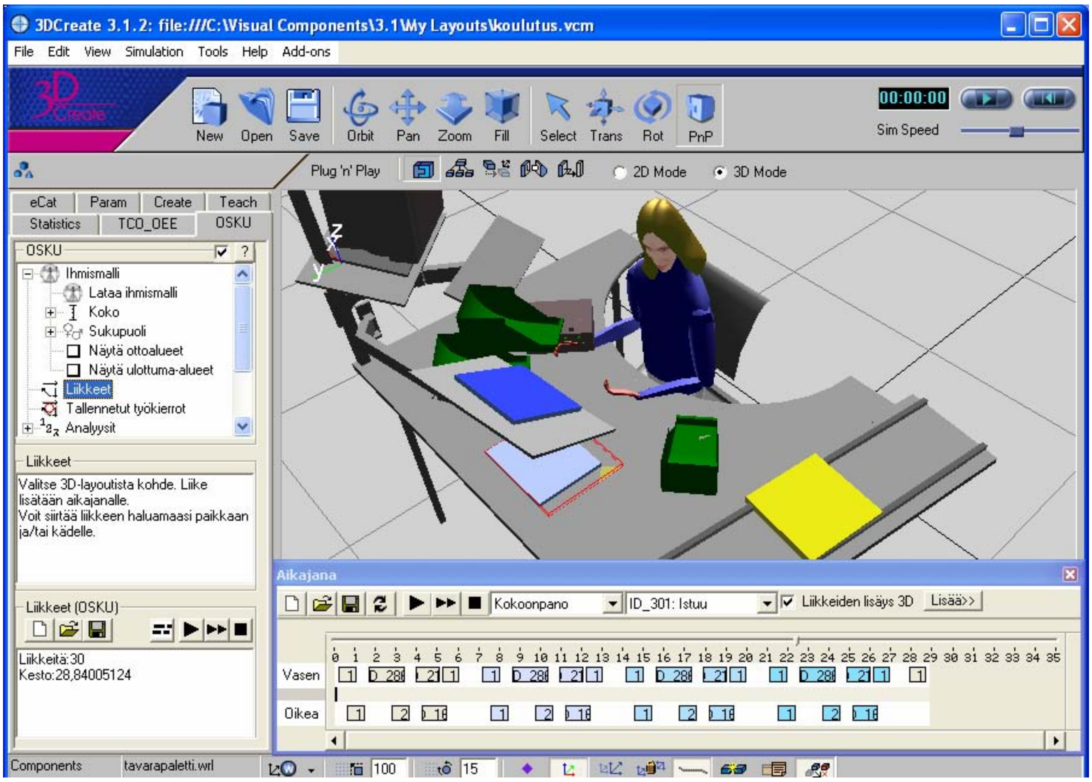

OSKU
Digital Human Model in the Participatory Design Approach

A New Tool to Improve Work Tasks and Workplaces

Kaj Helin, Juhani Viitaniemi, Susanna Aromaa, Jari Montonen, Teemu Evilä, Simo-Pekka Leino & Timo Määttä

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Title

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Abstract

The goal was to improve manual work tasks and workplace design. The objective was a new digital human model based participatory design approach, and as an implementation a tool, to be used concurrently with production design. It was emphasized that even an ordinary worker would identify workplace and work task problems and perhaps could produce illustrative alternative 3D solutions to control physical human load and to increase the productivity.

The developed tool exploits a production design simulation software platform. The OSKU tool includes basic human motions as an expandable database, and embedded ergonomic analyses, either timeline or sequent based when possible. It includes also additional checklists to assessing other ergonomic and workplace point of views. One can produce and compare alternative solutions for human work and production and evaluate their added value with each others. Thus human work, working environment, machinery, and production can be concurrently designed with exploiting the participatory design approach, too. The developed OSKU method benefits of participatory design method, which in collaboration with industry has been implemented to fit 3D modelling and simulation. It is focused on obtaining the end user and other shop floor level employees' experiences, tacit type information and skills to benefiting the design of work, workplaces and production concurrently.

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Preface

This report gives an exposition of the application of advanced, digital human model developed for participatory approach to improve work, work tasks and workplaces. The particular application case addressed is common semi-automated production system having a single place of work or a shop in bulk goods manufacturing industry. The basic method exploited is participatory approach, both to design and development, and to ergonomics, that rely on actively involving workers in implementing experiences, skills, knowledge, procedures and changes with the intention of improving product, production and work related factors such as equipment, environment, safety, productivity, quality, usability, comfort, and conditions. The developed digital human model tool bases on the real human motions. First the specific motions are recorded, processed, and analysed. Then this information is embedded into basic motion data, and finally composed to an expandable database. The tool includes useful means for evaluation of work task and workplace ergonomics, and for safety assessment, too.

The study was carried out at VTT in cooperation with four Finnish forerunner companies. The results belong to continuum of several previous research projects launched to develop new methods for system based simulation of human technology interaction with the aim set at producing generally acceptable and valid applications to meet the needs of concurrent product, production and work related design and development within the industry and other stakeholders.

Acknowledgments to steering group members Peter Rehnström from The Finnish Work Environment Fund, Jukka Turunen and Edvard Frisk from Ensto Busch-Jaeger Oy, Kari Leivo and Aki Savonen from Enics Finland Oy, Jukka Koskinen and Tomi Eskola from Oras Oy, Ari Honkanen, Mika Suoja and Pekka Horsma-aho from GWS Systems Oy, Risto Kuivanen and Jari Karjalainen from VTT, whose guidance during the study are highly appreciated. Grateful acknowledges go also to industrial members Mika Malo, Reijo Kallio and Kalle Koutajoki for their inspirations of practical approach and constructive criticism during study.

Compliments for implementing the ideas as a tool goes for Jari Montonen, who has produced the tool and motion database. Compliments for recording, composing and analysing the real human motions as motion database goes for Kaj Helin. Thanks for Susanna Aromaa, Heli Riikonen, Marjo Liusvaara, and many others whose motion samples are tracked and added into motion database. Special thanks for Timo Salmi, who in cooperation with authors has given support to obtain initial data from industry during study execution.

Authors

Contents

1. Introduction

Since the ages work was constructed differently, mostly individually to fulfil human's own basic needs. Nowadays work from a commissioning basis is usually beforehand planned at least to a level able to make comprehension about payment of work. The work of bulk production takes more consideration. Occupational health and safety deployment has fostered and carried on work conditions nearly two centuries. A century ago was a start for boom to development of accident prevention techniques, and to the advancement of safety engineering as a profession. Ergonomics became important during the Second World War since it was met serious problems with machinery and military equipment to be operated and controlled properly, efficiently. Investigations on new technologies and their possibilities such as large-scale systems design, simulations and evaluation have been keen of substances last half a century (Woodson 1981). Wilson and Corlett (1990) give an exposition about the usage of ergonomics or human factors to improve work and workplace. From 1980's computer aided methods have been more generally adopted to industrial work development. Also several approaches, ergonomics, occupational hygiene, or chemicals risk prevention, have been in major role to tackle new challenges in work and workplaces in modern industry.

The exploitation of information technology has rapidly expanded. Especially the areas of data collection, analysis, simulation and modelling of work, working conditions, workplaces and production systems, have increased to support design and development. However, the design approaches generally applied have different interests depending on either the design focus is generally on production equipment or on activity system of an individual workplace on shop floor level.

Now new challenge in work and workplaces has been met; during last couple decades work became more and more mediated by computers and applications of information technology. Moreover the systems are becoming more complicated to be well understood or controlled by a human in situations under continuous change. New approaches for design, training and practising are required.

1.1 Design of work and workplace

The modern design process of production systems concerning also the actual work in the shop floor level is a complicated process. However, even nowadays the design is commonly based on taking account efficiently technical and cost based limitations. It is common that priority of human factors catering come after the technical design problem solution (Launis & Kiviluoma 2001). Safety, ergonomics and usability are important part of the design and they should be acknowledged in the design process concurrently with other aspects (see e.g. standards SFS-EN 614-1&2, SFS-EN ISO 6385, SFS-EN ISO 13407, SFS-EN ISO 9241-11). Without doubt the design process benefits of the information and knowledge transfer between all involved persons such as designers, production schedulers, job planners, management, workers, ergonomists, and occupational safety and health professionals.

