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HOW UNIVERSAL DESIGN PRINCIPLES CAN ENHANCE THE INTERFACE OF 3D PRINTING PROGRAMS

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ABSTRACT
Experts have predicted that 3D technologies will take on a growing importance in the economy. Results from a previous research in a Norwegian College indicate that the use of 3D modelling programs and how intuitive students in Product Design feel they are depend on the students' previous IT knowledge. It also showed that teachers and students are interested in using 3D printing in Product Design education. The study presented in this paper focuses on how Universal Design (UD) and usability principles can enhance the interface of 3D printing programs. A heuristic evaluation has been conducted on a 3D modelling program, Rhino, using a set of guidelines based on theories from usability, universal design and product design process. The evaluation uncovered serious issues in the interface. The study concludes that UD and usability principles can contribute to creating more intuitive and user friendly interfaces in 3D modelling programs and enhancing the effectiveness of rapid prototyping which leads to more iterations and flexibility during the design process.

Keywords: 3D printing, universal design, heuristic evaluation, Product Design education

1 INTRODUCTION

Higher education should provide equal opportunities for all students regardless of background and abilities. However, technological innovations often create barriers. One example is in Product Design Education. The students need well-developed 3D printing programs to facilitate their learning and design process. Use of 3D printing for product designers is important on several levels. Common 3D-printers could represent the future for manufacturing businesses [1] and production overall. The technology can also give a new role for the Product Designers [2]. However it is important that the focus remain on the design process. These programs are mere tools and should be easy to use for anyone, be it someone with low IT-literacy, someone with dyslexia or even a blind or motor impaired person. A case study on the use of 3D printers in the library of Dalhousie University uncovered that printing 3D models which were designed by users with no knowledge of how the 3D printing worked was a challenge. Many flawed STL files illustrated a serious problem with providing a 3D printing service to students inexperienced in using this technology. The study concluded that a large learning curve needs to be addressed and 3D printing needs to be complemented by demonstrations and instructional seminars [3]. Interviews with students of Product Design uncovered that some participants did not use 3D printing because the program interfaces was too difficult [4]. This paper investigates how Universal Design (UD) and usability principles can be used to evaluate a popular 3D printing program and uncover its usability problems in order to enhance the interface design. The focus is on what technical problems exist in the system and how these can be addressed through the use of the seven principles of UD and Nielsen's 10 heuristics.

2 3D PRINTING

Prototyping and testing is an important part of the traditional design process. Different methods for prototyping can be used in this process. Among these is exploration of form with paper, cardboard, plastic materials etc. Mock-ups can be made for discovering form and functionality. Functional and/or aesthetic models are meant for describing the function of a product. Lastly there is the prototype; a visually correct and functioning model. For prototyping, 3D printing can be ideal to use since the model/prototype is lightweighted, fast to print and install. However, the computer programs used need to be accessible, efficient and user friendly. In this research we focus on the usability and accessibility of Rhino. Rhino (Rhinoceros 3D) is a stand-alone 3D modelling software developed by Robert McNeel & Associates. Rhino's popularity is based on its diversity in use, many multi-disciplinary functions and its flexibility to import/export over 30 different file formats. Therefore it is possible to use Rhino as a conversion tool between programs. In addition, Rhino claims to have a low learning curve [5].

3 BACKGROUND

An interview was conducted by the authors in autumn 2013 with four master students in Product Design. During the interview the participants were asked about their use of 3D modelling programs in their design process. Two of the participants said they did not use 3D printing because the program interfaces was difficult to use. They felt they needed to improve their skills to use it effectively. All the participants felt they should know about 3D printing before entering the job market and were very interested in additional coursing. This was partly because they thought that 3D prototyping often can be more effective than traditional methods of prototyping. It makes it easier to quickly make small changes in the product before and after user testing which allows more iterations. This study uncovered that use of 3D modelling programs and how intuitive they felt depends on previous IT knowledge. It also concluded that Universal Design can contribute to the development of more user friendly and accessible interfaces in 3D modelling and printing programs used in Product Design education [3]. It should also be noted that some of the participants were not particularly familiar with computer interfaces in general and might have benefited from a more self explanatory interface. This might also minimize the resources needed for coursing, demonstrations and instructional seminars.

