Experiments to evolve toward a tangible user interface for Computer Aided Design parts assembly

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ABSTRACT

In this paper, we present the concepts of the ESKUA (Experimentation of a Kinesics System Usable for Assembly) platform that allows designers to carry out the assembly of mechanical CAD (Computer Aided Design) parts. This platform, based on tangible user interface lead taking into account assembly constraints from the beginning of the design phase and especially during the phase of CAD models manipulation. Our goal is to propose a working environment where the designer is confronted with real assembly constraints which are currently masked by existing CAD software functionalities. Thus, the platform is based on the handling of physical objects, called tangible interactors, which enable having a physical perception of the assembly constraints. In this goal, we have defined a typology of interactors based on concepts proposed in Design For Assembly methods. We present here the results of studies that led to the evolution of this first interactors set. One is concerning an experiment to evaluate the cognitive aspects of the use of interactors. The other is about an analysis of existing mechanical product and fasteners. We will show how these studies lead to the evolution of the interactors based on the functional surfaces use.

Keywords: Tangible User Interface, Computer Human Interaction, Computer Aided Design part, Experimentation

1. INTRODUCTION

The computer graphics scientific community generally agrees that the traditional input devices, mouse and keyboard, are limited and that it is necessary to create new devices, in particular when three-dimensional scenes are to be visualized. New Computer Human Interaction systems have appeared proposing new concepts: for hardware (input and output devices) as well as for software (graphical interfaces). One of these new concepts is “Tangible User Interface” [1] quoted in [2] called (TUI) in following. TUI seek to make intuitive interfaces in order to combine the physical world and the numerical one in order to simplify interaction. TUI are based on the use of real objects which allow a representation of the data and a physical control of numerical information [3]. We are interested in TUI and especially on the assembly and the handling of physical objects called “tangible interactors”. The closest related works are the “Active Cubes” [4], and the system developed at Mitsubishi Electric Research Laboratory [5]. These applications allow only one kind of interactors (parallelepipeds) and allow combination by means of connectors.

We decided to tackle the problems of TUI but we concentrate on a particular field which is the mechanical design assembly. Current mechanical CAD (computer aided design) software do not allow indeed the designer to take into account of constraints which are more or less subjective concerning the difficulties of the assembly of certain parts. So this situation leads to the proposal of products which are sometimes very expensive in terms of assembly. The goal of our work is to propose to designers a working environment in order to enable them to be confronted with assembly constraints which are currently masked by existing CAD software functionalities. For example, positioning difficulties for two parts before fixing or parts insertion difficulties such as inaccessibility will be potentially identifiable by the designer during the handling of physical interactors.

Our aim is not to replace CAD software and the associated input devices (the mouse and the keyboard) but rather to assist them for some design activities and especially during the CAD parts assembly operations. Moreover, our work not concerns the sequencing aspects of assembly but rather focus on the part grasping, handling, and insertion aspects. Our

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ESKUA[1] platform allows designers to carry out assembly simulation while enabling them to immediately identify difficulties, and to foster design modifications of parts in order to simplify assembly. We think that this type of platform based on tangible user interface can provide user decision-making support, taking into account assembly production constraints, when technological choices are made in the design phase.

2. A FIRST SET OF TANGIBLE INTERACTORS FOR CAD PARTS ASSEMBLY

2.1 The CAD parts assembly problem

For the last forty years, much research has related to the product manufacturing steps in order to optimize the design, reduce cost and pre-market times and increase quality. The real need is to anticipate as soon as possible all product constraints during the design phase. However, we notice that the environments proposed by the traditional CAD software do not really allow a true immersion. In this context, the designer cannot take care of the assembly operation constraints. The product CAD model composed of several parts can be indeed easily visualized, handled and assembled in a virtual way by using the mouse and the various software functionalities often proposed by icons and drop down menus. Thus, the assembly of parts in CAD environment is relatively “easy” to achieve with traditional operations such as rotations, translations and settings in positions by constraints (co-axiality, parallelism, perpendicular, etc). Unfortunately, these functionalities suggested by the software do not take into account the real difficulties of the handling operations. The physical constraints, such as difficulties of setting in relative position of two parts before fixing or the difficulties of inserting one part with regard to the others related to the problems of gripping, inaccessibility or collisions of the parts, are masked by the functionalities existing in the CAD software. Moreover, studies and examples of various industrial cases [6] show that the designer in his environment within the engineering and design department cannot always rationalize his own creation.