The production system equipment, devices, and machinery for example are in best case design following the company's adopted human-centred design (SFS-EN ISO 13407) processes for interactive systems, and other recommended principles for the design of work systems as well as possible. However the fact that designers have followed these design approaches don't automatically ensure compatibility, feasibility or other properties of these commercially available equipment to fit or meet the goals and requirements of an individual company and its specified production. The actual work in every company will have not only variations but also clear differences compared to the user requirements implemented to the design and manufacture of equipment to be exploited as a part in a production system.

The each equipment in company's shop floor level production system should be able to composed and implemented to fulfil the actual work and activities in an individual company. Usually the participatory approach is a feasible method and applied. However, in order to encourage the companies themselves to assess, evaluate and ensure of the influencing factors, there is a need in companies for simplified tools to concurrently make the design, development and evaluation of their production systems. This is in clear accordance with the participatory approach principles, too.

There is strong argument for a participatory approach to ergonomics at an individual and organisational level in workplaces (Wilson & Corlett 1995). The participatory development groups consist of workers, experts and decision-makers and it has been increasingly used in industrial cases to develop work. Also professional teams who are responsible of their own work development have been used. The trend seems that also ordinary worker will be more responsible for development of his or her own work and working environment. At the same time when workers responsibility and influence possibility increases workers will be more committed to their work.

1.2 Research for modelling the human in work

Already in the late 1960's and early 1970's, several attempts were made to model the human (Hidson 1988). Because of lacks in computer graphics and display technology in those days, the computer models usually relied heavily on computing the position and motion of the digital human model with a very limited display support. To intensify work place design several different type of computer aided digital human models has been developed and implemented since (Chaffin 1969, Kroemer 1972, Väyrynen et al. 1985, Porter 1992, Chaffin 1992, Grobelny et al. 1992, Launis & Lehtelä 1992, Chaffin et al. 1999, Leino et al. 2002, Helin et al. 2005). Specific digital human models are available for examining e.g. physical factors such parameters as reach, physical clearances, effects of selected encumbrances, and vision. However, many of them are not feasible to ordinary designers either because of their poor availability, high (operation) costs or hindrances because of software limitations. Moreover only few of them actually include adequate variety of versatile assessment methods for practical workplace development. A common requirement is that also such special knowledge may be needed to use these digital human models in accurate way that ordinary users find insuperable difficulties with them. Although models can be very complex and accurate they seldom have same varieties of natural movements as real human being.

Virtual environments have been applied to model production systems. The digital human models have been used to transfer real human motions to digitised motions. Motion capture systems can help to obtain and record real human motions as they are performed in activities related to use cases. However the virtual reality systems are also high in costs and need special expertise to be used. The recorded motions can be reused in design and development by many ways (Määttä et al. 2003, Evilä et al. 2006). However virtual reality approach differs from pure desktop type of approach to exploit digital human model. In virtual reality based exploitation the digital human model is basically assisting and a mean to complement real human based assessments e.g. observations. The desktop based exploitation of digital human model is relying on the chosen method to do the modelling. A typical method is that the designer does the modelling by selecting all the motion intermediate point and joint values of limbs. There might be assistive postures modelled to be selectable for staring points or ending point of the motions. The most advanced digital human models do have also calculation of stability impacts on the motion parameters and values. There exist both kinematics and kinetic based digital human models. However the analysis of motions in many cases is based on simplified sequential posture like static analysis.

1.3 Previous studies made on digital human modelling

At VTT the research on the subjects for digital human modelling has started two decades ago leading to research team establishment. The interest of industry towards the research team studies has been active. However, only seldom the industrial partners in Finland have been keen enough to actively and continuously contributing to the research of digital human models, which has had affects to progress. Achieved results have been well moderate but yet without feasible tools aimed especially for usage of end users.

However the research team has gathered wide experience of different digital human models and about their properties and feasibilities into industrial development cases. In order to avoid too idealistic view and the non-relevance of the omnipotence considering the digital human models capabilities to anticipate or predict by simulation the actual work for days or hours in advance, we have to be still content with short moment or event based simulations. This is also very true because of the humans' non-causal behaviour. On the other hand this does not neglect the benefits available by using digital human models to development of work and workplaces.

The significant task is to foster the objectiveness of modelling human actions and activities in relation to work and existing conditions in work environment. The recent studies carried out by the research team and cooperative research partner, have made progress to basis of relevance and objectiveness of modelling requirements. It is obvious that this study will give also new information for the fulfilment of modelling requirements.

1.4 Goals of study

The objective of this study was to develop a new tool for manual work task and workplace design based on novel way of using digital human models. A demand was that the tool should be able to be used concurrently with production design, too. Also an ordinary worker should be able to identify quickly workplace and work task problems and spots that require improvement by using the tool. Moreover by using this tool it should be able to produce various illustrative 3D models as proposal for solution to control physical load of a human and increase the productivity. Additional objective was to introduce methods for taking account safety activities and improving influence and development capabilities of a worker.

In this study the recorded real human motions have been analysed and composed into a database to have a novel approach to digital human modelling. A computer based digital human model tool including ordinary basic postures and motions, and which can be used to design environment variations for existing systems or systems being at the development state, was a demand of industrial partners. The tool was to be applicable by most of people in every workplace or workgroup for work development illustrations and simulations. Moreover the tool was to be enlargeable and updateable for company's specific work and work environment, too.

2. Development of the new tool

2.1 Development background

The background for this study is composed of the industrial requirements and the state of the art in this specific subject field. There have been used methods such as semi-structured interviews and questionnaires, and literature search (e.g. Appendix A). Also deep discussions with industry have been used to cover different situations of design in industry's work development cases. During these discussions have been investigated real design cases that concurrently have carried out work and workplace design and production design. According to this background investigation the specified goals of the tool properties and features, and choice of the platform was done to develop the tool for the actual purpose and needs of the users in industry.

The first version of the tool was tested in laboratory case. The start of the development was to record few movements first to find out the correct process and methods. The continuation of development work was to expand the motion library little by little. It was important to test tool in laboratory to ensure the user requirements for the prototype before further development. The tool was tested also in use cases which correspond to real work such as manual handling task of a company.

2.2 User requirements

The background for a tool in development actions has arisen during the many previous development cases with industry. One of the factors that have hindered the use of new tools in development projects in industry have been the complexity of the tools. In addition, the tools available today, need special knowledge to use them. Therefore, considering ergonomic issues, the digital human model in a desktop mode, i.e. using common computers and screens for this as a tool, is vital for the analysis in order to be carried out almost in any place and any time, even by an ordinary worker. Furthermore the methods for the ergonomic analysis are not well known in development groups in industry. Thus, when analysing and designing production systems, the need for a user friendly simulation tool has been became an issue.

To collect the requirements for such a tool a preliminary requirement study was conducted. In this study interviews and questionnaire were used to collect the requirements and needs and hopes from the industrial partners of the project. Several persons from each partner were interviewed. The interviewed persons were workers, production managers, manufacturing method designers, development engineers, ergonomists and physiotherapists.

Altogether 21 persons were interviewed. The semi structured interviews included 27 questions regarding the background of the companies, interviewed persons, production model, development activities, development procedures, examples of typical development projects, tools used in development projects, measures used for analysing development needs, development needs in work places, ideal production planning method, requirements, needs and hopes for the new tools for production planning including ergonomic issues, other issues concerning production planning and work task development.

According to the results there was a clear need for a tool and procedure in development of work and workplace concurrently with production development. As a summary of the interviews and questionnaire the most wanted features considering the tool were (weight value at least 2–4 from 0–4):

- Easy to use
- Fast to use and implement
- Operation support
- Illustrative
- 3 D visualisation
- Logical functionality
- Includes digital human model(s) (with different size and shapes, possibly forming ability, with upper body motion, sitting posture minimum)
- Includes library models or digital models could be imported
- Includes different analysis tools (posture analysis, repetitive work analysis, production analysis, production parameters)
- Time factor included (possibly standard movements)
- Shaping features
- Editing features (in concept phase, switching models, changes in human model, etc.)
- Guiding features (guidelines, recommendations)
- Support for identification of problems.