4 METHOD

A heuristic evaluation of Rhino has been conducted using a set of guidelines adapted from Nielsen's heuristics [7] and the seven principles of Universal Design [6]. The evaluation was conducted with the educational context in mind. Student's points of view gathered from the interviews in 2013 were considered when applying the heuristics. The Centre for Universal Design at North Carolina University prepared seven principles for UD in 1997. The principles aim at UD in buildings, public spaces and technology (hardware and software) [6]. However since 1997, the principles have not been updated to better suit today's technology or aim for websites, applications etc. Jakob Nielsen developed 10 heuristics that aimed directly at software production that can also be applied to websites. These heuristics are broad enough to apply even though the technologies have drastically changed [7]. Here we map Nielsen's heuristics with the seven principles (Table 1) in order to create a new set of guidelines (Table 2) which are more suitable for producing and/or evaluating software, websites, applications etc. It is a goal that this new set is simpler to apply and suitable for a wider range of technologies than existing guidelines such as Web Content Accessibility Guidelines (WCAG). Compared with WCAG the guidelines are not so comprehensive and complicated. They are also not so technical, making them relevant for designers and consultants in addition to developers. Compared to the seven principles of UD are the guidelines more updated and focused on software design.

Table 1. The mapping of the seven principles of UD and Nielsen's 10 heuristics

The seven principles of Universal Design	**Nielsen's heuristics**
1: Equitable in Use	
2: Flexibility in Use	7: Flexibility and efficiency of use 1: Visibility of system status
3: Simple and Intuitive Use	2: Match between system and the real world
4: Perceptible Information	
5: Tolerance for Error	3: User control and freedom 5: Error prevention

	9: Help users recognize, diagnose, and recover from errors
6: Low Physical Effort	4: Consistency and standards 6: Recognition rather than recall 8: Aesthetic and minimalist design
7: Size and Space for Approach and Use	
	10: Help and documentation

Table 2. New set of guidelines

Top level criteria	**Second level criteria**
The system should be simple and intuitive to use	• The system should speak the users' language (clear language/simple English) • The system should use a standardized language, consistent in the system • The system should use intuitive icons and colours that are not cultural or demographically limited
The information should be perceptible to anyone	• The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities • The systems technology should not create compatibility barriers that can change or hide information for the users
The system should be flexible and efficient to use	• System should provide a choice in methods of use • System should accommodate right or left hand access and use • System should facilitate the user's accuracy and precision • System should provide adaptability to the user's pace • System should show user system status
Error handling	• System should tolerate error without crashing • System should help user prevent errors • System should help users recognize, diagnose, and recover from errors • System should have a clearly marked "emergency exit" • System should have room for version control in case the users makes mistakes or the system crashes before saving recent changes
Help and documentation	• System should be self-explanatory, but big, complicated programs will always need help and documentation • The system should have open for support in form of e.g. email, forums, and videos
The system should be equitable in use	• System should provide the same means of use for all users: identical whenever possible; equivalent when not • System should avoid segregating or stigmatizing any users • System should make sure that privacy, security and

	safety are equally available to all users
The system should demand minimum effort	• The system should let the user recognize instead of recalling to minimize memory effort • Dialogues should not contain information which is irrelevant or rarely needed • The system should support keyboard access so the user can switch between using different input methods

5 FINDINGS

The system, as a whole, was evaluated on each criterion. This also made it possible to uncover if some of the guidelines were redundant, which they were not. Because of time limitation, only an overall evaluation focusing on the standard toolbar version was executed, as highlighted in Figure 1.