At the beginning of the 80’s, methods and tools referred to the generic term of “Design for X” were created in order to include the various aspects of the product from the design phase. Among these works, the methods called “Design for Assembly'” or “DFA” [7] were developed to help the designers in their analysis of the product under development by providing assessment criteria for assembly. The main objective of DFA methods is to propose assessment criteria in order to evaluate the assembly difficulties of a product during the design phase. These methods are often proposed in a software environment which calculates a coefficient of “assemblability” of the proposed product. This coefficient is based on the description of the main operations (grasping, handling, insertion…) concerning the product’s parts assembly. In the DFA software [7], the user must provide a number of required data following several steps:

Step 1: Listing of the product parts
Step 2: Description of the assembly operations including the securing method used (screwing, snapping, riveting…) and the extra operation required (greasing, surface cleaning...)
Step 3: Check of the “minimum part criteria”. The aim of this step is to reduce the number of parts by questioning the user on the usefulness of each product part.
Step 4: Description of the envelope dimensions of each part. In DFA software, parts can be described as basic forms: disc, cylinder, plate, beam, and parallelepiped.
Step 5: Definition of symmetry axes of each part.
tep 6: Definition of handling and insertion difficulties. During this step, the user describes the product and identifies the parts handling difficulties: nest tangle, difficult grasp, flexible, tweezers, bulky… and the insertion difficulties: access, view, alignment, resistance …
Step 7: Definition of distances between the assembly operator and parts (or assembly tools).

Some subjective difficulties which are often forgotten during the design phase can be identified and evaluated using the “guidelines” proposed by DFA. However, the physical constraints of assembly operations are not always easy identifiable even with a DFA analysis. The main problem is that CAD and DFA software are based on the design and the evaluation of 3D parts and products of a “virtual world” whereas assembly (and especially manual assembly) are concerning operations of the “real world”.

[1] ESKUA means “the hand” in Euskara, the Basque language, and is a French acronym for "Expérimentation d’un Système Kinésique Utilisable pour l’Assemblage".

2.2 A new Tangible User Interface for CAD parts assembly
The problem of CAD part assembly lead us to propose a new TUI dedicated to this specific application field . With real objects, handling is simple but nevertheless can lead to identification of assembly difficulties such as symmetry, occlusions, and positioning of the parts. We think that the handling of real objects makes it possible to "anticipate" some physical aspects of the product assembly phase and leads the designer to raise questions in a "natural'" way by carrying out the gestures related to the assembly. Moreover, it is now admitted [8], [9] that the use of real objects for displacements and the control of the virtual objects is more powerful than the traditional systems such as 3D mouse. Existing TUI that we can find in the literature enable to assemble interactors by electronic connection. The assembly of these interactors with connectors does not seem relevant to us, because it induces too much restrictions for our specific application. To obtain a realistic mechanical parts assembly simulation, we must propose to designers a platform to make "free" face-to-face interactors assembly without impose predefined positioning and orientation systems. Thus all the existing TUI are neither designed and nor suited for CAD parts handling and assembly.

In previous work [10] we have proposed the ESKUA platform and presented specific interactors dedicated to the CAD parts assembly. We defined a typology of these interactors based on concepts proposed in "Design For Assembly" (DFA) methods [6]. We proposed to implement principles suggested by these methods through the use of specific interactors during the assembly of the CAD parts. In ESKUA, physical objects (the interactors) are associated with one or more virtual objects (the CAD parts). In this way, we have designed and manufactured a first interactors set made up of 60 elements with holes (see figure 1).