The basic idea for the development of the new tool for production development was that it would base on library modules, with which it could be easy to create a visualisation of an idea, how to improve a work place and the work task in production system. In addition it should also include some analysis methods for analysing production system and ergonomics. The easiness of modelling ones idea was the major new concept of the new tool. The concept of using library models is not new, but the novelty of the new tool is to use of pre-recorded basic movements made for digital human models and obtained with tracking system and real persons performing these. The technical solution of the tool should be achieved, implemented by using a platform and programming new software modules needed, or, if necessary programming from scratch, however not advisable.

The new tool was named as OSKU.

2.3 Selecting the platform for the tool

There was found various options for a platform such as to develop an independent design tool either a totally independent using e.g. VRML based platform or partially independent tool which is based on using commercial simulation platform. However comparison of possible outcomes (Table 1) and resources needed for development the tool gave a support for decision which also the partnership companies supported. Here the need was also concurrently be able to design work and workplace placed in wider context, the shop floor production system. The authors were simultaneously doing another study which also gave information and support for selection of the platform. The VRML based platform was namely the other shortlist main choice of platforms feasible. However, there are several items that would have to be developed also with the limited resources available. The interface of application and also support for importing models from several different CAD format would have taken large amount of excess resources. Also animation properties to be fully utilised would have taken extra development. There was an also experienced problem with the platforms executing VRML applications. Despite of the fact that the VRML is standardised language (three versions VRML 1, VRML 2, VRML 3 or X3D) it turned out to be unstable with certain features' permissible extent of interpretation on the case of earlier language version. There was also problem in getting VRML browsers executing the latest language version of VRML 3 or X3D, which taking account the facts in table (Table 1) recommended to select commercial based platform.

By selecting the platform based on Visual component software now released resources for especially ergonomic focus development which was also one main goal in this study. Moreover, the application module developed would be easily transferable to other platforms, too. The implementation was able to be work out by using an add-on technique, which was significant benefit. Here the decision was to choose a platform, Visual component software, which has been used and especially developed for purposes of production design. This was also significant benefit.

The selected platform, Visual component's 3DCreate software, is based on so called component modelling including most of the simulation codes in each component model.

Thus in modelling the workplace the idea is just collecting the components of a work environment from existing libraries that are made available by the manufactures of equipment and machinery. Also the designers of a company can easily model and code their own company specific models to be attached to the component library.

Table 1. Comparison of outcomes between a VRML based solution and Visual Components's platform based solution.

x = Feature installed (d) = Develop in project	Freeware	User interface	WEB – components	Production simulation	Ergonomics analysis	Static digital human model	Kinematical digital human model	Import several CAD formats	Animation
Visual Components		X	X	X	(d)	X	(d)	X	X
VRML + ActiveX	X	(d)	X	(d)	(d)	X	(d)	(d)	X

Although the building of a component needs skilful person to make it (coding, testing, verification etc.) the component is reusable and has well defined interface between components, which ensures that components are compatible with each others. The reusability property makes it possible for even a worker to model workplaces that will execute as they are meant to work.

The most important aspect in using the selected platform is the easiness of an ordinary worker to compose his or her own workplace just by collecting the components from libraries in house and in internet. The components can be connected by dragging and dropping them into the layout. A great benefit in modelling work is the fact that the component can be placed only in correct way to make production flow. This makes the modelling faster and ensures also that the layout is correct, which also is now easy to check.

For the development of the new tool simulation software on the market was selected as a platform for the OSKU. The benefits for using the selected simulation software were:

- The production related simulation features already in the tool

- A new external user's own module could be build on that tool based on open source concept
- The platform was tested in the market
- The platform had support mechanism that works well
- The platform had similar existing features that was introduces in the idea of OSKU (summary in the chapter 0)
- The platform had potential to be used widely in the industry (references of the simulation software vendor).

2.4 Applied principles in the digital human model

The digital human model here is based on exploitation of component models. The novelty is in the methodology that was developed to model the human actions of a work and work tasks. To improve the easiness of human action modelling it was decided to obtain the basic motion library. Library was decided to create by using real human motion recording as the basis for this purpose.

Figure 1. A testing system and a test person's location to table having on surface the matrix points of 2 x 2 centimetres in order to record motions by using a magnetic based wide range human motion capture system.

For achieving the necessary accuracy of digital human model, the motion capture system was used. The data suit MotionStar Wireless ® by Ascension Inc. and data gloves 5th Glove '95 by 5DT were used (Figure 1). The data suit was equipped with 8 tracking sensors for obtaining position, orientation and to perform calibration. The data gloves were attached to wireless data transmission system unit of the data suit. The position of the head was obtained from a sensor on top of the head. Other sensors were attached to the arms and feet, the lower and upper back. When transferring the real human motion data into use of the new digital human model also the Envision/ERGO digital human model was utilised.

Recorded motions were according the interviews in companies focused for manual assembly work (move to, pick up, move back and locate into). All hand (palm, fingers) motions were performed from starting point (the assembly work point) to matrix point and back (See Figure 2); matrix points were 2x2 centimetres; the purple, green and yellow points here describe the different matrix point levels by elevation of 20 centimetres; the distance between each matrix point horizontally were 20 centimetres; the basic assembly work point was located according recommendations in front of a test person; accuracy of motion capture was set up to app. ± 0.5 centimetres. All motions (to and back between points) were recorded three times and most suitable (subjectively well performed) was selected to database. The database consists of 198 different motions.

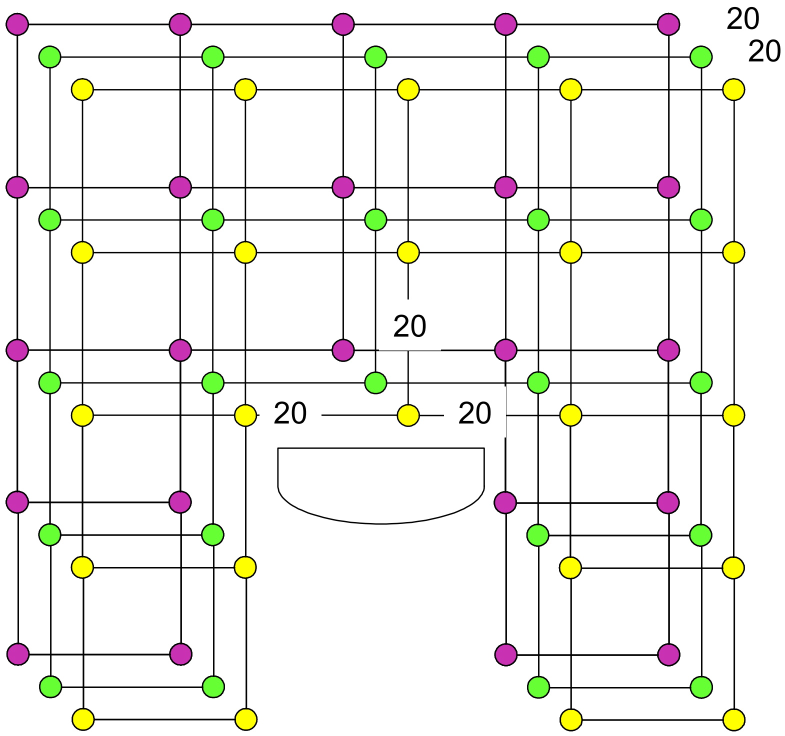


Figure 2. Recording of motions was obtained by using human motion capture system; here in the matrix point principle location diagram are seen also the extra points on both sides of a human.

Digital human model is aimed to be used as a tool for preliminary visualisation and as a recourse data for ergonomics analysis. The kinematics human model covers six different anthropometrics sizes; male and female both of P05, P50 and P95. The first version includes body postures for seating work but some trials were made to include also other type of body postures, too. Now according the interviews in companies OSKU tool uses the sedentary posture as a basic model. The recorded motions are easily selectable from the task menu of the tool and can be composed by user to wider motion sequences according the practical need. They can be saved and retrieved by user.

The basic motion database that is used to control digital human model motions is easily modifiable and extendable to any sort of motion required. The basic motions in database include also the ergonomic analysis data values and information of cycle time (from each data item to another). Also database content is extendable to fulfil user needs.