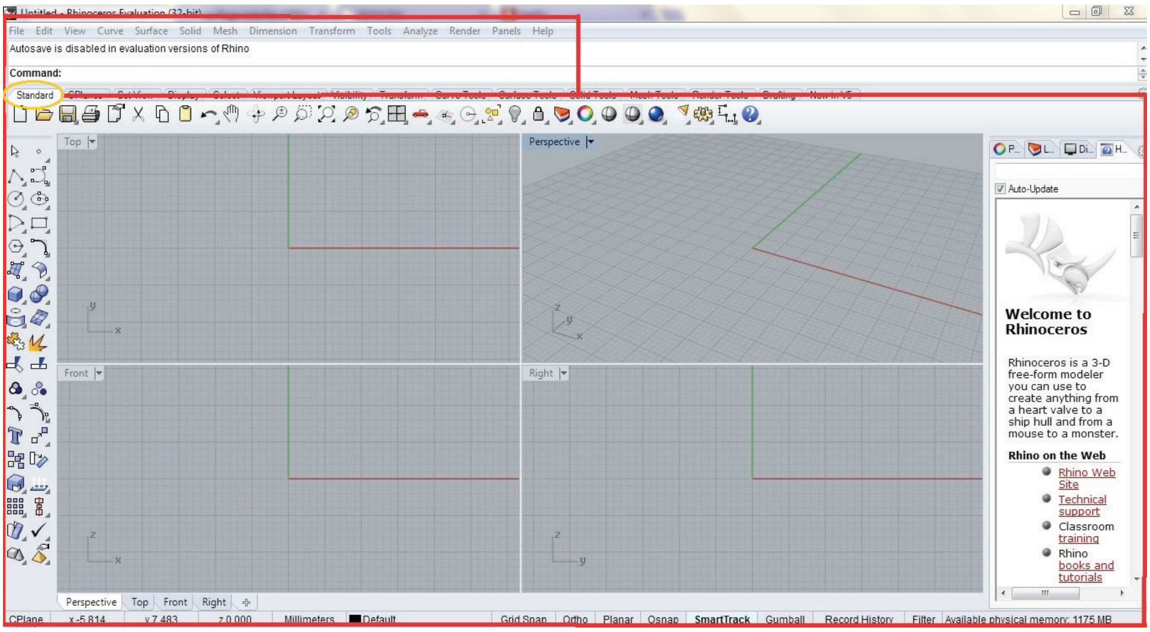

Figure 1. Screenshot Rhino desktop

5.1 The system should be simple and intuitive to use

As a first impression the desktop seems cluttered with many icons and text with no further explanation of usage. There is a left menu that contains functions presented as icons. The icons are a mix of unfamiliar icons and icons commonly used in similar tools. Furthermore there are four toolbars; two top, one right, one left, which seems like too much. The left menu is cluttered, making it difficult to distinguish each function (Figure 1). It is also debatable if these icons are intuitive for product designers, but this needs user testing. The two top menus offer to some extent the same functions, making it redundant. However the text and icons are more common and intuitive in these menus than the system in general, e.g. the save-icon and “file” part of the menu. It is up for debate whether younger people know what a floppy disk is and whether it is a common icon for the save function. For a person who is not familiar with any modelling software the system will seem confusing, cluttered and not intuitive. The tool does contain a consistent language and the labels used are common in modelling software. However, the labels might be difficult since they are only in English and demands IT-literacy. The language should be changed so it uses more familiar words for designers and does not demand much IT knowledge.

5.2 The information should be perceptible to anyone

The users will not lose any necessary information due to compatibility problems against varying conditions or the user’s sensory abilities versus the tool’s design. Such ambient conditions are more due to different screens and light settings on hardware level. However the design relies much on grey nuances making it difficult if the light in the user’s room makes the screen dark and difficult to distinguish the design. This could be avoided with better use of contrasts. Another issue is that the users can not personalize colours or contrast. Allowing users to personalize colours or contrast would make the system more flexible for users in situations such as when light on the screen creates a barrier. The tool is on a software level making it more flexible in theory for assistive technologies like screen readers etc. However compatibility barriers often depend on the individuals working habits and flow. To uncover other serious compatibility issues a larger user test is needed, not only to find possible barriers, but also to map all the possible ways to use the tool.

5.3 The system should be flexible and efficient to use

The tool provides various ways and choices to design a 3D model. It is also possible to remove or add different menu panels, change colours, font-size, font-type etc. This is done under preferences and here the navigation is complicated and the sub-menus do not explain properly what kind of options is offered. To change e.g. background colours, a lot of guesses were made before finding the right menu. There is also no way to change the placement of the panels that accommodate better right- or left-handed use. The tool facilitates the user’s accuracy and precision by making it possible to use drawing tools like mouse or touch pen. The system does not have any time restriction making it possible for the users to work at their own pace. The tool presents system status through text either in a dialog field or through popup boxes. The different menu panels also contain redundant functionality. To enhance the efficiency and minimize memory efforts for different actions, the design should be stripped for all redundancy and it should be only one panel to offer modelling functionality, one panel to offer overall system functionality e.g. save or open file. A last panel should only include documentation.