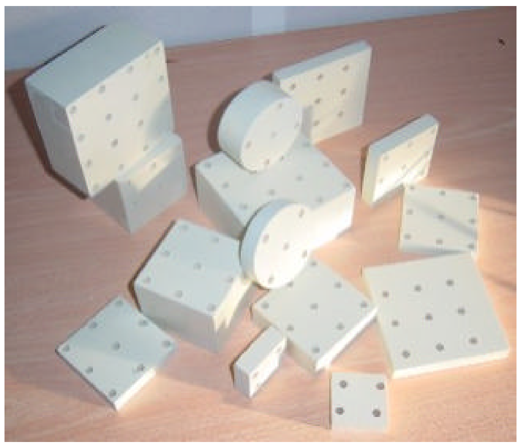

Fig. 1. Examples of our first interactors

The actions that the user will carry out on interactors (displacement, assembly, rotation, etc.) will be reproduced on the CAD parts on the display screen. The capture of the position and the orientation of the interactors is based on a system of video capture. Its low cost and its upgrading capacity (a number of cameras, choice of artifact shapes, identification with colors) seem to us very interesting assets. For motion capture, we intend to use model-based systems [11]. In this work, the authors use a hand model in order to capture the hand movements. Given a hand model in a starting pose and an input image, a model-based algorithm will make the model gradually converge to a final hand pose. We want to adapt this approach in our system. The interactors do not lose their forms contrary to the hand, but they are move in the space. Thus, the differences between two captured images are the translation motion (left/right, front/back) and rotations. However, it does not provide enough information to get the orientation of the interactor. For example: a rotation of 90 degrees between two captured image is not visible. To adapt this technique for interactors, we will use piercing as a texture to capture more information. Finally, we will use marks, by drawing symbols on specific face, in order to recognize easily faces and their orientations.

The different works concerning the development of ESKUA are still in progress. However, we want to present in the following sections the results of experiment we done with the first set of interactors without the use of capture video. This last point will lead us to present the evolution of the design of new interactors dedicated to the ESKUA use.

3. EXPERIMENT WITH FIRST INTERACTORS SET

3.1 Experimental protocol

We have done some experiments with different persons (called subject) to evaluate the relevance of our first interactors set. In fact, we created a test scenario in order to verify the following hypothesis:

- Does the use of interactors lead to think with more efficiency on CAD part assembly?
- Does the user think naturally to join several interactors for one CAD part?
- How the user associate interactors and CAD parts?

The test of these hypothesis led to the development of an experimental protocol that have been designed as follow:

1. Design of a test scenario
2. Validation of the test scenario by a referee subject.
3. Re-design of the test scenario

The scenario outline is concerning ten CAD parts which are display on a laptop screen with a CAD viewer. These CAD parts have been chosen to represent several difficulties of assembly. The subjects can rotate and translate the CAD parts with the mouse. We asked to the subject to associate interactors to CAD parts. We paid attention to give no instruction concerning the possibility to use one or several interactors for one CAD part.

The experimental protocol used for all subjects is the following :

1. Questions are asked for the subject characterization (age, experience in CAD software, etc.)
2. The scenario is given to the subject to describe the experiment.
3. Then the testing session begins recording with camcorder
4. After the end of test, questions/discussion are asked to obtain impressions' subject
5. Analyzing of records and questions, synthesis, propositions.

Our subjects are relatively familiar with computers and CAD software. But, they didn't know TUI and especially our interactors. We have four subjects : a designer, an ergonomist, an assembly expert, and a CAD user. The choice of subject is motivated by the end user of ESKUA, who are designers for assembly task and students.