2.5 Modelling properties

The developed digital human model tool, OSKU, has the features for controlling its motions and producing work task description in three different ways:

- Direct use of recorded basic human motions from the database
- Pointing the objects in the working area in order to obtain for that situation the relevant and sufficient motion; software calculates and selects the nearest basic human motion from the database and brings it to simulation model
- Retrieval of pre-defined sub work task, sequences, which are based on the composing of the recorded motions from database or are created interactively by integrating the basic human motions from the database.

The use of developed tool is described more precisely in OSKU tool manual (http://www.vtt.fi/proj/osku/). The user interface has been divided into three main areas (Figure 3). Main use of upper area is focused on creation and modification of digital human model and also analysis of designed work tasks by using the existing dialogues of the platform and the dialogues added to the platform. Middle area consist typically list type dialogues, e.g. to select recorded motions, to modify and change the gender and size of the digital human model, to control, analyse or to start simulation of selected sequences. In the middle area is also the information of work tasks modelled by user, information dialogues presenting the analysis data, and the model layout’s visual display. Lower area consist movable dialogues and lists, e.g. selected motion sequences for designed works tasks.

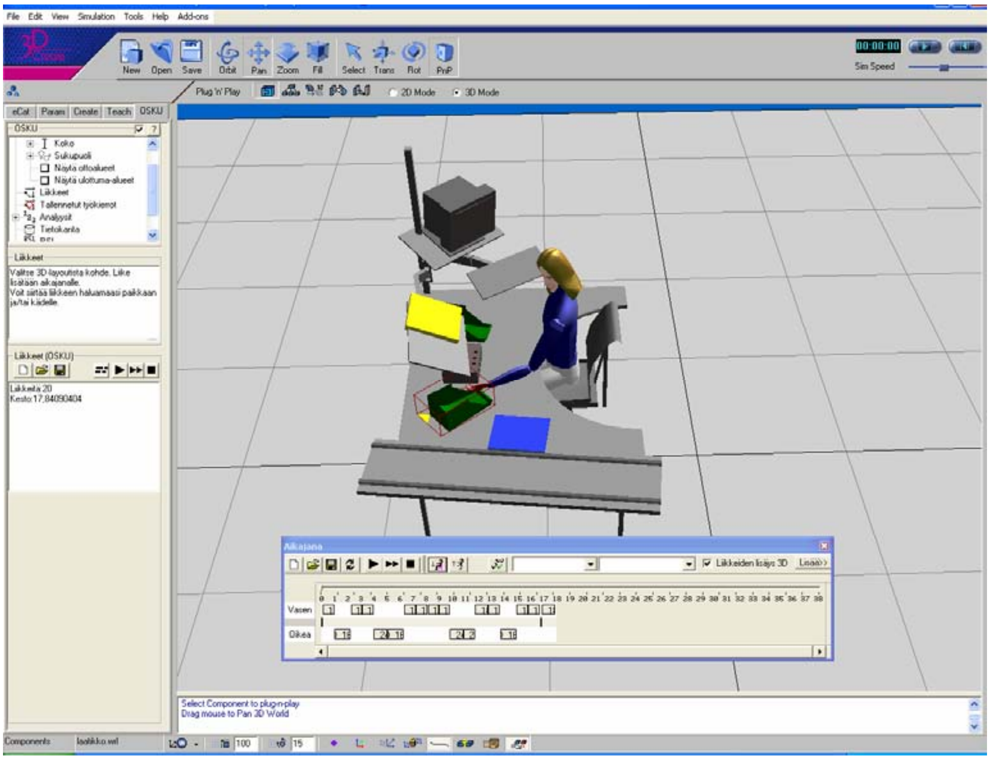


Figure 3. The user interface view of the developed tool; left down is a timeline dialog box of the defined left and right hand motion sequences of the digital human model.

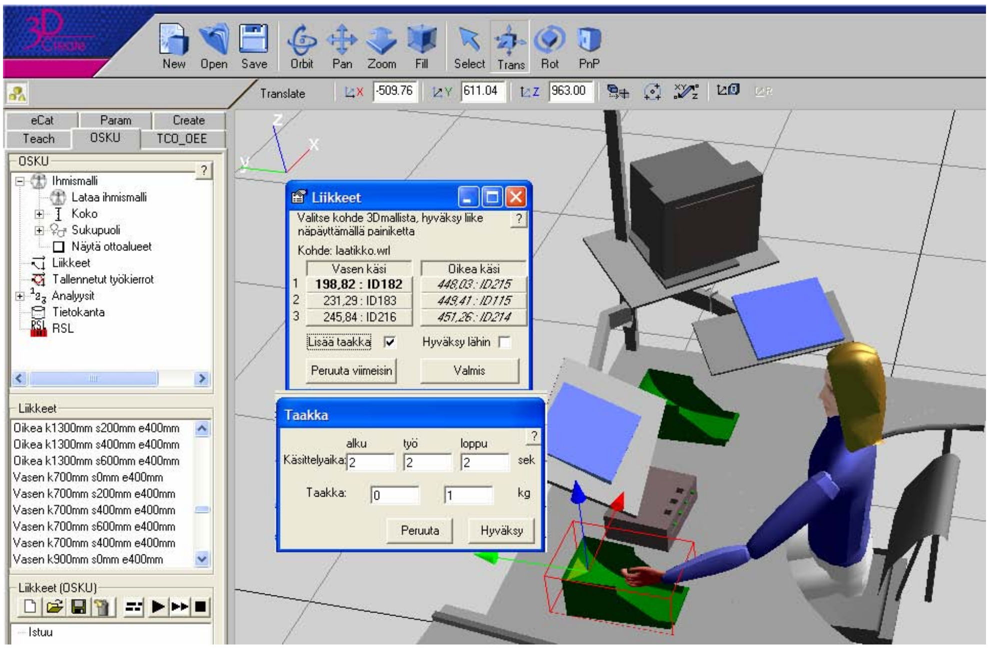


Figure 4. Modelling of work tasks include selection of relevant basic motions and/or picking points, time settings and weight of objects.

The basics in the modelling are to make first composed version for the layout of the workplace and works task and then to test it by loading and introducing the different digital human models relevant to the workplace. The work tasks are modelled then by using e.g. the pick pointing of relevant locations on the layout model to for example to pick some items to the assembly in front of the digital human model (Figure 4). Because of the fixing point technique the impact of different body sizes is easy to test by introducing just the relevant sizes of the digital human model and executing the simulation to obtain the analysis data. During simulation the progress of work task will be visualised also in the timeline dialogue box (Figure 5). Changing the order of task sequences in the dialogue list or by saving and retrieving where relevant is easy, thus modification of works tasks are easy to perform (Figure 6).

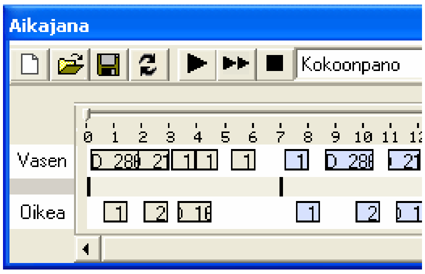


Figure 5. Timeline includes information visualised for the user during modelling, assessing, and simulation of the tasks. Changing the order of task motions can be done in timeline interface.