5.4 Error handling

During the evaluation, errors were deliberately made by the tester trying to crash the system. This did not happen. An attempt to use too much RAM caused the tool to freeze, but after a while the issue resolved itself and no work, even unsaved, was lost. However, when wrongly shutting down the computer without saving, Rhino did not give any status of the sudden shut down and what happened to the files. Note that this may be due to the use of an evaluation version of the software. Also because of this possible limitation it is not noted any possibility for a version control or help for the users to recognize, diagnose, and recover from such errors. The system gives feedback when the user attempts to overwrite an existing file and closes before saving the recent changes. The software has the usual window exit marked with an X-icon which is seen as intuitive.

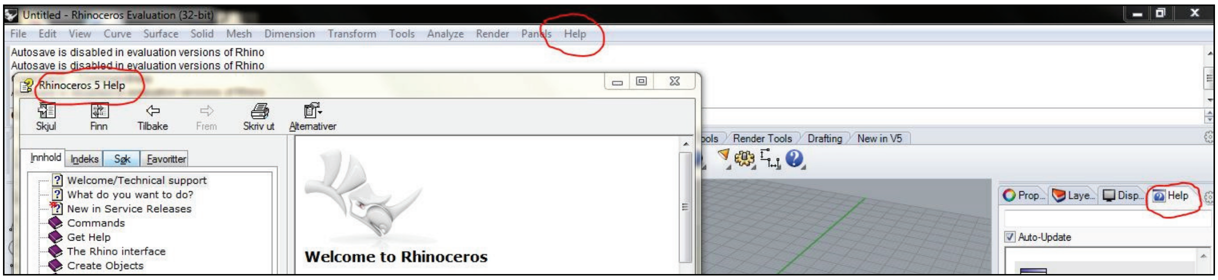

Figure 2. Screenshot of help options

5.5 Help and documentation

The tool has a documentation panel to the right that offers help and possibilities to learn more. This help section links to Rhino’s official website, but also offers offline documentation internally in the system. The documentation panel is cramped and the design is too complicated for such small space to be efficient and simple to use. In addition, when using some of the navigation links in this panel a popup window over the panel opens with more documentation. If using one of the links in this popup, it will close using the origin help-panel showing more documentation. This is somewhat confusing. There is also a help sub-menu at the top menu bar giving links to the same places of help, but some are in different format, e. g. a popup window giving the same information as the help panel (highlighted in figure 2). All this makes it confusing when trying to find help in Rhino and questioning what is different and/or best to use between all these options. The website also offers support in form of email, forum, user community and phone calls.

5.6 The system should be equitable in use

To check if the system provides the same means of use for all users: identical whenever possible; equivalent when not, user testing is more suitable than expert testing. The tool is neutral in icon use, language, and colours, avoiding stigmatizing. Users with approved license get equal privacy and thus security and safety considering users personal and credit information.

5.7 The system should demand minimum effort

The tool supports keyboard navigation as well as mouse and pen. There are few dialogues and those contain information about the system status, action confirmation, and the documentation panel. The tool is redundant in functions and documentation, making the overall system architecture more complicated than necessary. Many functions are also hidden behind sub-menus making it more difficult to remember where to execute the different actions and prompting the user to recall rather than recognize through icons. User testing should be conducted to validate these issues.

6 CONLUSION AND FUTURE WORK

This paper investigated how Universal Design and usability principles can enhance the interface of a 3D printing program, Rhino. The goal was to uncover possibilities for making the system easier to use, thus shifting students' focus from learning to use the program to using the program as a tool in Product Design education. The combination of universal design principles and usability heuristics allowed us to identify problems in different aspects of the interface, such as ease of use, error handling, flexibility and access to help and documentation. The findings indicate that implementing the combined principles could to some extent aid in making a more user friendly interface, which would better support the activities in Product Design education, such as the transition between 3D printing and materialisation evaluation, handling errors in the 3D printing process, and visual documentation for creative form development. Moreover contrary to the low learning curve claimed by Rhino [5], findings from our evaluation indicate a high learning curve and low accessibility and usability, may have severe consequences for students using the system. Future work may include a survey among Product Design students to confirm the general issues with the Rhino interface. In addition, user testing with a heterogeneous group of users with different backgrounds and capabilities could uncover issues beyond those found in the heuristic evaluation. Additionally, in order to provide support and guidelines to software professionals so that Rhino and other 3D modelling software can be more accessible and usable a prioritized list of principles could be valuable.

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