3.2 Results and analyze of the experiment

Our experiments highlight that subjects use different cognitive ways to associate CAD part with interactors. Basically, our experiments show that subjects propose different interactors combinations according to two kinds of criteria. The first criterion is the general forms of the part and the second one is the functional surfaces of the part. The example of the figure 2 illustrates these two ways of association:

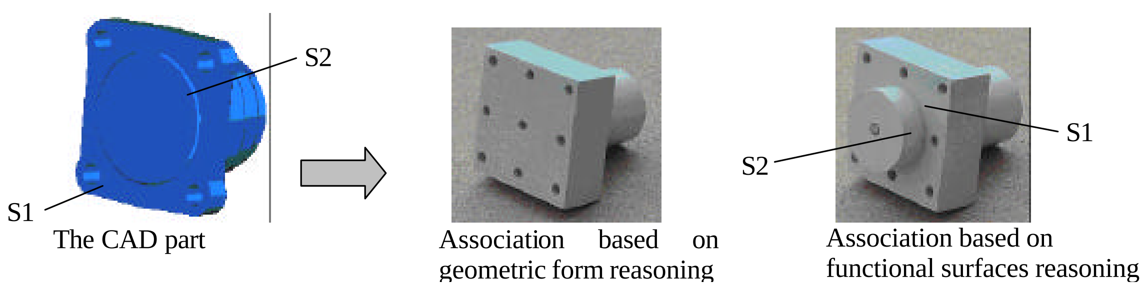

Fig. 2. Two kind of association between CAD part and interactors combinations

The CAD part (left figure of the figure 2) can be defined as a combination of two elementary forms. However, the functional surfaces of the front face of this part are the following: the plane surface (S1), the cylindrical surface (S2) and the cylindrical surfaces of the four holes. In the first proposition (center figure), an interactors combination is used in order to be coherent with the general form of the CAD part. In the second proposition (right figure), another interactor is added to allow the use of the second functional surfaces (S2) of the centering item.