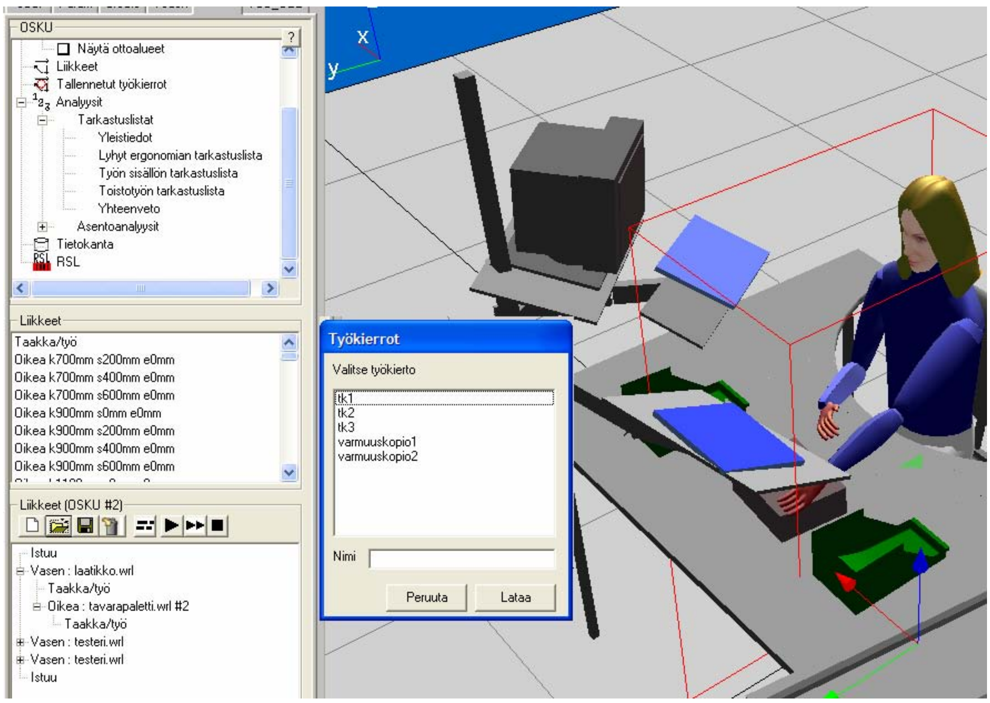


Figure 6. The tasks or sequences of tasks may be saved and retrieved. Also order of basic motion may be changed easily in the list dialogue (left down).

2.6 Assessment features of the tool

The OSKU tool includes various safety and ergonomic analysis possibly embedded partly into motion data. The use of standards, posture analyses and general ergonomic analyses was taken account in the development of the digital human model.

For analysing ergonomic postures RULA (McAtamney & Corlett 1993), OWAS (Karhu et al. 1977) and Ergokan (Määttä 1994) were implemented based on motion capture data and connected to the motions (Figure 7, Figure 8, Figure 9). To find out sufficiency of forces tables like SNOOK (Snook & Ciriello 1991) and standard based calculation were used.

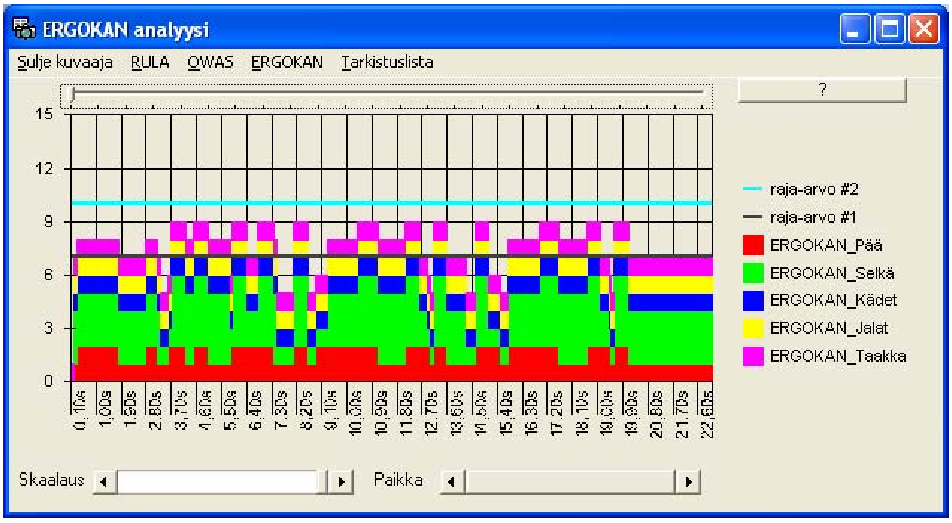


Figure 7. Posture analysis is visualised by graphics dialogue box where the analysis method may be changed by selecting it (RULA, OWAS, or Ergokan).

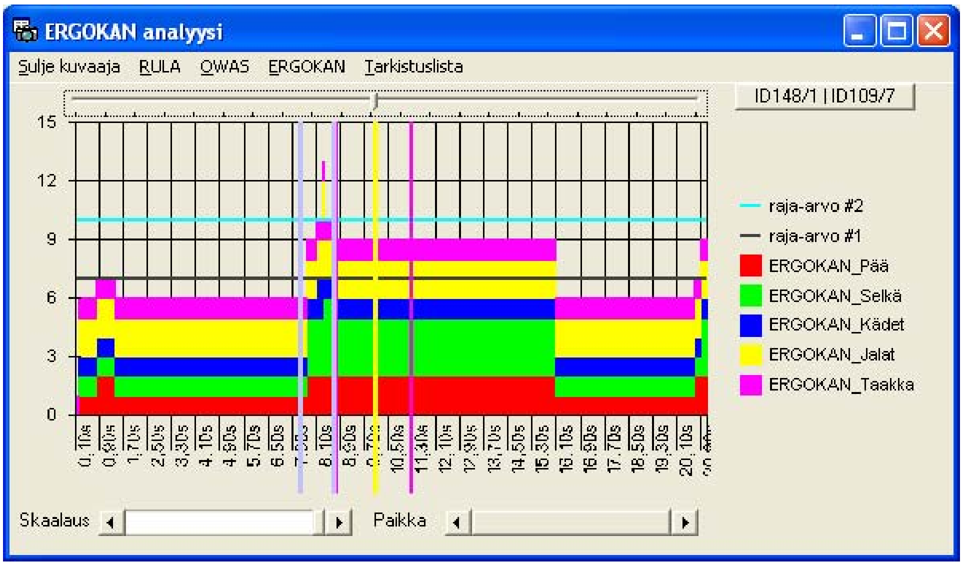


Figure 8. During simulation the vertical colour lines gives extra information considering the ongoing motion sequences for both hands of the digital human model.

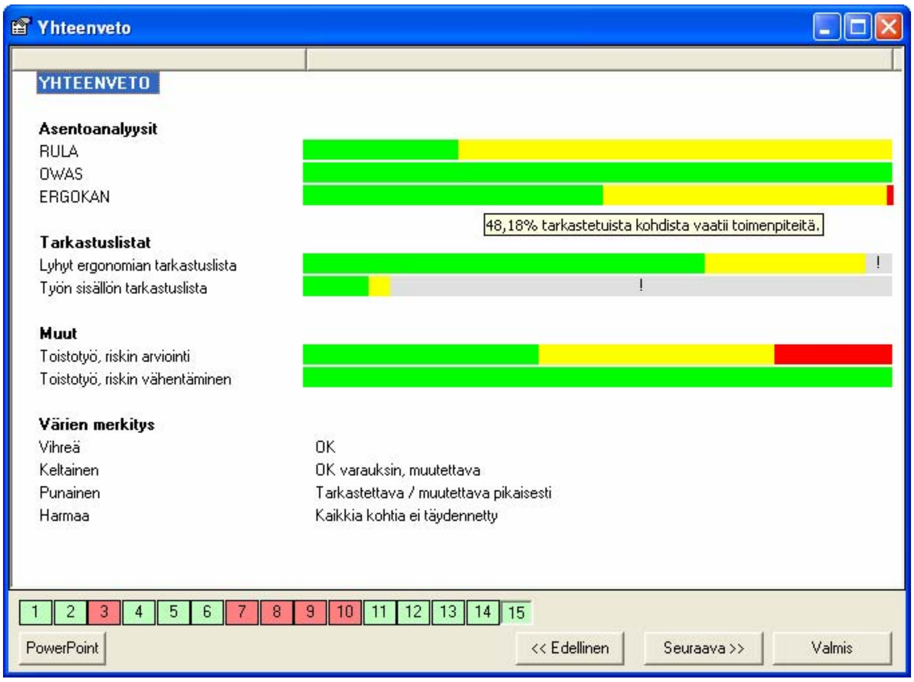


Figure 9. Conclusion windows of analysis, which based on ergonomic analysis and work analysis checklists.

Common standards for anthropometrics (e.g. EN ISO 14738, EN ISO 7250) and other recommendations workplace dimensioning were used in the development, too (Figure 10).