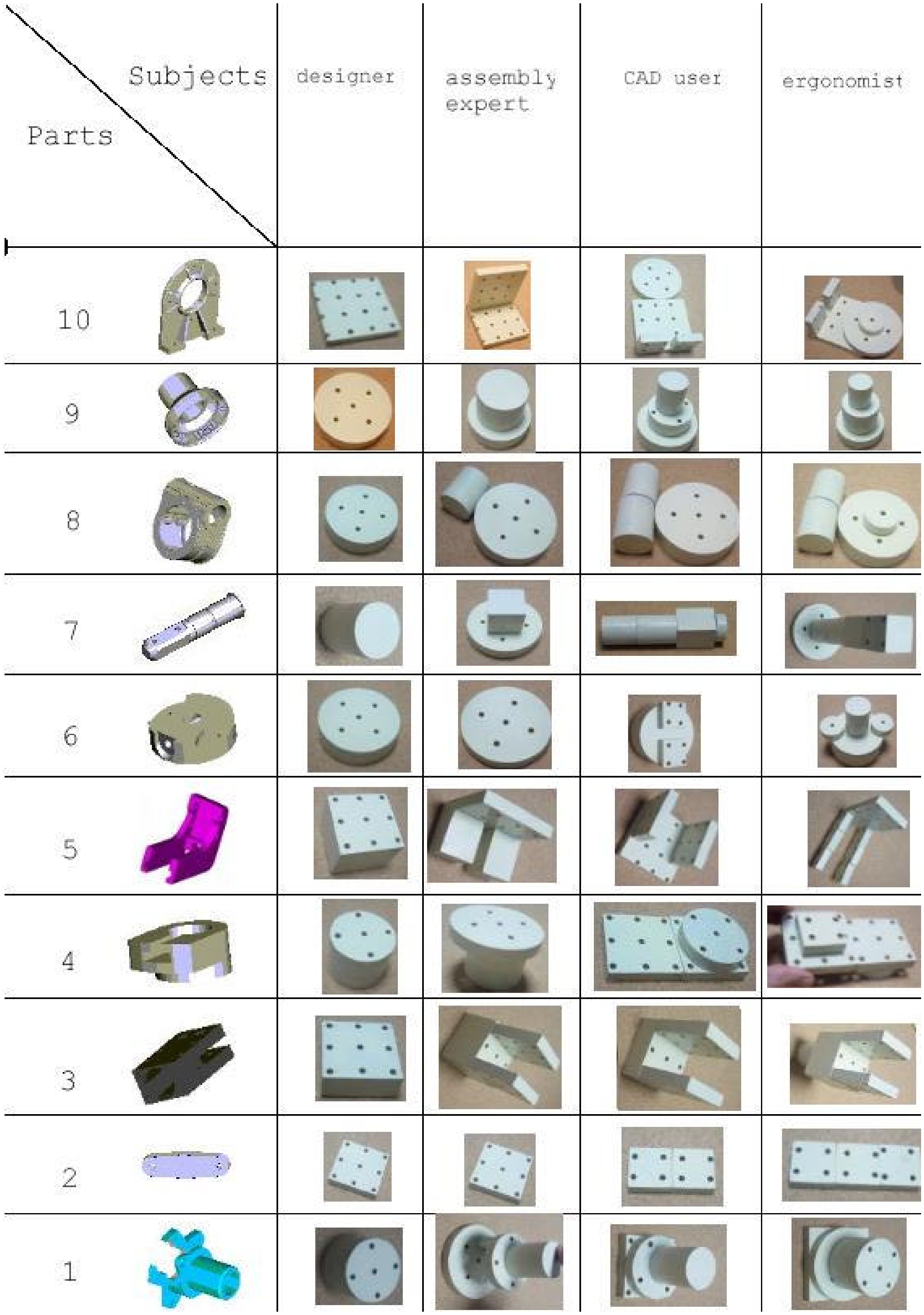

Fig. 3. Associations between CAD parts and interactors for different subjects

The associations between CAD parts and interactors made by the different subjects are display in the table of the figure 3. Some persons of our testing staff seem to use the first criterion and try to subdivide the CAD part in elementary forms. In this case, the general form of interactors combination is often a simplified model of the CAD part. Most of the time, the general form of the CAD parts is also relatively preserved in the different models built with interactors. However, we see that this way of association between CAD parts and interactors is not always suitable to make assembly operations.

Some persons of our testing staff seem to use the second criterion and try to identify the functional surfaces of the CAD part and especially those which are concerning in the assembly operations. In this case, the subject is taking into account contact surfaces between parts and proposes an interactors combination which is coherent with the functionalities of assembly. In these propositions based on functional surfaces analysis, the form of the model built with interactors can be relatively different from the CAD part. However, we think that this way of association between interactors and CAD parts is more appropriate for the use in the ESKUA platform. This is what we shall look in the following section.

4. SYNTHESIS – PROPOSITIONS FOR EVOLUTION

According to the different fastening technology (welded joint, screw fastening, bolted joint, riveting, gluing, clinching etc.), we can find removable or no removable joints in mechanical product. A number of principles and technological elements are commonly also used to facilitate the parts assembly process. However, with a mechanical point of view, the parts assembly process can be described in two main steps: the first one is concerning the positioning of the respective parts, the second one is concerning the fastening of the parts between them. We can notice that the first step required to identify functional surfaces where the parts going to be joined and positioned each others. In this way, an assembly expert tend also to identify these functional surfaces in order to analyze or to optimize the assembly of the product. Therefore, we decided to go further in the development of new interactors based on the method using functional surfaces identification.