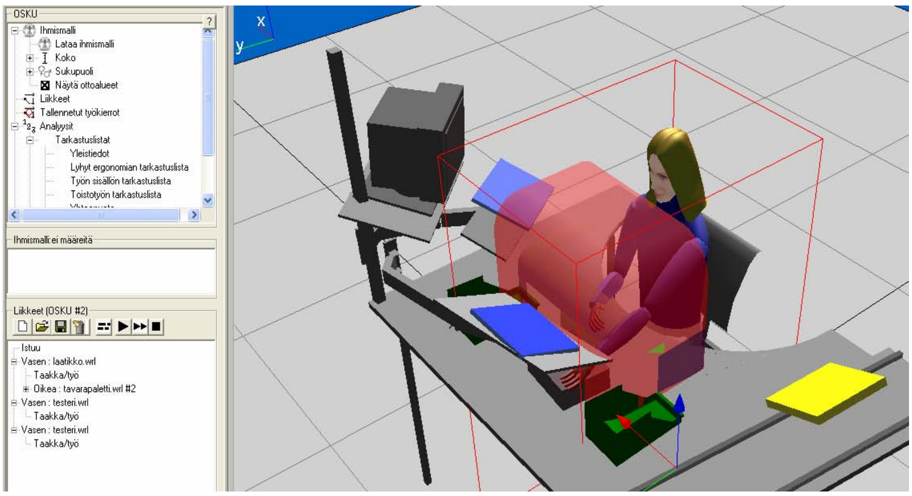
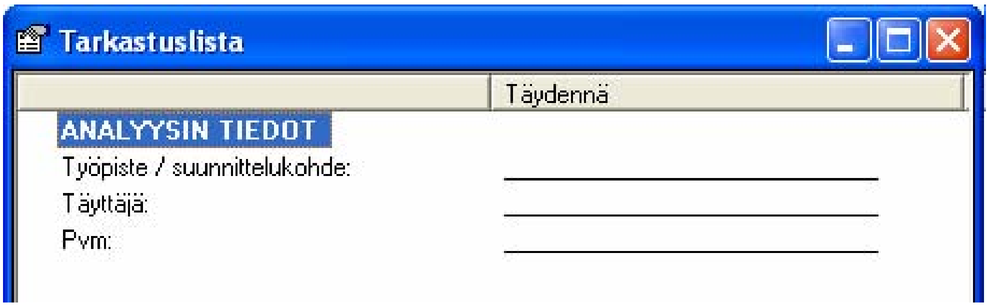


Figure 10. Recommended reaching area for e.g. different assembly work may be visualised by relevant envelope to aid locating objects in the assembly workplace taking account e.g. picking frequencies or weights of objects.

For general ergonomics and work environment analyse checklists were implemented (Figure 11). Checklists were also created to elicit the issues and aspects of cognitive ergonomics (e.g. EN ISO 10075).



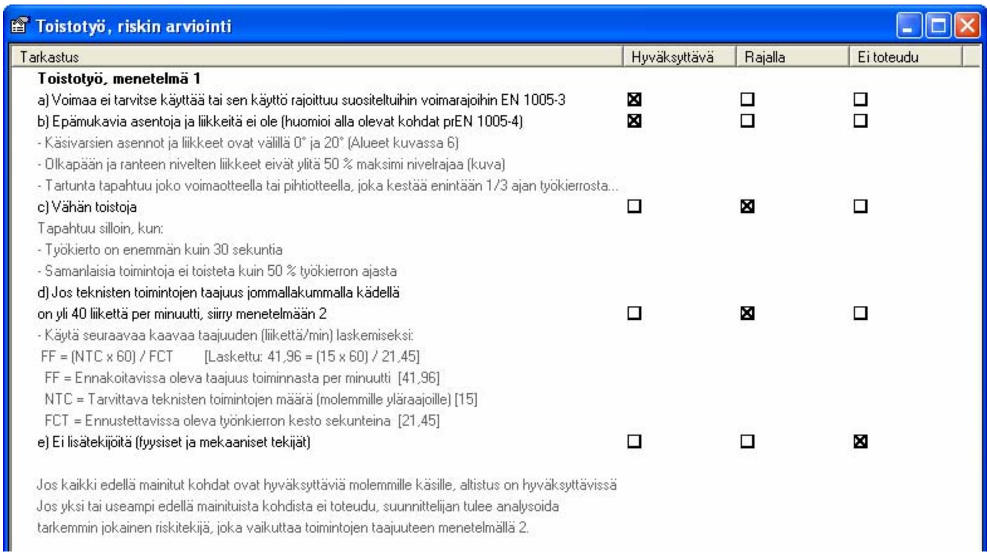


Figure 11. Three examples of checklist dialogue pages for enter data considering different point of views for general assessment of work and work conditions.

All the analysis results and checklist can be automatically output to a PowerPoint form, which can be printed e.g. to be used as a documentation of the work development.

3. Production system design with the tool

There are a variety of ways by which the usability, ergonomics and human factors can be considered while the design process proceeds. Methods giving high priority to the needs of the user include, for example: (a) Task analysis (Hackos & Redish 1998), (b) Cognitive work analysis (Vicente 1999), (c) Contextual design (Beyer & Holtzblatt 1999), (d) Usability testing (Nielsen 1993), (e) Heuristic usability evaluations (Nielsen 1993), (f) Ergonomics analyses (e.g. Karhu et al. 1977), and (g) Participatory design (Muller & Kuhn 1993). All these methods can be valuable in taking the user to the core of design. However, the use of all methods in a design project is a very time-consuming and resource demanding process. The value, applicability and priority of the methods should be made explicit for the particular area of application in a company. Here the principle method used was participatory design applying task analysis approach and ergonomics assessments.

3.1 Participatory design approach

In this study participatory design method has been used in working out industrial case studies. The method may be applied in several design stages and situations of the production design as recognised during the interviews of the industrial partners. Here the tool performs a very significant role applying the participatory design method approach. From the production design and work design point of view this is very important because by this way the information and knowledge may be transferred from different design stages and phases to following and iteratively also backwards. Moreover this can be performed by implementing the method in very sufficient way, including information in the form of models and simulation with analysis data and all the cumulative information entered into the widely compatible design and simulation system.

Participatory design is a procedure in which end users of a production process or machinery have the opportunity to take part in the design process, and can influence the design and development of a new product or process. In participatory design some or all of the workers who will work, for example, at a forthcoming plant take part in a number of design sessions during the different design phase (Mumford 1989).

However, there is a significant difference between user centred design and participatory approach based design and development. User centred design takes users as centres in the design process, consulting with users heavily, but not actually allowing users to make the decisions, nor empowering users with the tools that the experts use. It focuses on cognitive factors such as perception, memory, learning, problem-solving, etc., as they come into play during peoples' interactions with things. Use centred design seeks to answer questions about users and their tasks and goals, and then use the findings to drive development and design. Whereas participatory approach attempts to actively involve end users in the design and development process to help ensure that the target, a product or equipment, and work, work environment and conditions are designed to meet their needs and, is usable. Participatory approach is intended for non-experts, therefore approaches and methods differ from those, e.g. ergonomics, intended exclusively for experts. Participatory approach seeks to identify and correct factors that negatively impact the physical health of workers. The involvement of the workers in this process is based on the simple fact that a worker is an expert on his or her job. Thus it relies on the actively involving workers in implementing the knowledge, procedures and changes with the intention of improving working conditions, safety, productivity, quality, and comfort.

The advantages of participation are (Hirchheim 1989)

- *Better result of design*: As the users themselves can influence their working environment
- *Commitment*: Users will feel more ownership of the new system and implementation will be easier as they have contributed to the design
- *Work satisfaction*: Operators will be more satisfied with their job when they have influenced their working environment
- *Training*: Participation constitutes effective training for the operation of the new system, and users will generally have a greater knowledge of the work and processes
- *Efficiency*: Increased knowledge together with the new suitable tools will lead to more effective production
- *Participation as a value itself*: Participation is a feature of democracy and is, as a form of it, a value itself.

The design and development of complex systems will have more success with participatory design, because for example, by implementing participatory design it will be easier to control unexpected situations (Kallela 1996) compared to case without applying participatory design approach.