In that sense, we decided to focus on the evolution of the TUI in order to foster associations between CAD parts and interactors with a functional surfaces based reasoning rather than a geometric form based reasoning. Therefore, we have done a state of the art concerning the technology components mainly used in different mechanical products. This work allows us to propose a new set of interactors (see figure 5) with specific functional surfaces commonly used in assembly process such as:

- chamfer on shaft and bore (see n°1&4),
- fillet (see n°7),
- flat on shaft (see n°5&4),
- key and keyway (see n°4),
- groove and groove shoulder (see n°5&2),
- housing shoulder and recess (see n°7), shaft shoulder (see n°1),
- guide slot on a plane surface (see n°9,10,11,12),
- internal and external spline or multiple splines (see n°2&3),
- spot facing (see n°7),
- mortice (see n°8), spigot joint (see n°6+8)

More over, new “fastening interactors” (see examples on figure 4) will be also designed to allow the use of different fastening technology such as: bolt with nut, screw, centering pin, rivet, external and internal retaining ring, pin, positioning dowel, hole-pin joint.

Fig. 4. Examples of “fastening interactor”: screw, nut, pin

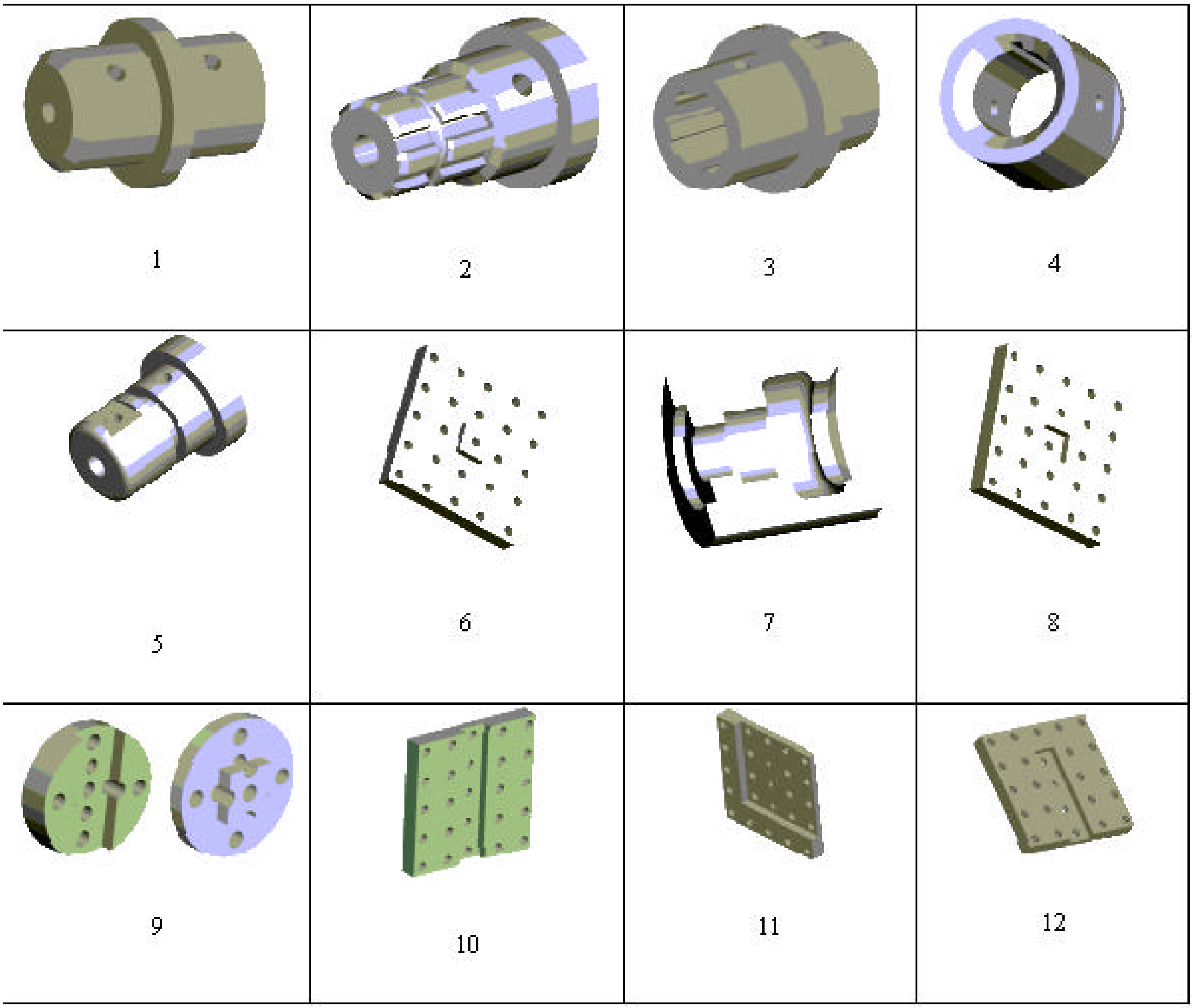

Fig. 5. New Interactors propositions

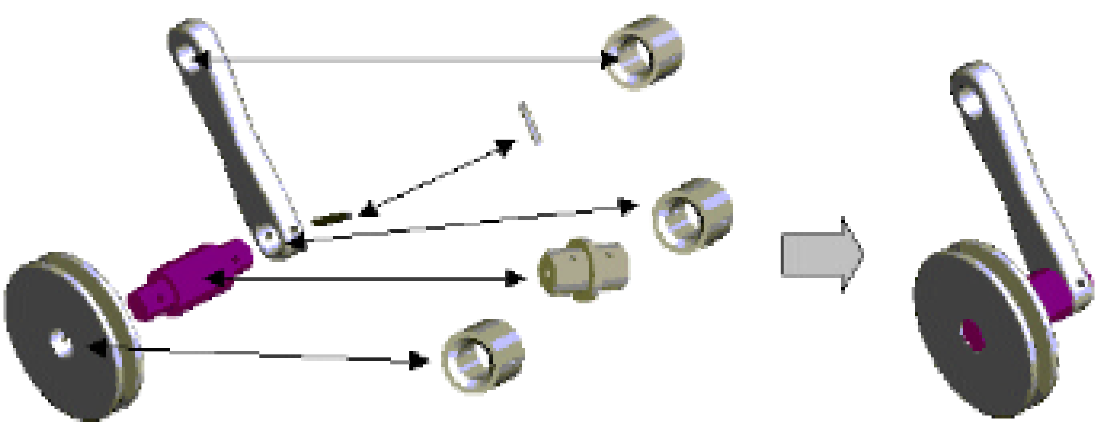

Fig. 6. Example of associations with new interactors

These propositions of new interactors (figure 5) lead us to complete the possibilities of association between CAD parts and interactors. Indeed, we intend to reduce the number of interactors of the first set by removing those which are not essential. In fact, we are going to remove all the interactors which was proposed to allow combinations to obtain approached geometric form of the CAD part. More over, we can imagine to combine different functional surfaces on a single interactor. With this new set of interactors, associations with CAD parts must be done by identifying assembly functional surfaces. An example of associations between interactors and a CAD parts assembly is given on the figure 6.

5. CONCLUSIONS

The manual assembly activity is difficult to formalize due to the diversity and the complexity of the operations and the tacit character of mobilized knowledge. The real constraints of assembly operations (such as positioning difficulties of two parts before fixing or the insertion difficulties of one part with regard to the others related to the problems of gripping, inaccessibility of the parts, etc.) are masked by the functionalities existing in the CAD software. The use of these software based on the visualization of 3D object cannot always allow anticipation of assembly difficulties because they are "too assisted" and produce "virtual'" results. Our tangible interface seek to make intuitive interfaces in order to couple reality and the numerical data while simplifying the interaction. With the ESKUA platform, the designer will associate interactors to CAD parts, and handle these physical objects to carry out the assembly of the product. So the user is confronted with real assembly operation constraints such as parts positioning difficulties or maintaining element in a joint position. Our new interactors based on functional surfaces reasoning allow to carry out physical simulations while enabling designers to identify assembly difficulties, and to modify parts design.

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