3.2 Development of the participatory based method

The principle of OSKU tool lies on the easy and fast use of the tool during a development project or continuous, even small steps improvement actions introduction to involved persons. The tool has potentials to be implemented in different development, training and marketing processes (Figure 12). It is planned to be used for designing small modification for a production system or whole new systems or workplaces by workers themselves or with a development group. Furthermore it could be used for training new workers to a new work place and work task. In addition it could used for marketing purposes for instance when a system supplier will introduce solutions for its customers.

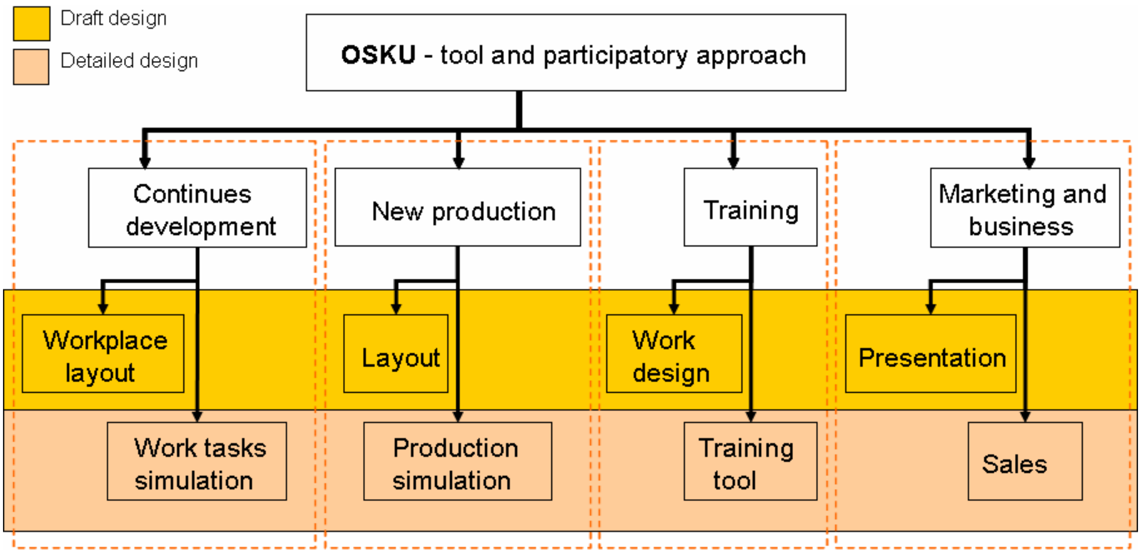


Figure 12. The principal levels of use with OSKU tool and participatory approach for production and work design.

All implementations could have different level of details. For instance layouts can be modelled and used with the tool already in a conceptual mode, and furthermore when it is used for factory or production simulation it will be used more detailed design.

The OSKU design method is divided in two stages: initial data and implementation (Figure 13). The initial stage includes data collection and analysis, and task description. The implementation stage includes modelling and design of a workplace, and connecting to the production control system, and production analysis. The objective of the use of OSKU tool is to create a balanced production system which is based on taking into account the technical, economical as well as the social factors in a balanced way.

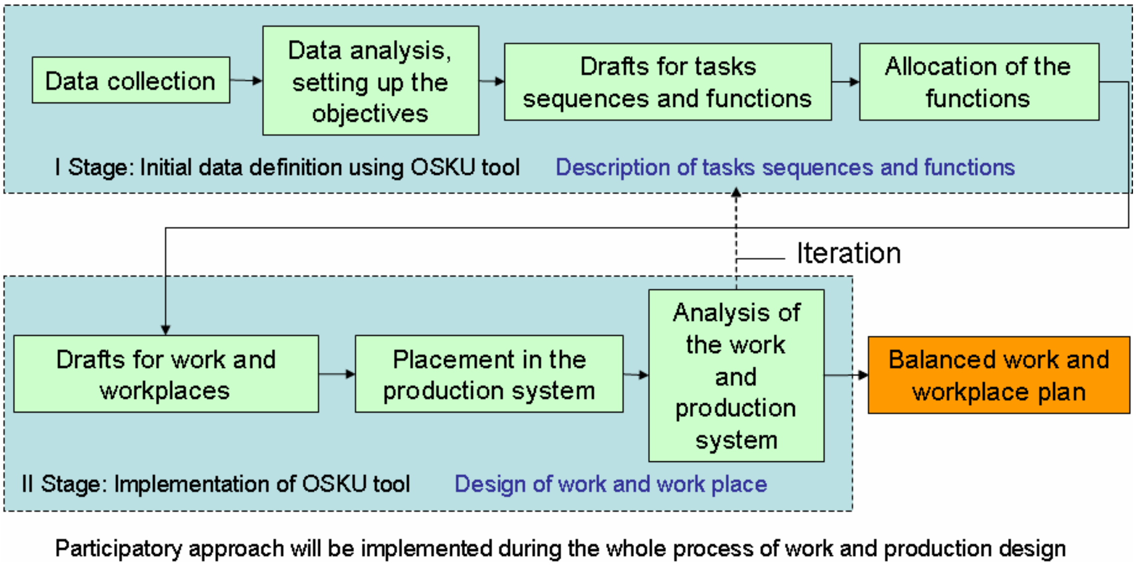


Figure 13. The two stage design process using the developed tool and method.

3.3 Testing in production system design

Before the testing of the developed OSKU tool and method the industrial partners and developers had training sessions together to get familiar with both platform and the developed tool. After training sessions the participants were able make even their own additional component modelling to introduce their own specific workplace equipment and instrumentations to be used as library models. The platform developer has also wide web-based library of typical components for layout modelling from different supplier vendors.

After a practical training period for modelling industrial partners own specific components, the latest version OSKU tool was introduced for each industrial partner separately with instructions about targeted subjects for testing with company's own development cases. The testing period was several months in order give enough time to get familiar with the OSKU tool and method, and the Visual Components platform. The aim was that in each company the training and testing was to be worked out by several persons, the involved persons related to work and workplace to be further developed to follow participatory design and development approach and principles.

4. Results and discussion

The novelty of the new method developed was expected to be in the capability to fulfil the demands for modelling the human actions of a work and work tasks tightly connected to the design of the production and the machinery. The development of this new method adding the required efficiency for participatory design, and applying the digital human models succeeded well. The implementation of this method as a tool, the OSKU tool was successful, too. The method and the OSKU tool combine the commonly different design areas to be able to carry out concurrently and exploiting participatory design approach. Following an ordinary human natural performance to work and to interact with machinery can be done by using the OSKU tool. Thus a designer or even a member of involved employees in production, can in a comprehend way ensure about the application of human based limitation and possibilities for technical design of workplace and machinery, and also influences to the production. Thus a designer or end-user can concurrently develop alternative solutions to be visualized and assessed by many ways as described, and also exploit participatory approach benefits.

Main feedback from the companies' end-user was that the OSKU tool can well be applied for participatory design of work and workplaces. Also the digital human model is easy to use and the interface has several user-preferable ways to choose and to carry out the design tasks. This is important for the easy use of the tool to be able apply each user's own habits to design the details.

4.1 Implementation in companies

There were unexpected problems in installation of the software platform itself in some companies because of the licensing process and non-floating usage. The basic interface of the software platform itself is simple but it includes plenty of features to be learned and trained, and also a requirement to be used frequently to be smoothly adopted in common practice of work and workplace design.

The installation of OSKU tool features was easily done which is an important characteristic for a tool. The OSKU tool was so far implemented using the most powerful version of the software platform which had strong influences to feedback, too. The modelling capabilities of human work were easy to use for those users experiencing other 3D software applications. The adoption of the OSKU tool features were smooth to get easily started applying also OSKU in design besides the other software platform design and simulation properties. The OSKU tool interface is added as a part of the software platform interface.

However the feedback was for ordinary users that some of the features included in the OSKU tool at the moment still need too much additional expertise. Therefore an ordinary worker can't use tool as effectively as it was expected. Because of still the early development phase of the OSKU tool, some of the dialog boxes are unlike and have still lacks of compatibility and visual features compared to those of the platform itself. There was a notice for some human motion prediction creation problems resulting to unnatural or too rough motion predictions for design. Another notice was for supporting weakly the design purposes, because of including too much of simplicity in obtaining the basic human motion data for database, or producing additional data to support design and dimensioning process yielding to difficulties comprehend the content.

4.2 Laboratory test case

The first version of the tool was tested in laboratory case. The start of the development was to record few movements first to find out the correct process and methods. The continuation of development work was to expand the motion library little by little. It was important to test tool in laboratory to ensure the user requirements for the prototype before further development. The tool was tested also in use cases which correspond to real work such as manual handling task of a company.

4.3 Cases in companies

Finally the tool was tested and iterated in companies by ordinary workers and the information for further development was be collected. Companies also got training to use of the tool.

All of the companies were interested of developing the workplace ergonomics. However there were differences on the motion accuracy pursued. The basic motion resolution accuracy was the most criticised feature in the OSKU tool. However the set up value for aimed matrix point resolution, 20 centimetres, was accepted at the beginning of development. From the posture analysis point of view this was acceptable but in practice it turned out to be too rough-grained from the animation point of view. The value should be approximately at the level of 1 to 2 centimetres at most. Thus the ordinary picking or placement would look natural.

Another criticised feature was the actual small quantity of basic motion cases that could be exploited at the moment. Also this issue was accepted at the beginning of the development. It turned out that only motions starting basically from assembly work point are not enough. There are plenty of cases where exist need for also motions from e.g. picking box to another place outside the assembly work point before the actual motion backwards to do placement into assembly.

The third general issue for criticism was the lack of or smallness of help for e.g. posture analysis content, repetition analysis and so on. This was recognised also by the developers themselves. However this was the question of choice either to develop features to introduce to testing or to do only few features with help function. The choice was put to develop first several features to OSKU tool and to get feedback of them for further development.

At the moment of testing phase there were some minor problems to transfer existing CAD models from other formats to formats accepted in the platform. Also with huge models including great amount of detail data were not working properly.

4.4 General aspects

The principle of exploitation recorded real human motions does work. However there are needs to get more accuracy for motions, when retrieved as works tasks of the digital human models. Also the motion selection should be larger including different type of movements from one point to another without all time going through assembly work point. The database structure is now extendable and also easily transferable to other platform applications. Because this tool has been implemented as add-on module, it could be transferred from one platform application to another.

5. Conclusions

The results show that the developed tool OSKU is feasible for individual and group design work, and has positive impacts both on the design process and on the way how individuals can influence on her or his future work in production system. The functionality properties and data may be added or modified later on, models are reusable, thus enabling to take account more precisely the characteristics and requirements of use cases during their whole life cycle.

This kind of easiness will build a very strong level of confidence and that is nowadays the key issue in the fast paced industry. Thus this kind of tool will enable in a company that different people can work together to arrive at the best possible solution with the greatest level of confidence and in the shortest possible period of time.

The users of tools like this OSKU have noticed that the focus is on the creation of a solution, a concept and the speed of understanding it by all the involved. It is known that the use of interactive visual representations will remove ambiguity and make the involved persons even more innovative and keen to continue in making further efforts. The production workers can be more responsible for the development of his or hers own work and working environment, and thus they may be more committed to their work and also in fulfilling the productive efficiency.

In addition, the data generated during the development stage, is able to be utilised once again in many ways such as in product marketing, documentation, and in training material, too. Thus the digital 3D models are used to create a common understanding of the unique operational issues of production and benefits throughout companies own organisation as well as their potential sub-suppliers and partners. These kinds of tools have also great potentials in enhancing communication internally in a company between design, manufacturing, sales, applications, operation and service.

The get a more advanced tool, an enhanced OSKU, from the basis of this work, is still under development and needs further research to enhance the capabilities in analysis and design of the various production systems and human activities in the system. At the moment there is going on a trans-national study to develop the tool further according the feedback of this study and the new set of requirements.

6. Summary

The study is based on the industrial requirements and the state of the art in this specific subject field of digital human modelling and motion prediction. Methods such as semi-structured interviews and questionnaires, and literature search were applied. Also complementary discussions with industry have been used to cover different situations of work and production design in industry's work development cases; thus taking account the real design cases that concurrently have carried out work and workplace design and production design. This background investigation produced the specified goals of the tool properties and features.

Altogether 21 persons were interviewed. The semi structured interviews included 27 questions regarding the background of the companies, interviewed persons, production model, development activities, development procedures, examples of typical development projects, tools used in development projects, measures used for analysing development needs, development needs in work places, ideal production planning method, requirements, needs and hopes for the new tools for production planning including ergonomic issues, other issues concerning production planning and work task development.

The objective was to develop a tool for manual work task and workplace design, based on novel way of using digital human models taking account the participatory design approach. The tool was aimed to be used concurrently with production design, in a way that also an ordinary worker should be able to identify quickly workplace and work task problems and spots that require improvement by using the tool. On the other hand by using this tool it should be able to produce various illustrative 3D models as proposal for solution to control physical load of a human and increase the productivity. Additional objective was to introduce methods for taking account safety activities and improving influence and development capabilities of a worker.

According to these targeted objectives the participatory design approach conceptual model was developed using and exploiting the tool especially as in a central position in fulfilling the knowledge and information transfer from person to person and also from separate functions to each other in a company e.g. between design of work, work task, workplace, training, rehearsal, product design, production design, or marketing and sales. However in order to use resources efficiently but still ensuring enough freedom, the platform selection of commercial simulation software was done to enable the development the tool as an own complementary add-on module. Despite it was ensured to achieve the actual purpose and needs of the users in industry to apply more efficiently their own way to influence according the participatory design approach and also for working in smaller groups or even as individuals.

The real human motions have been recorded, analysed and composed into a database to have a novel methodological approach to digital human modelling. Also a computer based digital human model tool including ordinary basic postures, motion prediction and analysis capabilities, was developed. The tool can be used to design alternative solutions for existing systems or systems being at the development state. The tool can be used by most of people in every workplace or workgroup for work development illustrations and simulations. Moreover the tool can be implemented for various specific work and work environment design in a company by enlarging the human motion database content. The work, work tasks, workplaces, work environment and production can be design concurrently thus accelerating design as a process and increasing possibilities to influence and review each design stages more widely than possible in case of traditional design process..

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Appendix A: The occurrence of features in ergonomics applications

Features	Occurrence of feature
Kinematical digital human model	17
Ergonomic design	14
Lifting analysis	13
Posture analysis	12
Field of view analysis	10
Energy consumption analysis	10
Check list	9
Anthropometrics database	9
Reach analysis	9
Production design	8
Walking	8
Motion generation between static postures	8
WWW-tool	7
Push/Pull analysis	7
Grabbing to object	6
3D features	6
Object following	5
Inverse kinematics	5
Force/moment analysis	5
Ergonomics self learning	4
Repetitive work analysis	4
Virtual Reality connections	4
Balance analysis	3
Collission detection	3
Pictures and movies	3
Stretching guidelines	1
Cloths	1

Applications
AutoMATS Software/MKSG Inc.
Computer Based Training/ErgoWeb Inc.
Job Evaluator Toolbox/ErgoWeb Inc.
Ergotivity/Ergonomic Technologies Corp.
eM-Human/Tecnomatix Technologies Inc.
Ergo/Delmia Inc.
ErgoEase/Ease Inc.
EaseWorks/Ease Inc.
Ergointelligence/NexGen Ergonomics Inc.
ErgoImager/ NexGen Ergonomics Inc.
ErgoMaster/ NexGen Ergonomics Inc.
ManneQuinPro/ NexGen Ergonomics Inc.
ManneQuinBE/ NexGen Ergonomics Inc.
ManneQuinElite/ NexGen Ergonomics Inc.
ErgoMOST/H.B.Maynard & Co.
Job Evaluator Toolbox Software/ErgoWeb Inc.
ErgoTrack Internet Applications and Checklists/ErgoTrack Software Inc.
Integrated Performance Modeling Environment/Micro Analysis Design Inc.
Safework/Delmia Inc.
OCS-VCR Toolset/Triangle Research Collaborative Inc.
Office Ergonomics/Clayton Group Services
Risk Priority Management/Humantech Inc.
Jack/Engineering Animation Inc.
VisJack/Engineering Animation Inc. (Jack light-version)
WinCrew/Micro Analysis & Design Inc.
Stretch Break for Wheelchair Users/ Para Technologies
Stretch Break Pro/Para Technologies
Multimedia Video Task/NexGen Ergonomics Inc.

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